Cyfoeth
Naturiol
Cymru
Natural
Resources
Wales

Environmental Change Network Yr Wyddfa/Snowdon site

Summary of measurements and trends over the period 1995-2015

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NRW Evidence Report No 166

This report is dedicated to Jonathan Yeardley, one of our best volunteers, who sadly lost his life in a car accident in May 2016.

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Contents

Crynodeb Gweithredol

Mae safle'r Rhwydwaith Newid Amgylcheddol ar Yr Wyddfa yn rhan o rwydwaith monitro 11 safle daearol a 42 safle dŵr croyw. Ymgymerir â gweithredoedd ar y safle gan Cyfoeth Naturiol Cymru (CNC) (a gan Gyngor Cefn Gwlad Cymru yn flaenorol) gyda chefnogaeth Llywodraeth Cymru. Mae'r monitro yn canolbwyntio ar effaith newid hinsawdd, llygredd a defnyddio tir ar strwythur, gweithrediad ac amrywiaeth ecosystemau daearol a dŵr croyw. Mae elfen ddaearol y safle wedi bod yn gweithredu ers 1995 a'r elfen dŵr croyw ers 2006.

Mae'r safle monitro yn bwysig o fewn cyd-destun Prydeinig yn ogystal â Chymru. Hwn mwy neu lai yw'r unig safle yng Nghymru sy'n ymgymryd â'r fath ystod o fesuriadau integredig dros raddfa amser mor hir. Mae ei ganlyniadau yn sail ar gyfer deall ecosystem ucheldir Cymru a bydd ei wasanaeth yn hysbysu rheolaeth adnoddau naturiol yn y dyfodol. Mae'r mesuriadau a wnaed ers 1995 a'r tueddiadau a adroddir hefyd yn darparu cipolwg ar y newidiadau tymor hir sy'n digwydd yn amgylchedd Cymru ac, gyda data rhwydwaith ychwanegol, yn cyfrannu at ddealltwriaeth o'r newidiadau sy'n digwydd ledled y DU.

Cynhwysa'r crynodeb gweithredol nifer o'r prif dueddiadau sydd yn is-set fach o'r holl dueddiadau a gynhwysir yn yr adroddiad.

Newidynnau ffisegol

Tymheredd

Mae cydberthynas sylweddol rhwng tymheredd Yr Wyddfa a mynegai Osgiliad Gogledd yr Iwerydd yn ystod 7 mis yn y flwyddyn. Does dim tuedd llinol arwyddocaol mewn tymheredd dros gyfnod 1995-2015, ond mae tymheredd blynyddol wedi cynyddu'n sylweddol ers cyfnod cofnodi'r Rhaglen Fiolegol Ryngwladol (1966-1977). Ar lefel fisol, mae mis Awst wedi arddangos tueddiad oeri gyda gostyngiadau sylweddol mewn tymheredd cymedrig, yn y nifer o ddyddiau tymheredd uchel a thymheredd cymedrig a thymheredd cronedig dyddiol cymedrig (diwrnod-gradd).

Glaw

Nid oes unrhyw dueddiad sylweddol i'w weld mewn glawiad blynyddol dros gyfnod cofnodi safle meteorolegol y RNA, ond mae'r nifer blynyddol o ddyddiau eithafol o wlyb wedi cynyddu. Mae cynnydd sylweddol wedi bod mewn glawiad dros gyfnod 1945-2015. Ym mis Rhagfyr 2015, cofnododd y mesurydd glaw hwn y mis gwlypaf erioed yn y DU, gyda chyfanswm o 1396mm o lawiad. Ar raddfa fisol, mae mis Awst a mis Rhagfyr wedi dod yn fwy gwlyb, gyda chynnydd yn y nifer o ddiwrnodau glawog (>=0.2 mm/diwrnod) a diwrnodau gwlyb (>= 1mm/diwrnod). O'i gymharu â data 1966-77 y RBR, mae 1995-2015 wedi bod yn wlypach gyda chynnydd cyfartalog o 295 mm/blwyddyn.

Newidynnau cemegol

Dyddodiad gwlyb

Mae crynodiadau dyddodiad gwlyb sylffad, nitrad ac amoniwm mewn glaw wedi gostwng yn sylweddol ac mae'r pH wedi cynyddu. Bu newidiadau cyfatebol sylweddol mewn dyfroedd wyneb a dyfroedd y pridd. Mae crynodiadau carbon organig toddedig wedi cynyddu mewn dyfroedd wyneb, yn wahanol i nifer o safleoedd ucheldirol eraill. Nid oes llawer o newid mewn crynodiadau catïonau ac o ganlyniad bu cynnydd sylweddol mewn Cynhwysedd Niwtralu Asid mewn dyfroedd wyneb. Mae isafswm llwythi critigol ar gyfer asidedd yn dal i gael eu rhagori ar gyfer llawer o gynefinoedd ar yr Wyddfa, ond mae'r lefelau o dan uchafswm y llwythi critigol.

Dyddodiad sych

Mae lefelau dyddodiad sych sylffwr deuocsid wedi gostwng yn sylweddol, ond ni welir llawer o newid yn lefelau nitrogen deuocsid dros y cyfnod cofnodi. Mae osôn troposfferig, a samplwyd ym Marchlyn Mawr, wedi dangos gostyngiad sylweddol mewn crynodiad blynyddol. Nid yw gormodiant yn y llwyth critigol ar gyfer AoT40 (dos cronedig dros 40ppb yn ystod golau dydd o fis Ebrill-Hydref) wedi newid yn sylweddol, er ni weler gormodiannau eithriadol uchel ers 2006.

Newidynnau biolegol

Fertebratau

Mae niferoedd yr adar wedi dangos cryn amrywiant rhyng-flynyddol, ond dim newid sylweddol o ran niferoedd nac amrywiaeth. Mae ystlumod hefyd yn dangos amrywiadau blynyddol, ond does dim tuedd cryf. Mae hyd amser datblygu brogaod o grifft i oedolyn wedi gostyngu'n sylweddol ers 1996, yn gysylltiedig â newid mewn gradd o bosib.

Anifeiliaid di-asgwrn cefn

Gweler gostyngiad sylweddol yn nifer y chwilod daear, un o'r prif ysglyfaethwyr di-asgwrn cefn sydd wedi cael eu monitro ers 1999. I'r gwrthwyneb, ni welir llawer o newid yn nifer y pryfaid cop oni bai am gynnydd bychan mewn rhai glaswelltiroedd asidig. Ni welir unrhyw duedd sylweddol yn nifer y pili palod dros y cyfnod cofnodi.

Planhigion a llystyfiant

Mae darlun cymhleth wedi dechrau dod i'r amlwg ar gyfer llystyfiant. Ar gyfer planhigion fasgwlaidd a mwsoglau, mae cynnydd wedi bod mewn cyfoeth rhywogaethau ar gyfer glaswelltir. Dengys gwerthoedd dangosyddion Ellenberg fod gostyngiad mewn lleithder ar gyfer gorgors, tra ar gyfer maetholion (EbN), bu gostyngiad ar gyfer llystyfiant gwlyptir. Ar gyfer adwaith (EbR), mynegai ar gyfer asidedd, bu cynnydd ar gyfer glaswelltir a gwlyptir, tuag at amodau llai asidig, o ganlyniad i'r gostyngiad mewn lefelau sylffad a nitrad yn ôl pob tebyg.

Gwelir newidiadau sylweddol yn amser blodeuo ystod o blanhigion, gyda rhai rhywogaethau megis Blodyn y Gwynt a'r Friallen yn blodeuo'n gynt, tra bod rhywogaethau eraill megis y Grug Croesddail a Suran y Coed yn blodeuo'n hwyrach.

Defnydd tir a gwasanaethau diwylliannol

Y prif ddefnydd amaethyddol ar y safle yw defaid yn pori, ac er y dengys rhifau duedd o ostyngiad ers 1997, maent wedi bod yn sefydlog yn y ddegawd ddiwethaf ar tua 50% o'r rheiny ers dechrau cofnodi. Gweler cynnydd sylweddol yn nifer y geifr, o ganlyniad i lai o fyn yn marw oherwydd gaeafau mwyn diweddar yn ôl pob tebyg.

Cofnodir gwasanaethau diwylliannol ar y safle’n wythnosol ers 2 flynedd ac mae’n dangos set amrywiol o weithgareddau hamdden a defnydd ar bob lefel addysgol.

Executive Summary

The Environmental Change Network (ECN) site on Yr Wyddfa/Snowdon is part of a UK monitoring network of 11 terrestrial and 42 freshwater sites. Operations on the site are undertaken by Natural Resources Wales (NRW) (and previously by the Countryside Council for Wales) with support from the Welsh Government. The monitoring focusses on the impact of climatic change, pollution and land-use, on the structure, function and diversity of both terrestrial and freshwater ecosystems. The terrestrial component of the site has been operational since 1995 and the freshwater component since 2006.

This monitoring site is important in both a Welsh and a UK context. It is virtually the only site in Wales undertaking such a range of integrated measurements over such a long time-scale. Its results provide a basis for understanding the Welsh upland ecosystem and its services and will inform future natural resource management. The measurements undertaken since 1995 and the trends reported here also provide an insight into the long-term changes occurring elsewhere in the Welsh environment and, with other network data, contribute to an understanding of changes occurring at a UK level.

This executive summary contains a number of headline trends which are a small subset of all the trends included in the report.

Physical variables

Temperature
There is a significant correlation between Snowdon temperatures and the North Atlantic Oscillation index for 7 months of the year. There are no significant linear trends in temperature over the period 1995-2015, but annual temperature has increased significantly since the International Biological Programme (IBP) recording period (1966-1977). At a monthly level, August has exhibited a cooling trend with significant decreases in mean temperature, number of high-temperature days and accumulated daily mean temperature (day-degrees).

Rainfall
Annual rainfall shows no significant trend over the recording period at the ECN meteorological site, but the annual number of extremely wet days (>= 100mm/day) have increased. For the manual Crib Goch raingauge, there has been a highly significant increase in rainfall over the period 1945-2015. In December 2015 this raingauge set a new record for the wettest month ever in the UK, with a total rainfall of 1396mm. At a monthly scale, August and December have become wetter, with increased numbers of rain days (>=0.2 mm/day) and wet days (>= 1mm/day). Compared to the 1966-77 IBP data, 1995-2015 has been wetter with an average increase of 295 mm/year.

Chemical variables

Wet deposition
Concentrations of wet deposited sulphate, nitrate and ammonium in rainfall have significantly decreased and pH has increased. There have been corresponding

significant changes in surface waters and soil waters. Dissolved organic carbon concentrations have increased in surface waters, in contrast to many other upland sites. Cation concentrations are relatively unchanged and as a result there has been a significant increase in Acid Neutralizing Capacity in surface waters. Minimum critical loads for acidity and nutrient nitrogen are still being exceeded for many habitats on Snowdon, but the levels are below the maximum critical loads.

Dry deposition

Dry deposited levels of sulphur dioxide have fallen significantly, but nitrogen dioxide has shown little change over the recording period. Tropospheric ozone, sampled at Marchlyn Mawr, has shown a significant decrease in annual concentration. Exceedance of the critical load for the biologically significant AoT40 (accumulated dose over 40ppb during daylight from April-Oct) has not changed significantly, although extremely high exceedances have not been seen since 2006.

Biological variables

Vertebrates

Bird numbers have shown considerable inter-annual variability, but no significant change, either in numbers or diversity. Bats, also show large annual variations, but exhibit no strong trend. The duration time of development for frogs from spawn to adult has shown a significant decrease since 1996, possibly linked to changes in day-degrees.

Invertebrates

Ground beetles, one of the main invertebrate predators, and monitored since 1999, have shown a significant decline, in common with other upland sites in the UK. Spiders, by contrast, have shown little change apart from a small increase in some acidic grasslands. Butterflies show no significant trend over the recording period.

Plants and vegetation

For vegetation, a complex picture has started to become apparent. For vascular plants and mosses combined, there has been an increase in species richness for grassland. Ellenberg indicator values show a decrease in moisture (EbF) for blanket mire, while for nutrient (EbN), there has been a decrease for wetland vegetation. For reaction (EbR), an index for acidity, there has been an increase for grassland and wetland, towards less acidic conditions, probably as a response to decreased sulphate and nitrate levels.

Significant changes in the flowering time of a range of plants have been observed with some species such as Wood Anemone and Primrose showing earlier flowering, while others such as Cross-leaved Heath and Wood Sorrel are flowering later.

Land-use and cultural services

The primary agricultural use on the site is sheep grazing and while numbers show a downward trend overall since 1997, they have been stable in the last decade at around 50% of those since recording started. Significant increases in goat numbers have been seen, which are probably driven by reduced kid-mortality from recent mild winters.

Cultural services have been recorded weekly for 2 years on the site and show a diverse set of recreational activities and use at all educational levels.

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1. Introduction

The Environmental Change Network (ECN) is a multi-agency programme which was launched in 1992 with the aim of establishing a network to identify, assess and research environmental change nationally (Sier & Scott, 2009). The network consists of a series of 11 terrestrial and 45 freshwater sites (Figure 1), each of which collects data from a range of physical, chemical and biological variables using standardised protocols. The data generated is sent to the ECN Central Co-ordination Unit (CCU) at the Centre for Ecology and Hydrology (CEH) at Lancaster. The network is supported by a wide range of sponsors covering the majority of the environmental agencies in the UK.

The Yr Wyddfa/Snowdon site joined the network in 1995 and is funded by NRW (previously CCW) and formerly the Welsh Government.

The site comprises 712 ha located within the Yr Wyddfa/Snowdon National Nature Reserve and containing Yr Wyddfa or Snowdon, the highest mountain in England and Wales. The site extends from 200m OD to the summit of Snowdon at 1085m OD, and contains three other mountain summits, Crib Goch (923m), Crib y Ddysgl (1066m) and Y Lliwedd (898m). The majority of the site is located within Cwm Dyli within the Snowdon Horseshoe, with smaller parts extending to include parts of Cwm Glas and Cwm Llan (Figure 2). The principal land uses of the site are for agriculture and recreation. The vegetation is mainly grassland but with significant areas of heathland, mire, scree and rock. There are three lakes within the boundary of the site, the largest of which, Llyn Llydaw is used as a reservoir for hydroelectric power. The highest lake, Glaslyn, lies at 600m, and has suffered in the past from heavy metal pollution from adjacent disused copper mines which operated from the 18th to early 20th centuries.

Physical measurements at the terrestrial site include meteorology (both manual and automatic) and surface water discharge. Chemical analysis is undertaken of rain water, surface water and soil water for pH, conductivity, a range of anion and cation determinands, dissolved organic carbon and alkalinity. Biological recording of birds, bats, frog spawning, butterflies, ground predators, spittle bugs and vegetation occurs seasonally, and land-use is monitored all year. Non-ECN measurements include snow-lie duration, phenology, arctic-alpines, pollinators, fungi and cultural services. In addition samples are collected for other networks including UKEAP (UK Eutrophying and Acidifying Atmospheric Pollutant network) and the Welsh Air Quality Forum at Marchlyn Mawr nearby where ozone and nitrogen oxides are monitored continually.

The majority of the most frequent protocols are undertaken close to a 1 ha area known as the Target Sampling Site (TSS) located at the eastern end of Llyn Llydaw. Close by is an exclosure with manual and automatic meteorological instrumentation, precipitation collectors and diffusion tube holders.

In 2007, at Nant Teyrn, the outflow stream of Llyn Teyrn, within the terrestrial ECN site, a freshwater site was set up and joined the network. In addition to the weekly sampling already undertaken at this location, additional recording consists of monthly collection of water samples for analysis of a range of chemical determinands and pH, conductivity, Biological Oxygen Demand (BOD) and dissolved organic carbon (DOC). Temperature, conductivity and water discharge are recorded continuously. Epilithic diatoms and macrophytes are recorded annually and benthic invertebrates are sampled twice a year (Table 1). Chlorophyll-a levels are measured monthly.

In May 2014, ECN celebrated its 20 years of operation with a symposium at Lancaster University which looked both backwards to the successes of the network and forwards to the challenges of the future. A special issue of Ecological Indicators entitled “Assessing ecosystem resilience through Long Term Ecosystem Research: the observations and requirements of the UK Environmental Change Network” is due for publication in September 2016.

This report comprises summary overviews of measurements and trends for physical, chemical and biological variables, supported by data summaries, presented mainly in graphical format.

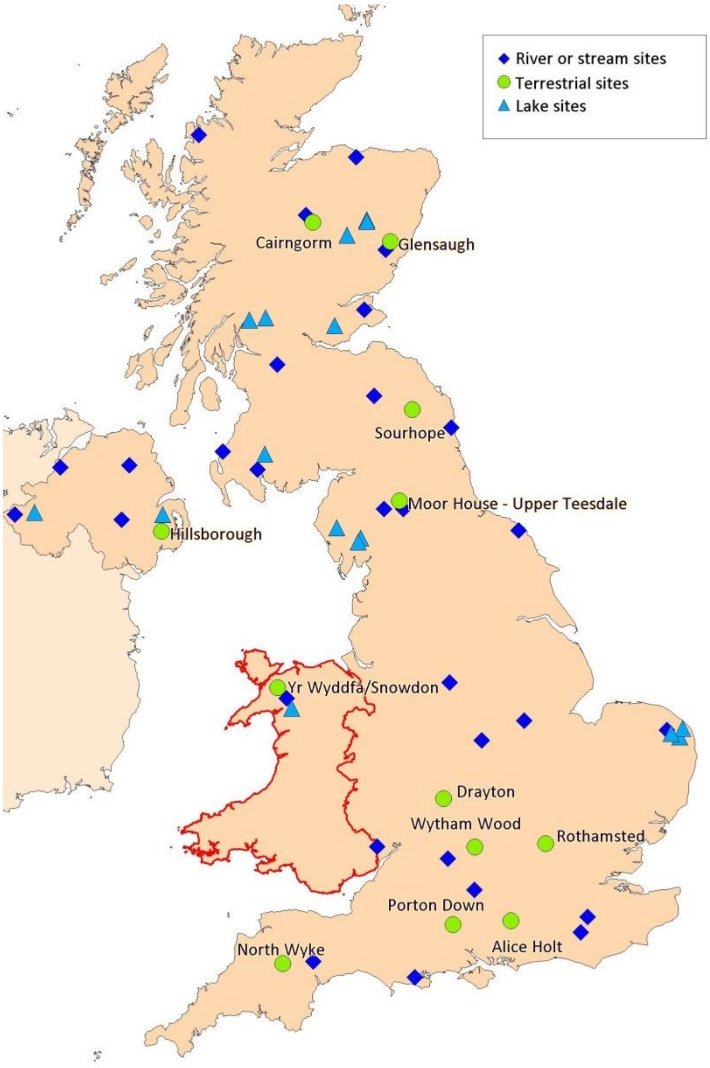


Figure 1: The UK Environmental Change Network sites

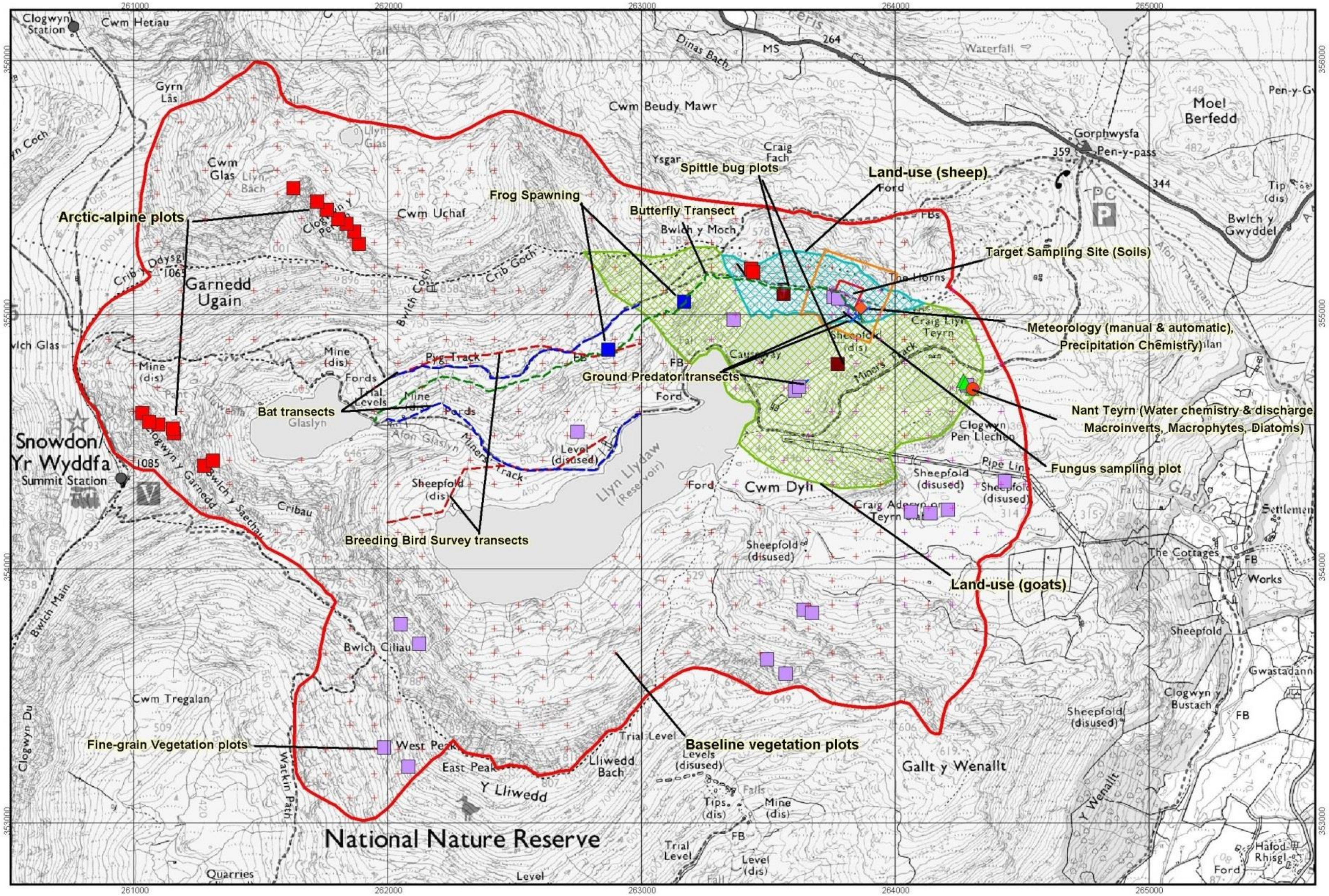


Figure 2: Location of protocols undertaken on the Yr Wyddfa/Snowdon ECN site. Small + are coarse-grain and baseline vegetation plots. Crown copyright and database rights 2016 Ordnance Survey 100019741

2. Site Protocols

2.1 Summary of measurements undertaken on Snowdon

The ECN terrestrial and freshwater measurements carried out at Snowdon are itemised in Table 1. Details of ECN terrestrial and freshwater measurements can be found in Sykes & Lane (1996) and Sykes *et al.* (1999) respectively; both are available on the ECN website www.ecn.ac.uk.

As well as the core ECN protocols, there are also a number of extra measurements which fall into two categories: (a) those carried out on behalf of other networks and (b) measurements instituted on the site which were suggested by the ECN Advisory Committee for the site and which are relatively easy to undertake.

Measurements undertaken for other networks and institutions include:

- Ammonia at Snowdon ECN site and Plas y Brenin (UKAEAP)
- Precipitation chemistry and NOx dry deposition (UKAEAP)
- Ozone and nitrogen oxides at Marchlyn Mawr (Welsh Air Quality Forum/Ricardo-AEA)
- Pollen Network (University of Hull)

Additional non-ECN measurements include the following:

• Arctic-alpine plants	(2000-2015)
• Cultural services	(2014-2016)
• Fungal fruiting	(2007-2016)
• Phenology	(1998-2016)
• Rain gauges	(from 1945-2016)
• Snow level recording	(1995-2016)

The atmospheric chemistry measurements undertaken for other networks enhance the understanding of chemical processes occurring on the site, in particular those for ammonia and ozone. Where they overlap with the ECN measurements, they provide a degree of quality assurance. The benefit of the “extra” measurements largely outweighs the small amount of extra effort needed to undertake them, and some (e.g. snow levels) can provide a sensitive indicator of changes occurring on the site. Others (e.g. fungi) are unique in throwing some light on changes which are usually neglected in other studies. Furthermore, the profile of cultural services is increasing and interpretation of changes on the site requires some input in terms of recreational and educational activities.

Table 1: Protocols undertaken on the Yr Wyddfa/Snowdon ECN site.

CODE	DRIVER OR RESPONSE VARIABLE	MEASUREMENT	METHOD	FREQUENCY
TERRESTRIAL: Physical				
MA, MM	Meteorology	Temperature, precipitation, wind speed and direction, solar irradiance, soil temperature and moisture, surface wetness	Automatic weather station and manual measurements	Hourly and weekly
WD	Water discharge	Surface water discharge	Automatic recorder	Every 15 minutes
(SN)	Snow-cover recording	Snowline, snowpatch duration	Manual estimates of altitude and duration	Weekly (autumn – spring)
			Automatic camera	Hourly
TERRESTRIAL: Chemical				
PC	Rainfall chemistry	pH, conductivity, alkalinity, Na, K, Ca, Mg, Fe, Al, NO$_3$-N, SO$_4$-S, Cl, PO$_4$-P, DOC, Total-N,	Chemical analysis	Weekly
WC	Water chemistry		Chemical analysis	Weekly
SS	Soil solution chemistry		Chemical analysis	Fortnightly
(AEA-PC)	Rainfall chemistry for UKEAP		Chemical analysis by UKEAP	Fortnightly
AN	Atmospheric chemistry	Nitrogen Oxide	Diffusion tubes	Fortnightly
AS		Sulphur dioxide	Diffusion tubes	Monthly
(OZ)		Ozone & oxides of nitrogen at Marchlyn Mawr for Welsh Air Quality Forum & UKEAP	Automatic analyzer	Hourly
(NH3)		Ammonia, ammonium and others for UKEAP at ECN site and Plas-y-Brenin	Diffusion tubes and Alpha sampler	Monthly
(AEA-N)		NO2 diffusion tube for UKEAP	Diffusion tubes	Monthly
SF	Soils	Physical structure and chemistry	Physical and chemical analysis	5- and 20-yearly
TERRESTRIAL: Biological				
BB	Vertebrates	Birds	Breeding Bird Scheme	Twice yearly
BA		Bats	Counts along two transects	Four times yearly
BF		Frog spawning	Timing of lifestage events, chemical analysis	Weekly during season
IB	Invertebrates	Butterflies	Butterfly Monitoring Scheme	Weekly (April - September)
IG		Ground beetles and spiders	Species and individual counts	Fortnightly (March - November)
IS		Spittle bugs	Quadrat counts	Twice yearly
POL		Pollinators	2 5 minute counts	Weekly
VF	Vegetation	Fine-grain sampling	Quadrat counts	3-yearly/subset annually
VC		Coarse-grain sampling	Quadrat counts	9-yearly
PH		Phenology for UK Phenology Network (in part)	Flowering species counts	Weekly
AA		Arctic-alpines	Quadrat cell counts	3 yearly/subset annually
POL	Pollen for Pollen Monitoring Programme	Rainwater collection	Pollen grain counts	Quarterly
FUN	Fungi	Fungi	Species counts	Fortnightly

Table 1 continued

CODE	DRIVER OR RESPONSE VARIABLE	MEASUREMENT	METHOD	FREQUENCY
FRESHWATER: Physical & Chemical				
FWC	Chemistry	BOD, orthophosphate, SiO_3, As, Cd, Sn, Cu, Pb, Ni, Zn, V, Mn, Hg, Fe, SO_4, Na, K, Ca, Mg, NO_2, Total-P	Chemical analysis	Monthly
WD	Conductivity and temperature	Conductivity and temperature	Automatic logger	Every 15 minutes
FRESHWATER: Biological				
FMA	Vegetation	Aquatic macrophytes	Species percentage cover	Annually
FPP	Phytoplankton	Chlorophyll-*a*	Acetone extract	Monthly
FIN	Invertebrate fauna	Macro-invertebrates	Species counts from kick sampling	Twice yearly
FDT	Diatoms	Epilithic diatoms	Slide counts from submerged rocks	Annually
LAND-USE				
LU	Land use	Sheep and goat numbers	Counts within sample areas	Weekly
SOCIAL				
CUM	Cultural services	Human activity	Counts (timed)	Weekly

Key:

ECN core protocol
Other network data collection
NRW site specific protocol

Abbreviations:

BOD	Biological Oxygen Demand
UKEAP	UK Eutrophying and Acidifying Atmospheric Pollutants network

Figure 3 ECN meteorological exclosure.

Figure 4: Nant Teyrn weir.

3. Terrestrial and Freshwater measurements and trends

3.1 Summary of trends for physical variables

The main physical drivers measured under the ECN program are meteorological and hydrological. Additional non-ECN drivers made on the site include snow lie and duration.

Of the meteorological drivers, perhaps the most important is temperature, and in particular air and soil temperature. Taking air temperature first, the trend over the period of recording shows a non-linear character with a sustained rise from 1996-2006 which was significant, followed by more variable years subsequently which have reduced the significance. The cooler winters around 2009-2011 were a major factor in this, and the trend in winter temperatures exhibits something of a sinusoidal trend with a possible trajectory towards warmer winters in 2015-2016. Spring temperatures also show a decline after 2010, but here there is no evidence of any upturn. Summer and autumn air temperatures show a rise until around 2010 but then a levelling off.

Air temperature on Snowdon shows strong correlations with the North Atlantic Oscillation index (NAOI) and the Arctic Oscillation index (AOI) and at a monthly scale, there is a varying linkage between the two indices and average monthly dry-bulb temperature. Over the winter period and into early spring (December-March), both indices are significantly positively correlated with average temperature (Figure 7). In mid-spring (April), the correlation is only significant with the AOI. There is no correlation in May and June, but in mid-summer (July-August), a significant positive correlation can be found between the NAOI and average temperature. The correlation falls off again, until November when there is again a correlation with the NAOI. On a monthly level, August shows a significant negative trend ($p < 0.01$).

Soil temperature at 10cm and 30 cm depths show similar patterns to air temperature, but the initial trend in annual temperature from 1996 is only significant at 30cm depth. As with air temperature, there has been a significantly decreasing trend in soil temperature in August at both 10cm ($p < 0.001$) and 30 cm ($p < 0.01$).

Numbers of high temperature days (>= 20 ºC) over the recording period show little overall trend (Figure 8), but as with air and soil temperature, there has been a significant decreasing trend during August ($p < 0.01$). Frost days show no obvious trend over the period, with the exception of a reduction in December ($p < 0.01$). There is some evidence of a sinusoidal trend in both frost days and frost sum with a minimum around 1999-2000 followed by a maximum around 2009-2012. Since then totals fell to the lowest levels during the winter of 2013-2014 with some recovery during 2014-2015 (Figure 9).

Three accumulated temperature variables have been examined, which have varying degrees of significance for the growth of plant species. Accumulated day-degrees above 0 ºC and above 5.6 ºC and T-Sum show broadly similar trends (Figure 10), and at an annual and seasonal scale these are not significant (T-Sum is defined as the accumulated sum of positive daily temperatures from January 1st). As for air and soil temperature, August also shows a significant decreasing trend for all three indices. For day-degrees above 5.6 ºC there is additionally a decreasing trend for May, while for T-Sum, there is a decreasing trend for March. A further accumulated temperature statistic, is the number of growing season days, defined as the number of days where the temperature exceeds 5 ºC. The trends for this have no significance at an annual, seasonal or monthly scale.

Rainfall is the second main physical driver of change, and is important in a part of the UK with some of the highest annual rainfall totals. There is no significant annual or seasonal trend over the period of ECN recording. There is, however, a significant increasing trend for monthly rainfall for July, August and December ($p < 0.5$). The increasing trend for August is most probably linked to the decreasing trend in August temperature, and that for December is very likely linked to the decrease in the number of frost days. There are two other monthly rain gauges within the Snowdon ECN site, Crib Goch (730m) and Llydaw Delta (450m), both of which have records extending back to the early part of the 20^{th} century. Over this longer period, there is a highly significant increasing trend for the Crib Goch annual rainfall ($p < 0.001$) and a significant increasing trend for Llydaw Delta ($p < 0.05$). Examining seasonal data for Crib Goch over the same period, both autumn and winter show a significant increasing trend ($p < 0.05$ and $p < 0.01$ respectively). In late autumn 2015 and the early winter of 2015/16, there was very heavy sustained precipitation and the Crib Goch rain gauge monthly reading was recorded as 1396.4mm (Figure 15). This has been provisionally confirmed by Dr Stephen Burt, Dept. of Meteorology, University of Reading, as the highest monthly rainfall ever recorded anywhere in the British Isles.

In a similar way to temperature, there is a complex link between rainfall and the NAOI and the AOI. This has been noted across the whole network over the period 1993-2012 by Monteith et al. (2016, in press). They found a significant positive correlation between rainfall and NAOI during the winter while there was a negative correlation during the summer. On Snowdon, over 1996-2015, the positive correlation during the winter is significant ($r = 0.689$,*** and 0.570,*** respectively), and the negative during the summer ($r = -0.703$,*** and -0.376,* respectively).

On a monthly scale, the NAOI has significant positive correlations with December and February rainfall and a significant negative correlation with June rainfall (Figure 11). The Arctic Oscillation also has a significant correlation with the February and December rainfall totals, but is not significantly correlated with June rainfall. It does have, however, significant positive correlations with May and October rainfall totals.

As would be expected with increased rainfall, the number of rain days (days with rainfall >= 0.2 mm) is high and they average 249 per year. There is no significant annual or seasonal trend but some months show an increasing trend. August shows a significant increase, along with May and December ($p < 0.05$).

Wet days (days with rainfall >= 1 mm), which average 215 days/year, have no annual or seasonal trend but at a monthly scale show an increase for August also, as well as January and December ($p < 0.05$).

Moving to more unusual weather (Figure 12), very wet days, with >= 25mm rainfall/day, which occur on average 12.7 days/year, again show no annual or seasonal trend, but show a significant increase in December ($p < 0.05$) while October and November show a significant decrease ($p < 0.05$). Finally, extremely wet days, with >= 100mm/day, occurring on average 1.2 days/year, show an increasing annual trend. There were three of these days in 2015, all occurring in December, with the rainfall on the 26th reaching 166mm.

Weather data was collected over the 11 years that the International Biological Programme operated (1966-1977) on the site now used for ECN recording (Heal & Perkins, 1978), and some of the same instrumentation is still being used today. This enables a comparison to be made and differences are presented in Table 3. Briefly, both temperature and rainfall have increased significantly since the 1960s/70s with mean temperatures 1.37 °C higher ($p < 0.001$) (Figure 16) and rainfall is 5.67mm higher per week ($p < 0.01$) (Figure 19), which translates to an average increase of 296mm/year. Grass minimum and soil temperatures are also significantly higher by 2.02 °C and 0.87 °C respectively ($p < 0.001$) (Figure 17).

Continuous measurements of water flow have been made since December 2000, and show no strong trend but the effect of the unprecedented rainfall in late 2015 is shown in Figure 21 with a spike more than 50% higher than the previous maximum monthly flow. Water temperature and conductivity have been undertaken since 2007, and show a distinct seasonality. The data set is too short, however, for any significant trend to be apparent (Figure 22).

Finally, two of the non-ECN measurements: cloudiness and snow lie. Cloudiness is measured weekly, using oktas (or eighths) of the sky covered. Annual average cloudiness has increased significantly since 1995 (Figure 18). The average proportion of days with complete cloud cover in a year is 58%, while days with no cloud cover only account for 3% of the total.

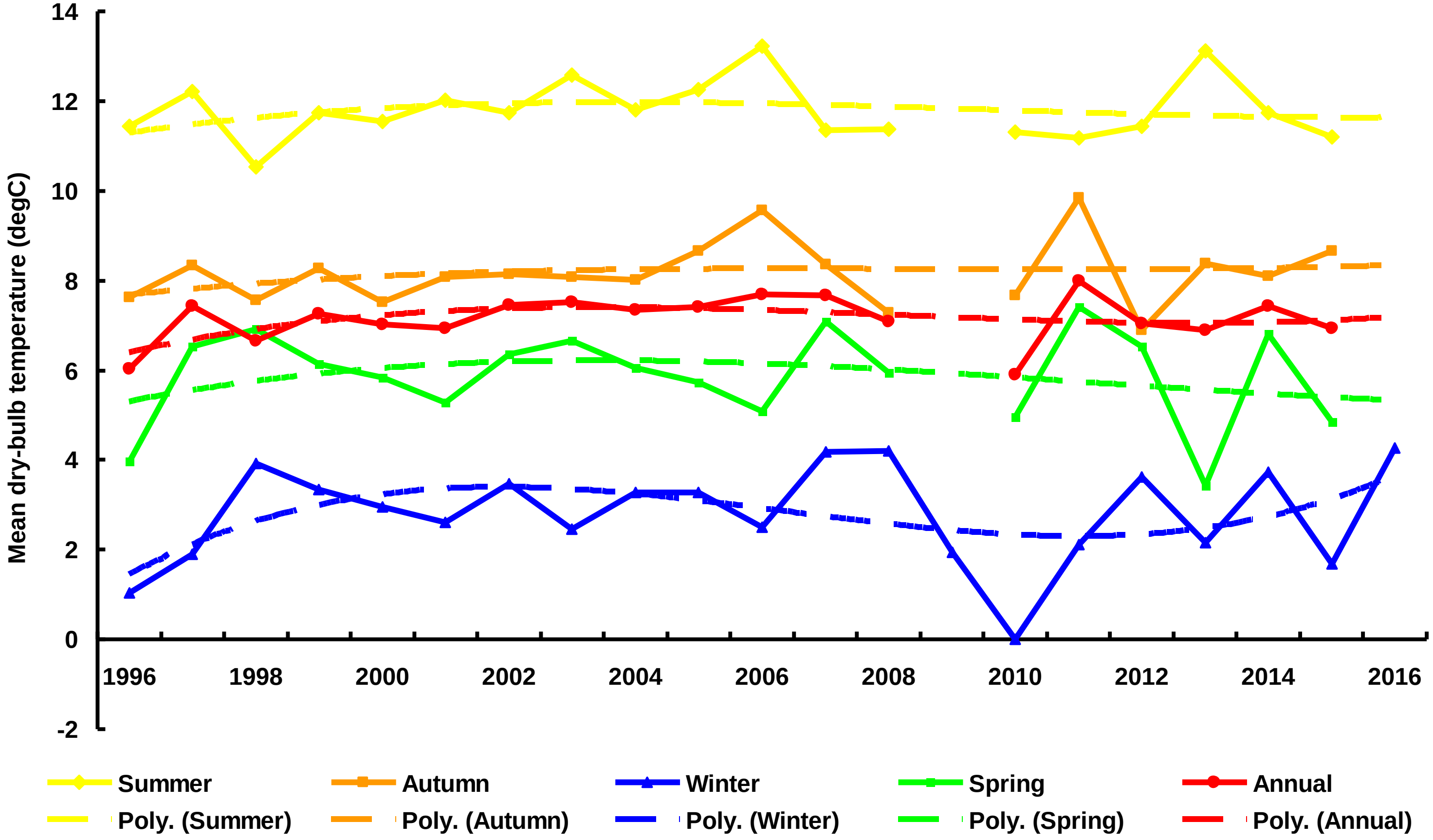
Snow lie or snow duration is recorded weekly during the winter and spring months, and Figure 22 shows changes in the date of last snow lie (i.e. last patch present) and number of Wednesdays with snow present, in some form or another, on the site. Neither shows a simple increasing or decreasing trend, but rather a more sinusoidal trend similar to that for winter temperature.

Table 2: Summary of trends for physical variables

Measurement	Period	Annual	Spring	Summer	Autumn	Winter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean temperature	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-, *	ns	ns	ns	ns
Mean soil temperature (10cm)	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-, ***	ns	ns	ns	ns
Mean soil temperature (30cm)	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-, **	ns	ns	ns	ns
High Temp days (>= 20degC)	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-, **	ns	ns	ns	ns
Frost days	**1995/6-2014/5**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-, **
Frost sum	**1995/6-2014/5**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day-degrees > 0 degC	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-, *	ns	ns	ns	ns
Day-degrees > 5.6 degC	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	-, *	ns	ns	-, *	ns	ns	ns	ns
T-Sum	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	-, *	ns	ns	ns	ns	-, *	ns	ns	ns	ns
Growing Season Days, Mean Temp >= 5 degC	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rainfall (ECN met site)	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	+. *	+. *	ns	ns	ns	+. *
Raindays (>=0.2mm/day)	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	+. *	ns	ns	+. **	ns	ns	ns	+. *
Wet days (>=1.0mm/day)	**1996-2015**	ns	ns	ns	ns	ns	+. *	ns	ns	ns	ns	ns	ns	+. *	ns	ns	ns	+. *
Very wet days (>=50mm/day)	**1996-2015**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-, *	-, *	ns	+. *
Extremely wet days (>=100mm/day)	**1996-2015**	+. *	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rainfall (Crib Goch)	**1996-2015**	ns	ns	ns	ns	ns												
Rainfall (Llydaw Delta)	**1996-2015**	ns	ns	ns	ns	ns												
Rainfall (Crib Goch)	**1945-2015**	+. ***	ns	ns	+. *	+. **												
Rainfall (Llydaw Delta)	**1945-2014**	+. *	ns	ns	ns	ns												
Cloudiness	**1996-2015**	+. *	ns	ns	ns	ns												
Snowlie	**1995-2015**	ns																
North Atlantic Oscillation Index	**1996-2016**	ns	ns	-, **	ns	+. *	ns	ns	ns	+. *	ns	ns	ns	-, **	ns	ns	+. *	+. *
Arctic Oscillation Index	**1996-2016**	ns	ns	-, *	+. *	ns	ns	ns	ns	+. *	ns	ns	ns	-, *	ns	ns	+. *	ns

Positive trend	+. *	p < 0.05	+. **	p < 0.01	+. ***	p < 0.001
Negative trend	-, *	p < 0.05	-, **	p < 0.01	-, ***	p < 0.001

Terrestrial - air temperature trend

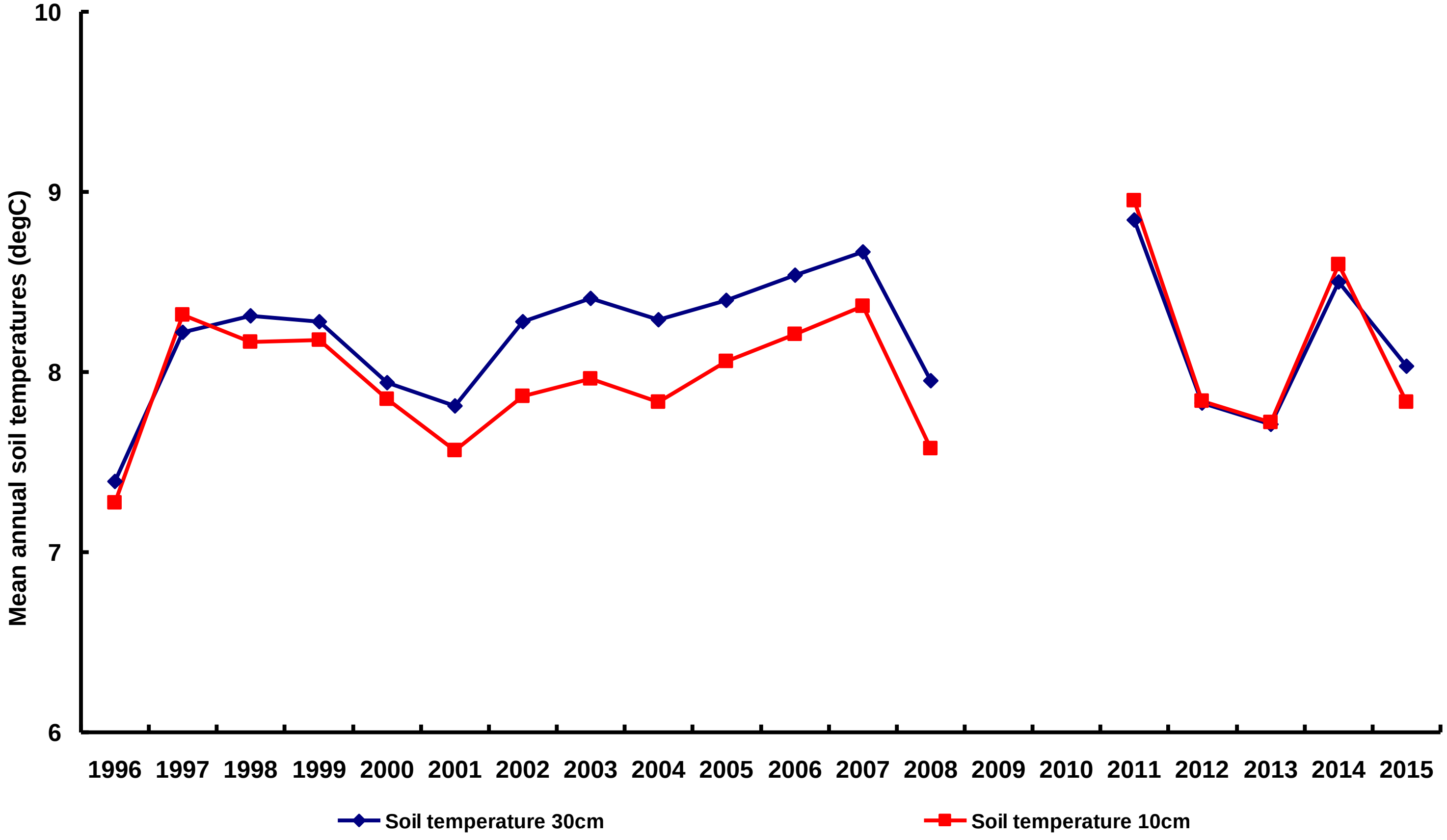


Annual average AWS dry-bulb temperatures show no significant linear or monotonic trend over the period 1996-2015 but rather there is some evidence of a hump-backed trend, with a rise to around 2006-07, followed by a fall with the colder winters of 2009-2011, and since 2012 there has been some evidence of a renewed rise in temperature in winter temperature.

Looking at the first decade, there were significant rising trends for annual, summer and autumn dry-bulb temperatures ($p < 0.05$). The second, decade, however, temperatures were more variable and none of the trends were significant.

Figure 5: Average annual and seasonal automatic weather station dry-bulb temperatures for the period 1996-2016.

Terrestrial - soil temperature trend

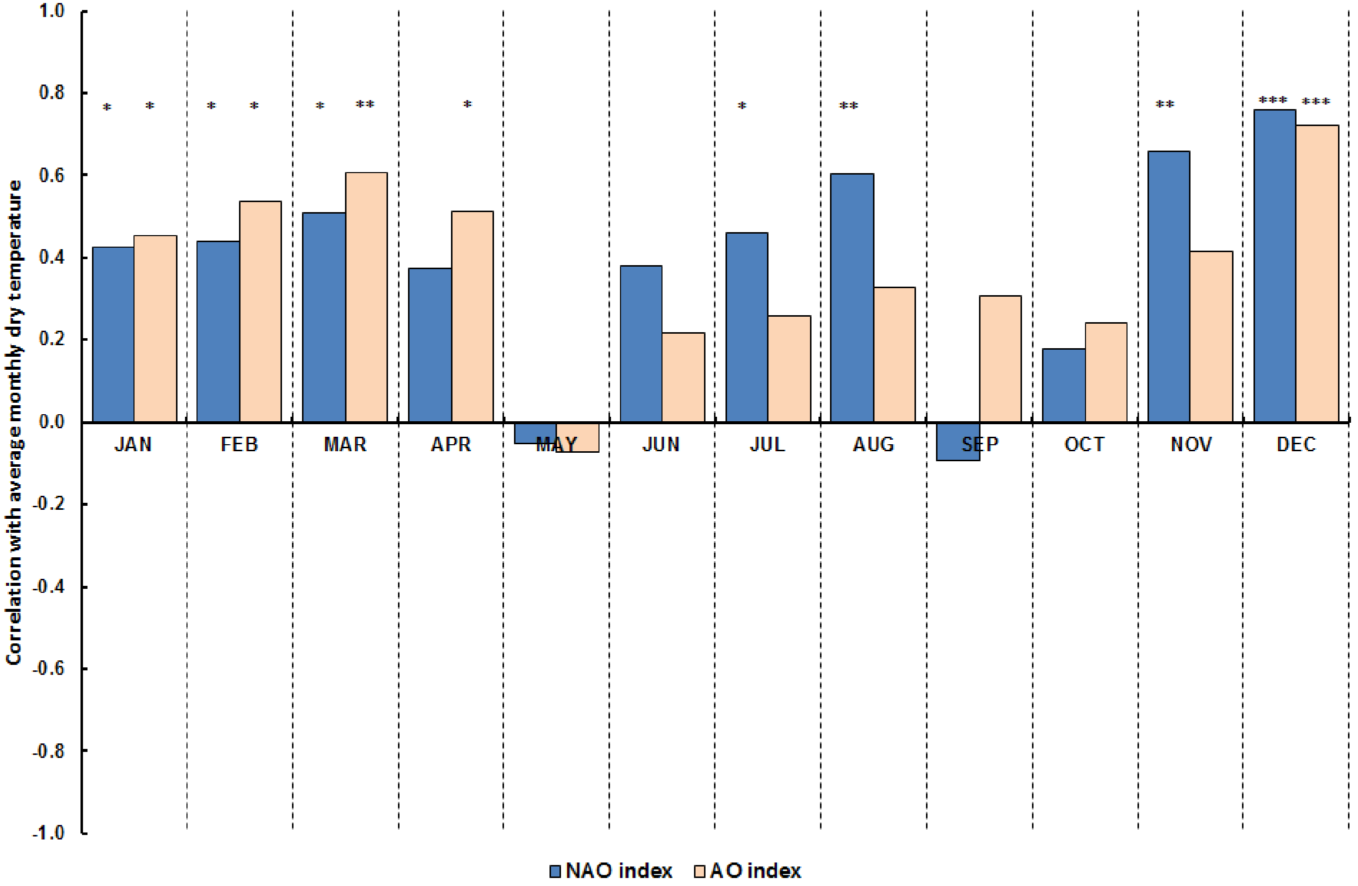


Annual and seasonal mean soil temperatures, at 10cm and 30cm depth, over the period 1996-2015, show no significant monotonic trend.

At 10cm depth, there were additionally no significant trends over the first or second decades. At 30 cm depth, however, the there was a significant increasing trend over 1996-2006.

Figure 6: Average annual soil temperatures for 10cm and 30cm over the period 1996-2015.

Terrestrial - mean monthly temperature v atmospheric oscillation indices



Mean monthly temperature v NAOI and AOI:

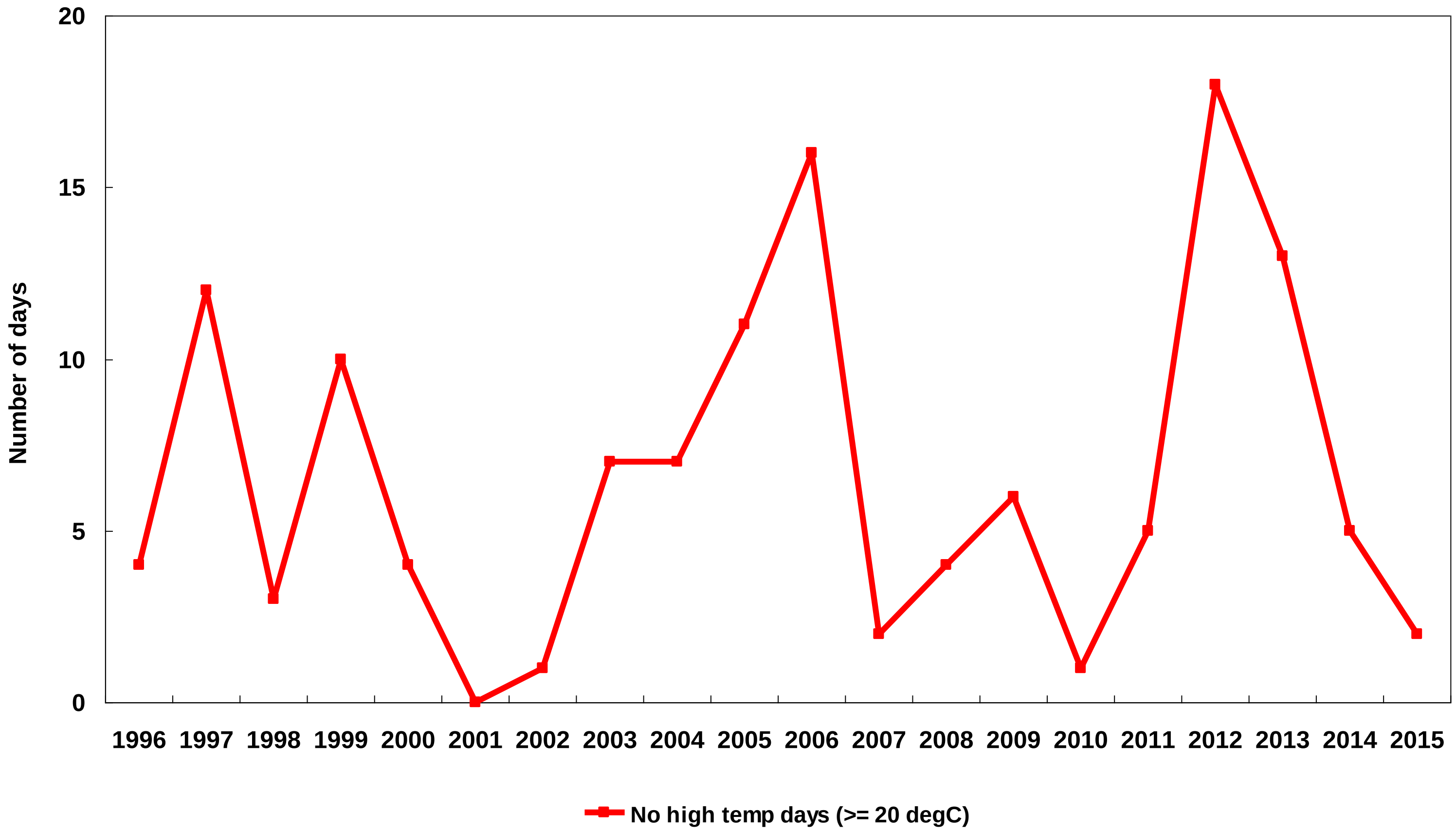
Monthly dry-bulb temperature during the period of recording show clear correlations with the North Atlantic Oscillation Index and the Arctic Oscillation Index.

The patterns of correlation are similar, with both showing positive significant correlations from December through to March. The AOI also has a strong significant positive correlation in April, while the NAOI has additional significant positive correlations in July, August and November.

The trends in the AOI and NAOI over the same period showed a significant positive trend in April and November and a negative trend in August, however the trends in monthly temperatures are not significant except for August which shows a negative trend ($p < 0.05$)

Figure 7: Correlations between monthly AWS dry-bulb temperatures and monthly North Atlantic Oscillation (NAOI) and Arctic Oscillation (AOI) indices from June 1995 to Feb 2016. (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

Terrestrial - high temperature days

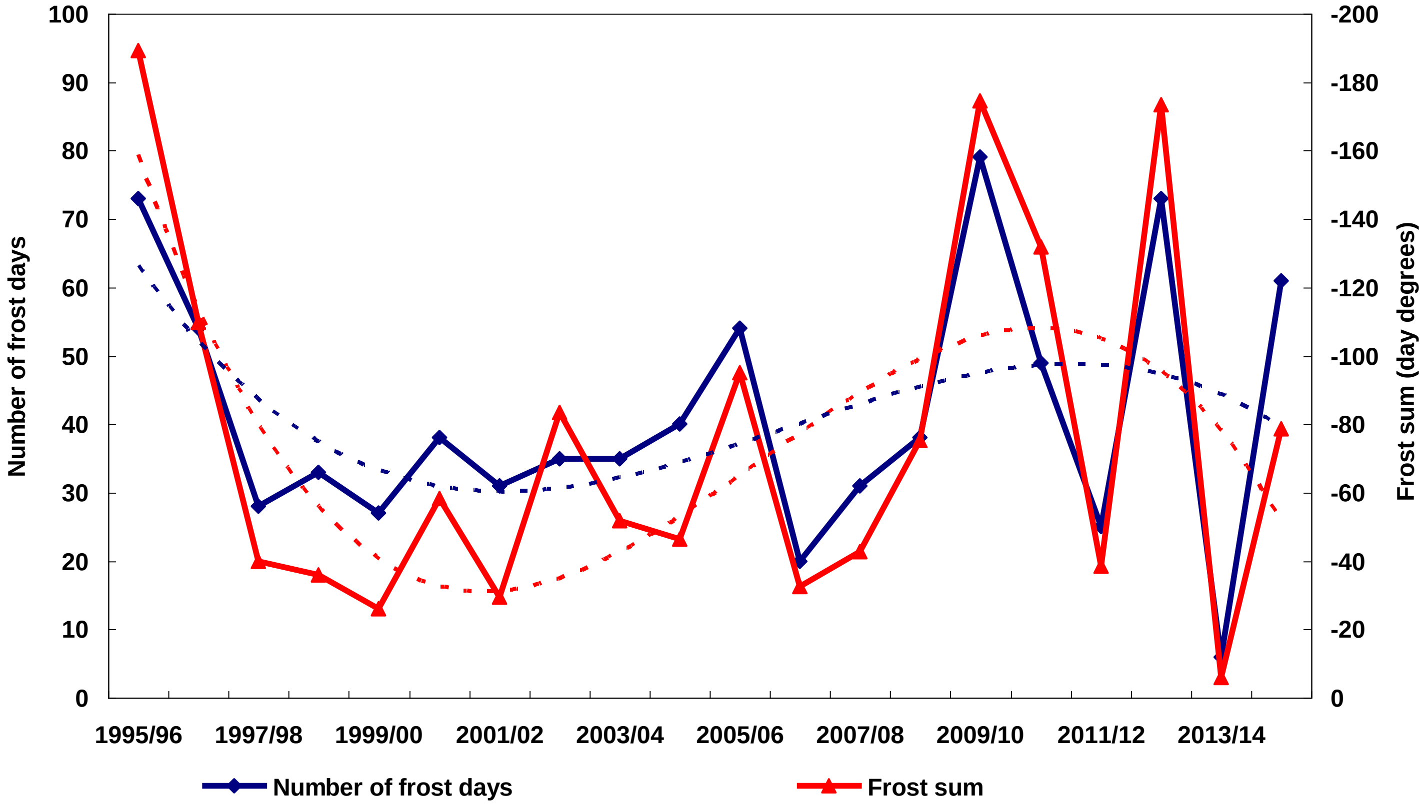


The number of high-temperature days (defined as days with a maximum temp >=20.0° C) shows a sawtooth pattern over the 19-year period with peaks in 1996. 1999. 2006 and 2012.

For the annual count, there is no significant trend; there has, however, been a decrease in high temperature days in August which is significant, and is possibly linked to a similar decrease in the average North Atlantic Oscillation Index over the same period for August.

Figure 8: Annual number of high temperature days over the period 1996-2015.

Terrestrial - frost days and frost sum

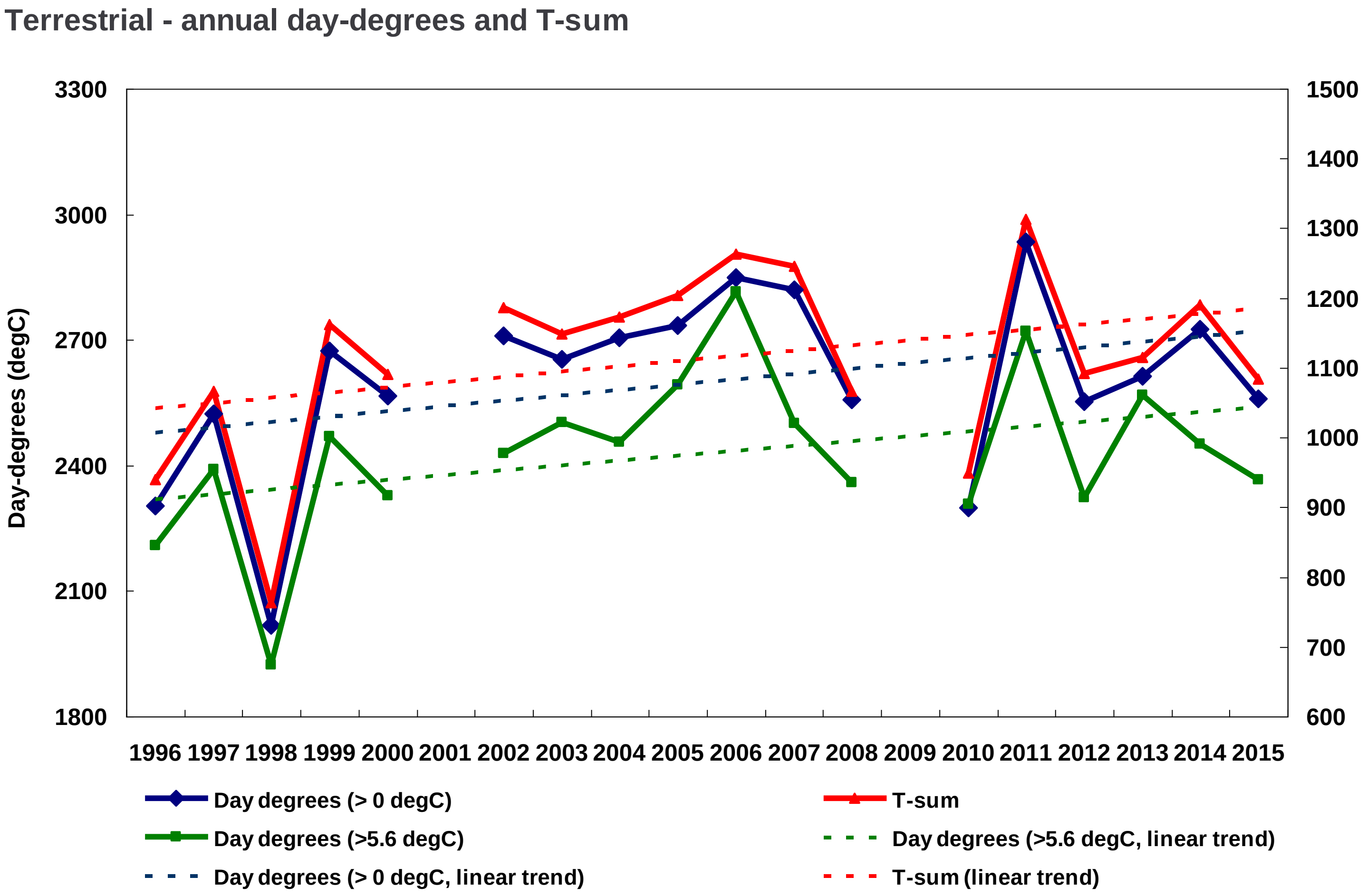


The number of frost days during the year (measured from 01 Sept - 31 Aug) is a measure of the intensity of the coldest part of the year. It is closely matched by the by the cumulative negative sum of all the minimum temperatures during the same period called here the Frost Sum.

The trend over the 19-year period is not significant, but does show a U-shaped trend over the period 1995/96 to 2009/10 and some evidence of a continued downward trend to 2014/15.

At a monthly level, there has been a significant decrease in December frost days ($p < 0.01$), probably linked to a significant increase in precipitation over the same period.

Figure 9: Annual number of frost days and frost sum over the period 1995/96 - 2014/15. The right hand axis is reversed. The trend curves are fitted 3rd degree polynomials.

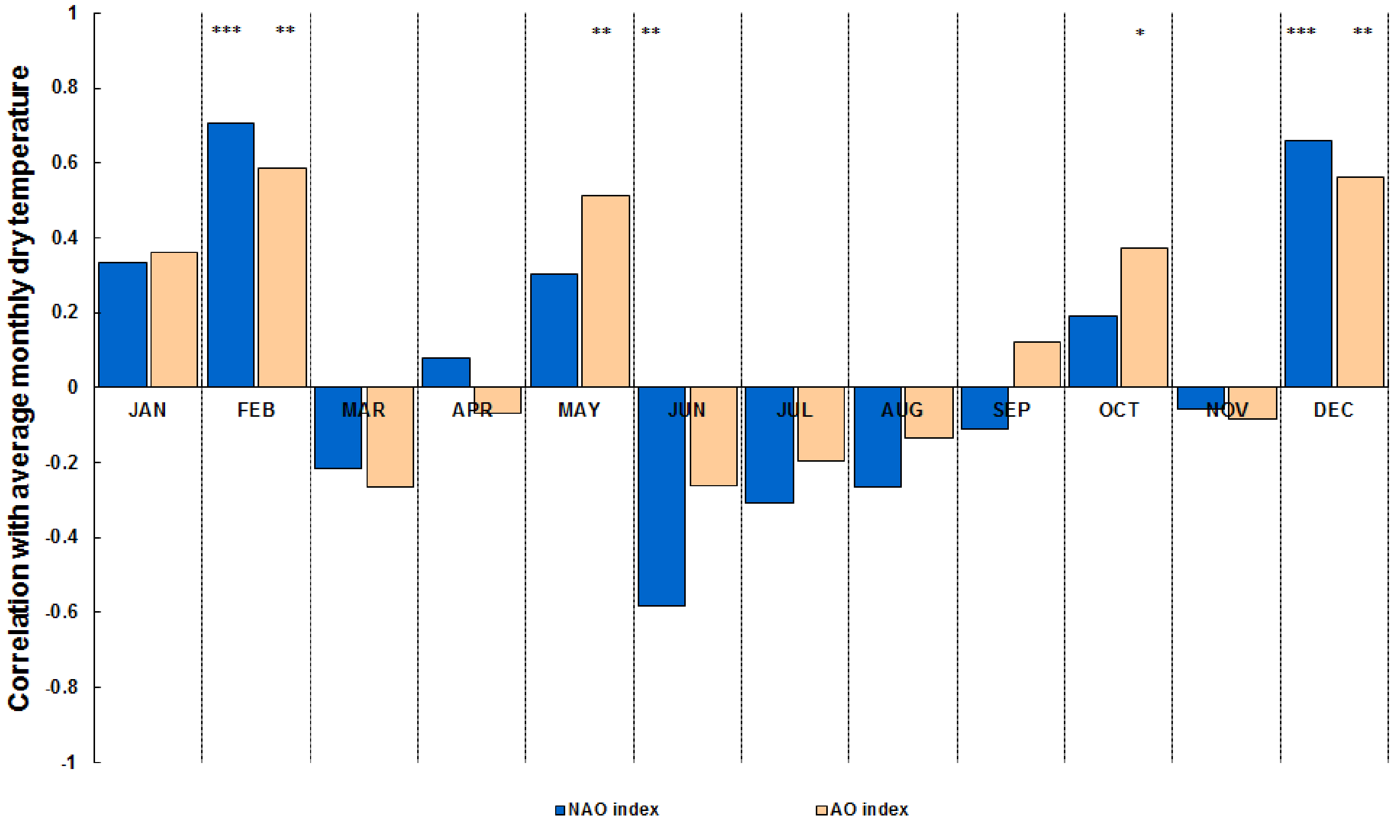


Cumulative annual day-degree sums, for both >0°C and >5.6°C, and T-sum show apparent rising trends over the 19 year period but these aren't significant.

At a monthly level, there have been decreases in all three indices for August ($p < 0.05$), and also for May for day degrees above 5.6 °C ($p < 0.05$) which may be linked to increases in monthly rainfall. T-Sum also shows a significant decrease for March ($p < 0.05$).

Figure 10: Cumulative annual day-degrees and T-sums over the period 1996-2015.

Terrestrial -monthly rainfall v atmospheric oscillation indices

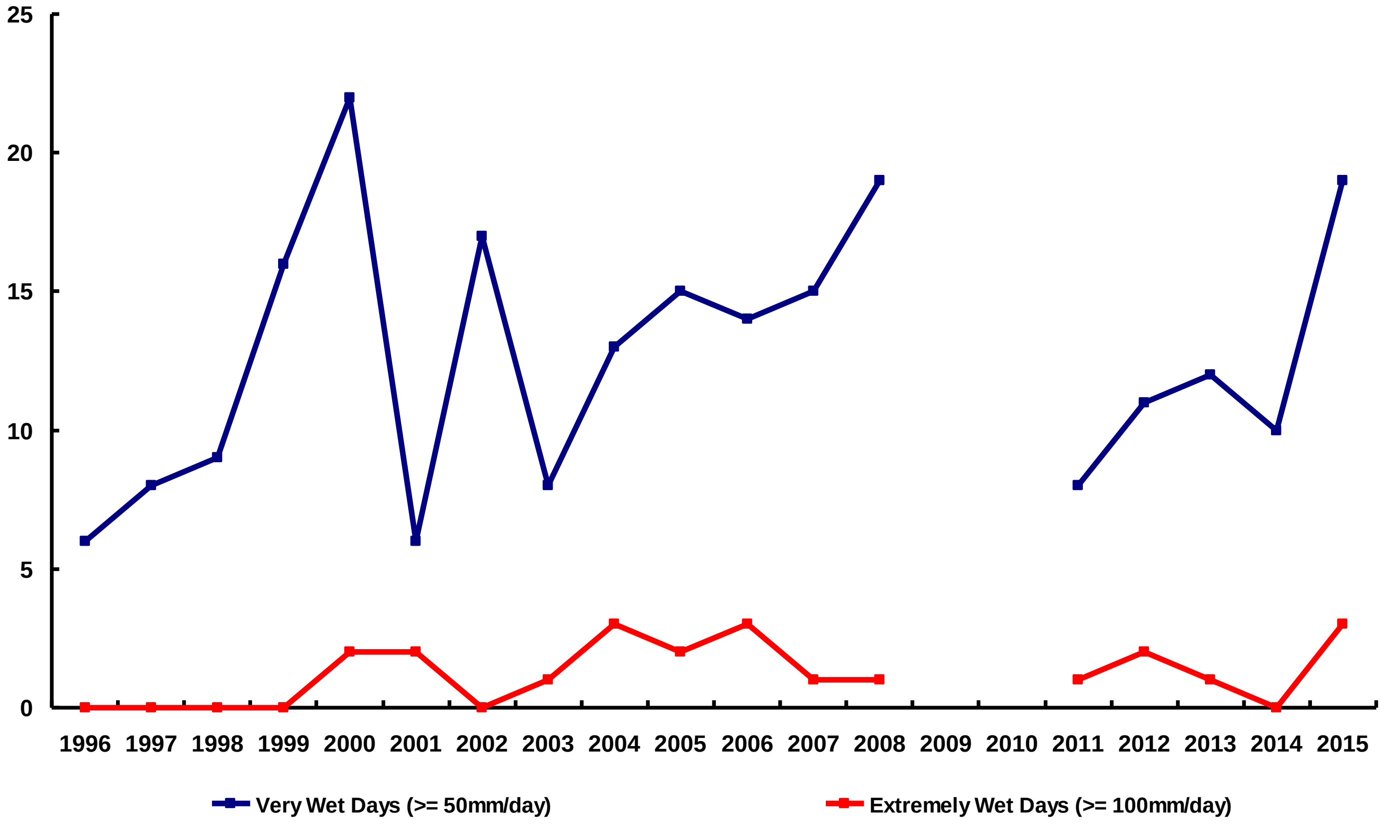


Rainfall v NAOI and AOI:

Strong correlations between winter and summer rainfall and the NAOI for Snowdon rainfall have been noted by Monteith et al. (2016) over the period 1996-2012. The summer relationship with NAOI is negative with the strongest correlation occurring in June (r = 0.581,**) and decreasing thereafter. Winter correlations are positive and strongest in December and February (r = 0.658,*** and 0.707,*** resp.). The correlation with the AOI occurs in a similar pattern to the NAOI but to a lesser degree. There are additional correlations between the AO and May and October rainfall totals (r = 0.513,** and 0.372,** respectively). The correlations with the NAOI for the early spring and autumn months are low.

Figure 11: Correlations between monthly rainfall and the North Atlantic Oscillation and the Arctic Oscillation indices over the period May 1995-Feb 2016. (* p < 0.05, ** p < 0.01, *** p < 0.001)

Terrestrial - high rainfall days



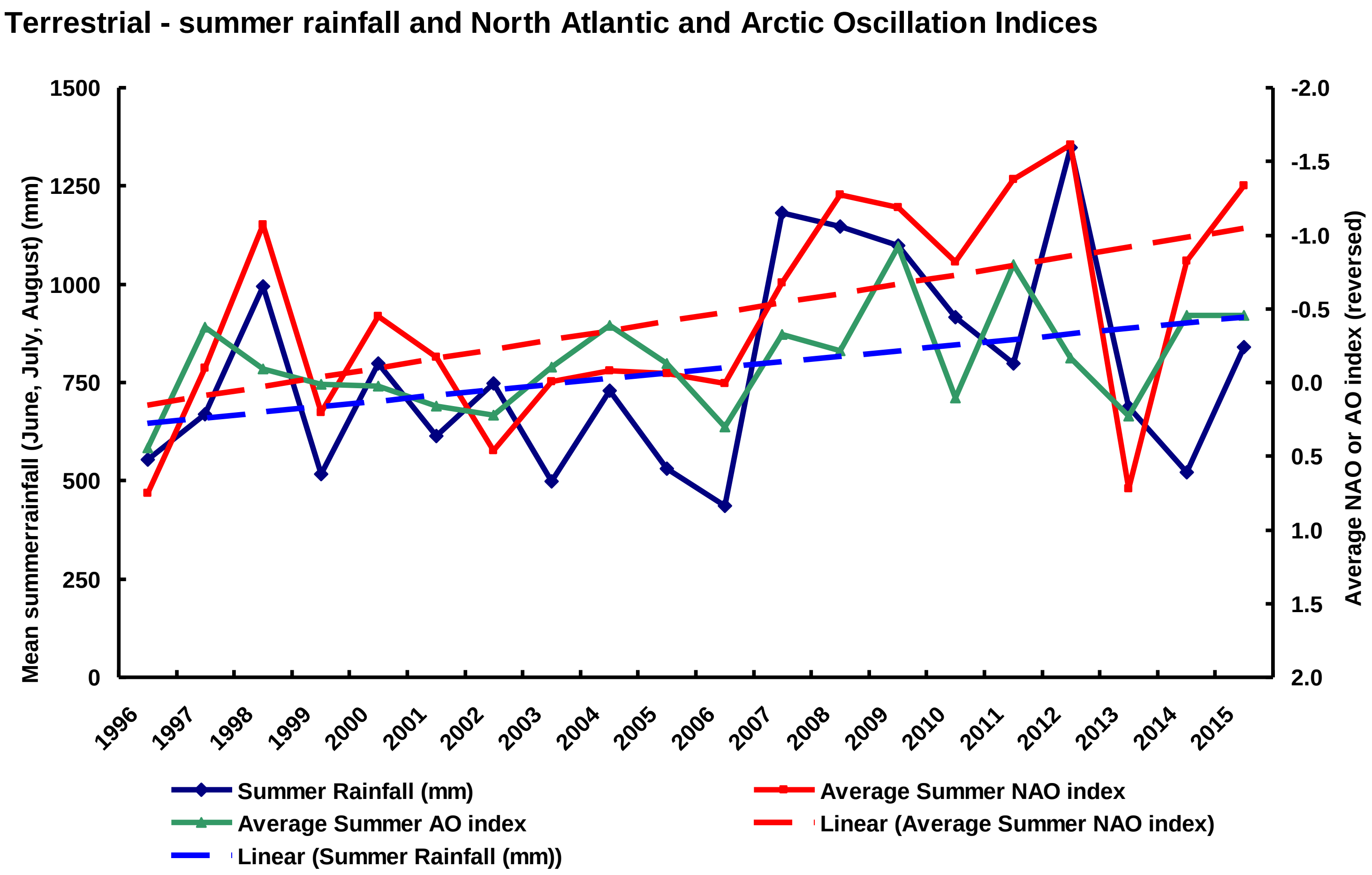
High-rainfall days

Very wet days and extremely wet days are defined those with daily rainfall totals >= 50mm and >= 100mm per day respectively.

There is no significant trend over the period, but the number of extremely wet days, although small, has increased significantly ($p < 0.05$).

At a monthly level, there has been an increase in very wet days in December ($p < 0.05$), but also a decrease in September and October ($p < 0.05$). The trend for extremely wet days, is not significant at a monthly level, although there were 3 days in December 2015, and a total monthly rainfall at the ECN met site of 1163mm.

Figure 12 Number of days per year with rainfall totals of >= 50mm/day and >=100mm/day over the period 1996-2015. Data missing from 2009 and 2010.



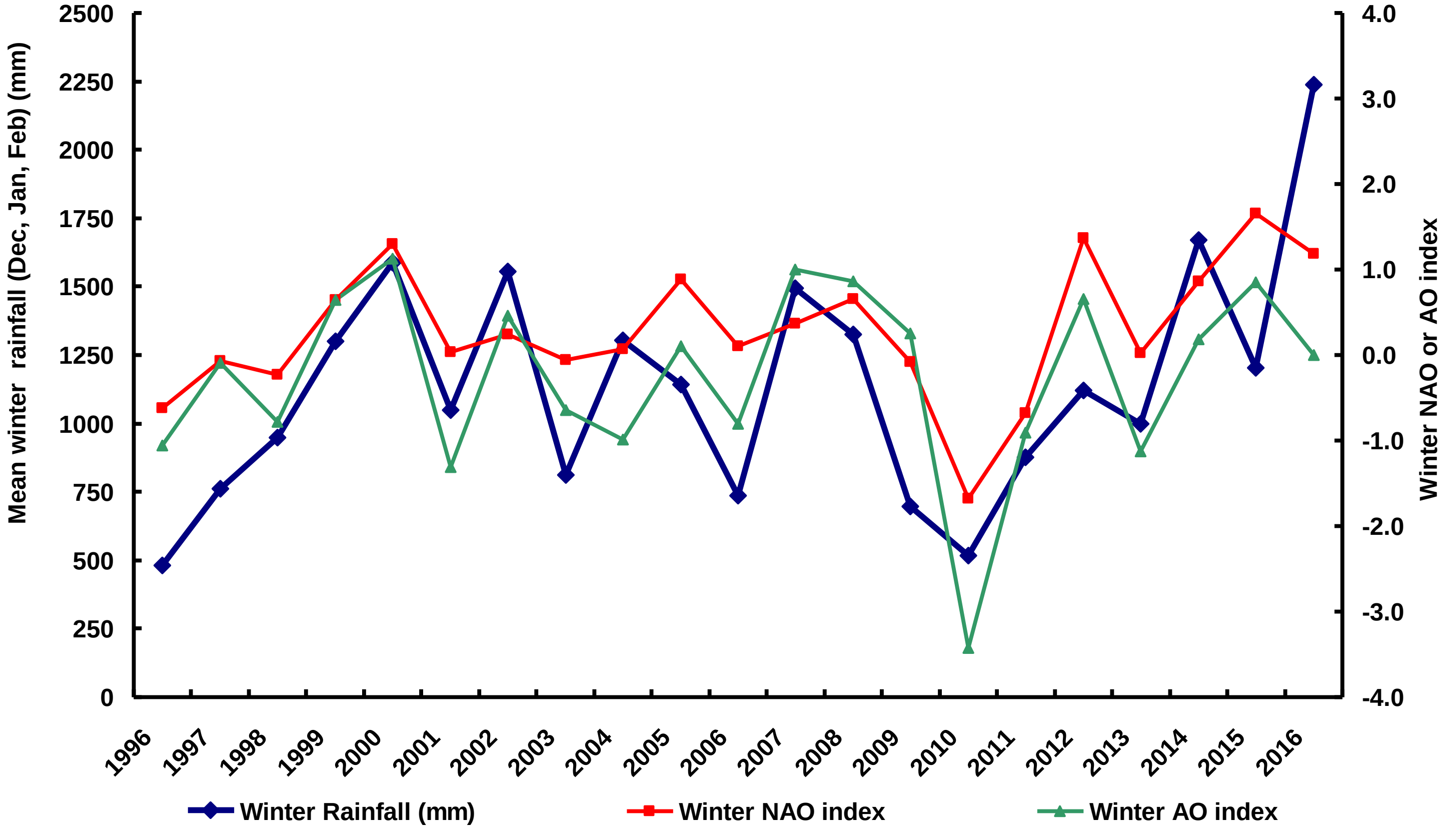
Summer rainfall:

The rising trend for summer rainfall totals over the period 1996-2013 was significant, mainly due to a series of wet summers from 2007-2012. Drier summers from 2013-2015 have reduced the significance of the trend.

The significant negative relationship between summer rainfall and the NAOI and AOI can be seen with r = -0.703,*** and -0.376,* respectively.

Figure 13: Summer rainfall totals from 1996-2015 with average summer North Atlantic Oscillation index and Arctic Oscillation index. Note the right-hand axis is reversed. Significance levels $p < 0.05$ *, $p < 0.01$ **, $p < 0.001$ ***.

Terrestrial - winter rainfall and North Atlantic and Arctic Oscillation Indices



Winter rainfall:

Winter rainfall for the Crib Goch rainfall (alt - 730m) shows a rising trend over the period 1945-2015 ($p < 0.01$), but over the shorter period of the covering the operation of ECN (1995-2016), the trends for Crib Goch and for the ECN met site aren't significant.

The relationship with the NAOI and the AOI is positive and strong (r = 0.689,*** and 0.570,*** resp.). The winter rainfall total of 2237mm for 2015/16 is noteworthy. The Crib Goch rain gauge has historically had a much higher rainfall and its total for the winter, 2891mm, was the highest since 1945.

Figure 14: Winter rainfall totals from 1996-2015 with average winter North Atlantic Oscillation index and Arctic Oscillation index. Significance levels $p < 0.05$ *, $p < 0.01$ **, $p < 0.001$ ***.

Terrestrial - Crib Goch rainfall (1945-2016)

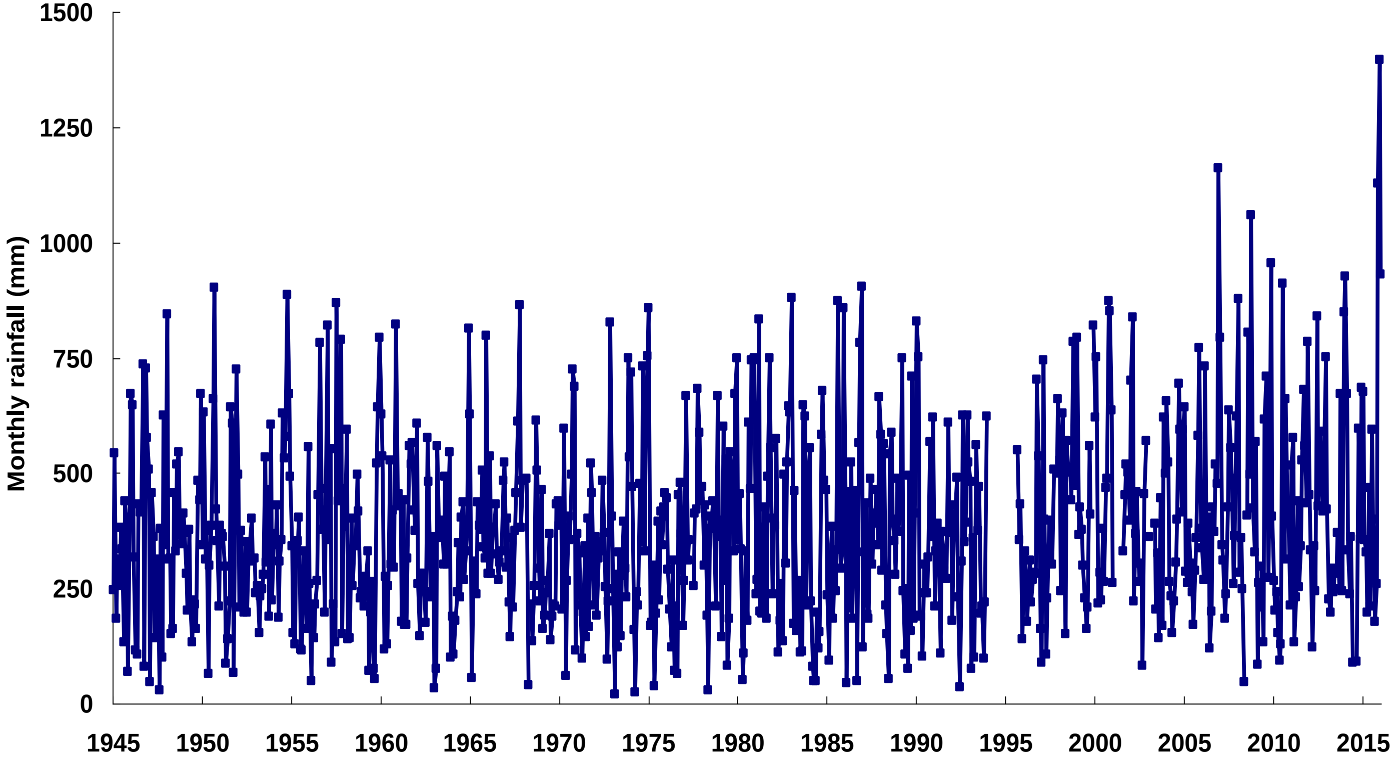


Figure 15. Monthly rainfall from Crib Goch rain-gauge, Snowdon over the period 1945-2015**.**

Extreme rainfall event in 2015

As well as the AWS and manual rain-gauges used for the ECN project, there are two other monthly manual rain-gauges on the ECN site – Crib Goch (altitude 730m) and Llydaw Delta (altitude 450m). For these rain-gauges, the record extends back to the early 1900s and data from 1945 is held by NRW.

During December 2015, the rainfall was sufficient to completely flood the Llydaw Delta gauge, and the Crib Goch gauge which has a greater capacity was filled almost to capacity. The resulting recorded rainfall, 1396.4mm, is provisionally estimated to be the highest monthly rainfall ever recorded in the UK (pers com Stephen Burt, Dept Meteorology, Reading Univ.).

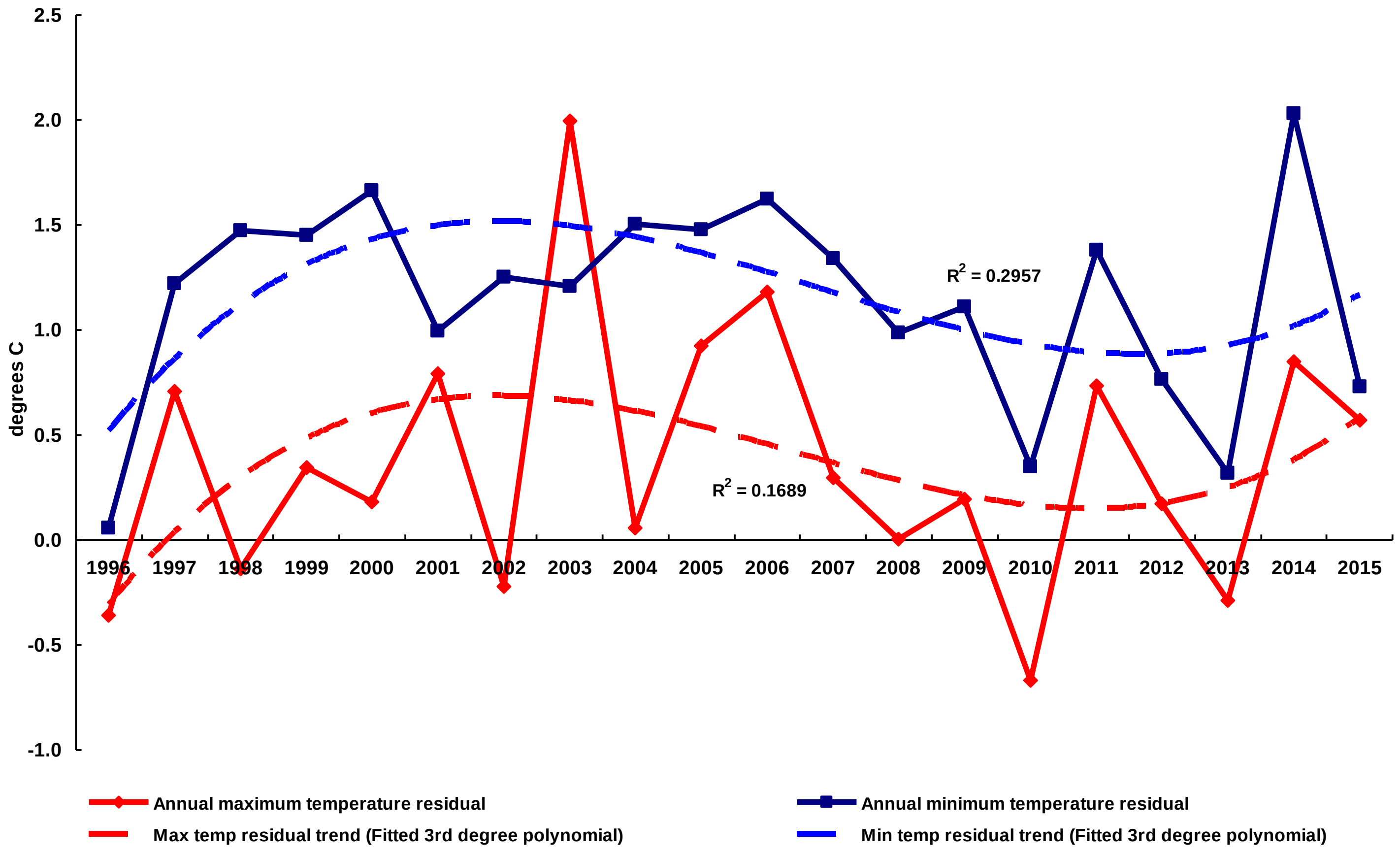
Table 3: Residuals for weekly maximum, minimum, grass minimum and soil temperatures, temperature range and weekly rainfall for 1996 to 2015, compared with mean values for 1966-77.

Year	Statistic	Maximum temp. residual (deg C)	Minimum temp. residual (deg C)	Temperature range residual (deg C)	Mid-range temp. residual (deg C)	Grass min. temp. residual (deg C)	Soil temp. residual (deg C)	Manual rainfall residual (mm)
1996 to 2015	Mean	0.36	1.15	-0.80	1.37	2.02	0.87	5.67
	SD	3.11	2.29	3.10	2.40	3.05	1.28	55.67
	n	1010	1029	1010	1014	989	1027	1027
	SE	0.10	0.07	0.10	0.08	0.10	0.04	1.74
1996	Mean	-0.36	0.06	-0.42	0.51	1.24	-0.11	-11.02
1997	Mean	0.71	1.22	-0.51	1.63	2.77	0.98	-5.48
1998	Mean	-0.14	1.47	-1.61	1.33	3.48	0.86	13.09
1999	Mean	0.35	1.45	-1.10	1.56	1.33	0.88	12.31
2000	Mean	0.18	1.66	-1.48	1.59	0.38	0.62	22.87
2001	Mean	0.79	1.00	-0.36	1.61	-0.10	0.64	-8.60
2002	Mean	-0.22	1.25	-1.47	1.18	-1.23	0.87	11.60
2003	Mean	2.00	1.21	0.81	1.20	2.61	1.26	-5.84
2004	Mean	0.06	1.51	-1.45	1.45	2.43	1.28	5.28
2005	Mean	0.92	1.48	-0.55	1.87	2.58	1.39	5.56
2006	Mean	1.18	1.62	-0.44	2.07	2.49	1.49	7.92
2007	Mean	0.29	1.34	-1.05	1.48	1.78	1.30	6.31
2008	Mean	0.00	0.99	-0.99	1.16	2.69	0.65	18.16
2009	Mean	0.20	1.11	-0.92	1.32	3.33	0.69	4.72
2010	Mean	-0.67	0.35	-1.02	0.51	3.32	0.30	-2.32
2011	Mean	0.73	1.38	-0.64	1.72	1.73	1.07	4.53
2012	Mean	0.17	0.77	-0.71	1.18	3.69	0.62	13.30
2013	Mean	-0.29	0.32	-0.61	0.68	1.49	0.48	-0.80
2014	Mean	0.85	2.03	-1.18	2.11	2.27	1.34	2.37
2015	Mean	0.57	0.73	-0.16	1.32	1.65	0.75	16.54

Table 4: Average weekly maximum, minimum, grass minimum and soil temperatures, temperature range and weekly rainfall for the period 1966-1977.

Year	Statistic	Maximum temp. (deg C)	Minimum temp. (deg C)	Temperature range (deg C)	Mid-range temp. (deg C)	Grass min. temp. (deg C)	Soil temp. (deg C)	Manual rainfall (mm)
1966 to 1977	Mean	12.53	2.69	9.84	7.60	-0.64	7.91	55.09
	SD	5.26	4.45	3.33	4.58	4.68	3.64	48.21
	n	599	599	599	600	523	570	598
	SE	0.21	0.18	0.14	0.19	0.20	0.15	1.97

Terrestrial - air temperature compared to IBP 1966-77 recording period



Maximum and minimum manual dry-bulb temperatures were 0.36°C and 1.15°C respectively over the period 1996-2015, in relation to the IBP base-line data from 1966-1977. The increases are significant ($p < 0.01$ and $p < 0.001$, respectively)

The overall trends since the start of recording on the ECN site in 1995, has been for a rise up to around 2002-03, followed by a fall with the colder winters of 2010-2012, and since 2012 there has been some evidence of a renewed rise in temperature.

Figure 16: Annual maximum and minimum manual dry-bulb temperature residuals for the period 1996-2015 in relation to baseline IBP data from 1966-1977.

Terrestrial - soil temperature compared to IBP 1966-77 recording period

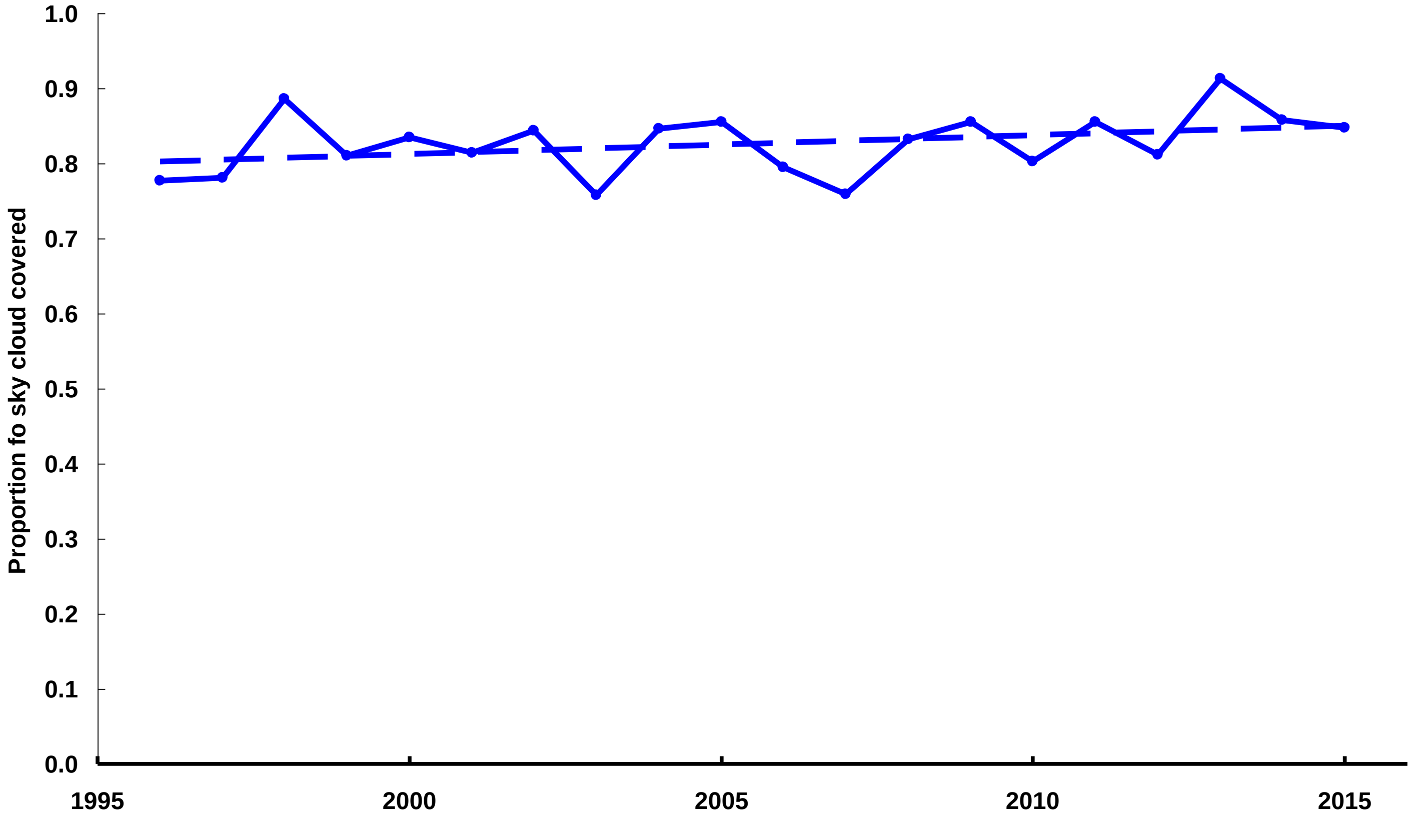
Compared to the 1966-77 IBP data, soil temperatures over the period 1996-2015 are significantly higher (+0.75°C, $p < 0.001$).

Soil temperature as measured by the AWS show no significant linear trend over the period 1996-2015, but there has been a significant decrease in monthly soil temperature for August which parallels the similar decrease in air temperature.

As with the maximum and minimum temperature residuals (Figure 16), the trend over the period is best fitted with a 3rd degree polynomial. Highest mean soil temperature for winter (+8.71° C) occurred in 2015/16.

Figure 17: Annual soil temperature residuals for the period 1996-2015 in relation to baseline IBP data from 1966-1977.

Terrestrial - cloudiness



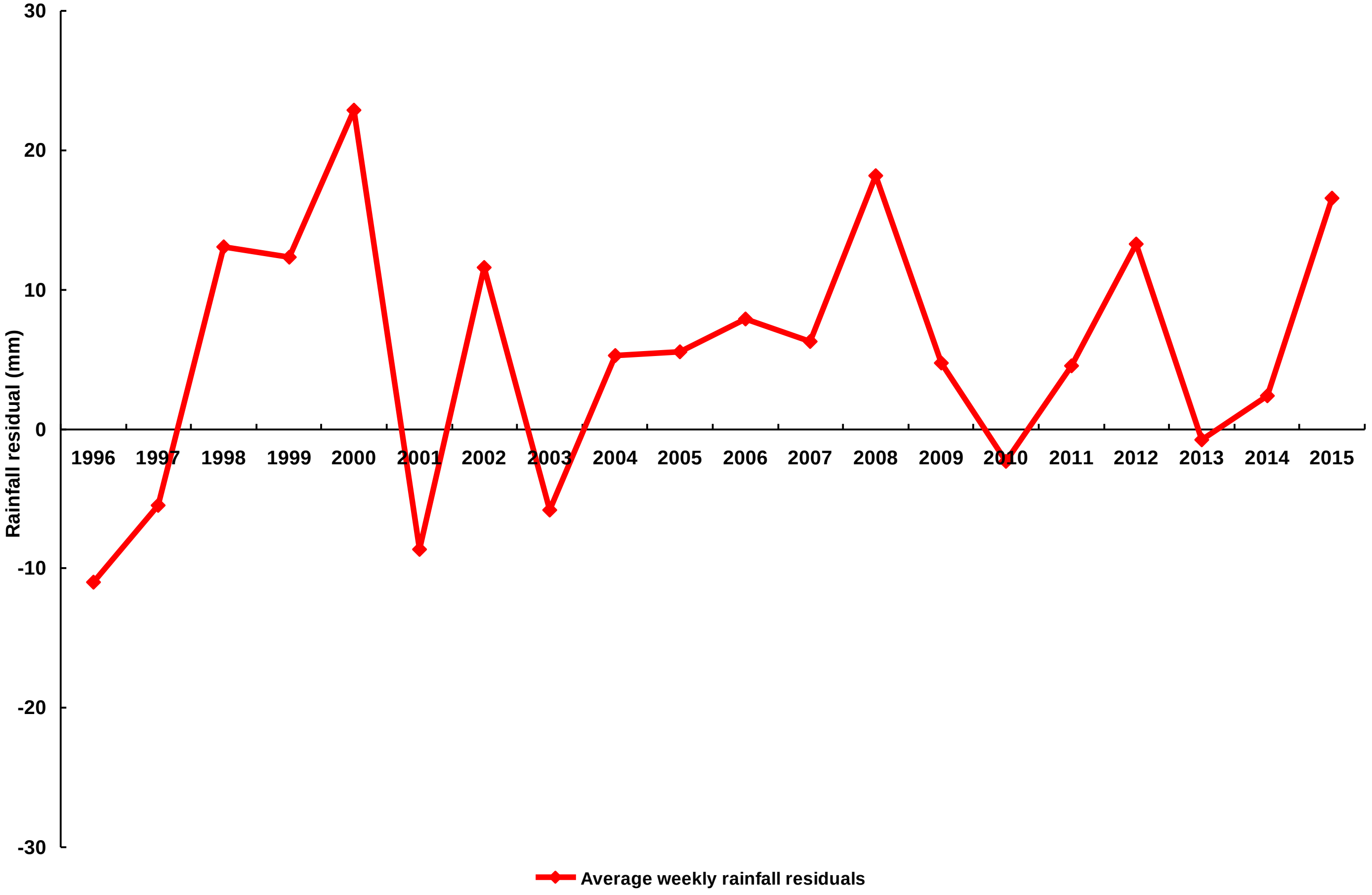
Cloud cover

Estimates of cloud cover are made weekly from the ECN met site using oktas. The annual average cloud cover shows a significantly increasing trend over the period 1996-2015 ($p < 0.05$).

There was complete cloud cover on 58% of recording occasions, while cloudless skies occurred only about 3% of the time.

Figure 18: Annual average cloud cover over the period 1996-2015.

Terrestrial - rainfall compared to IBP 1966-77 recording period

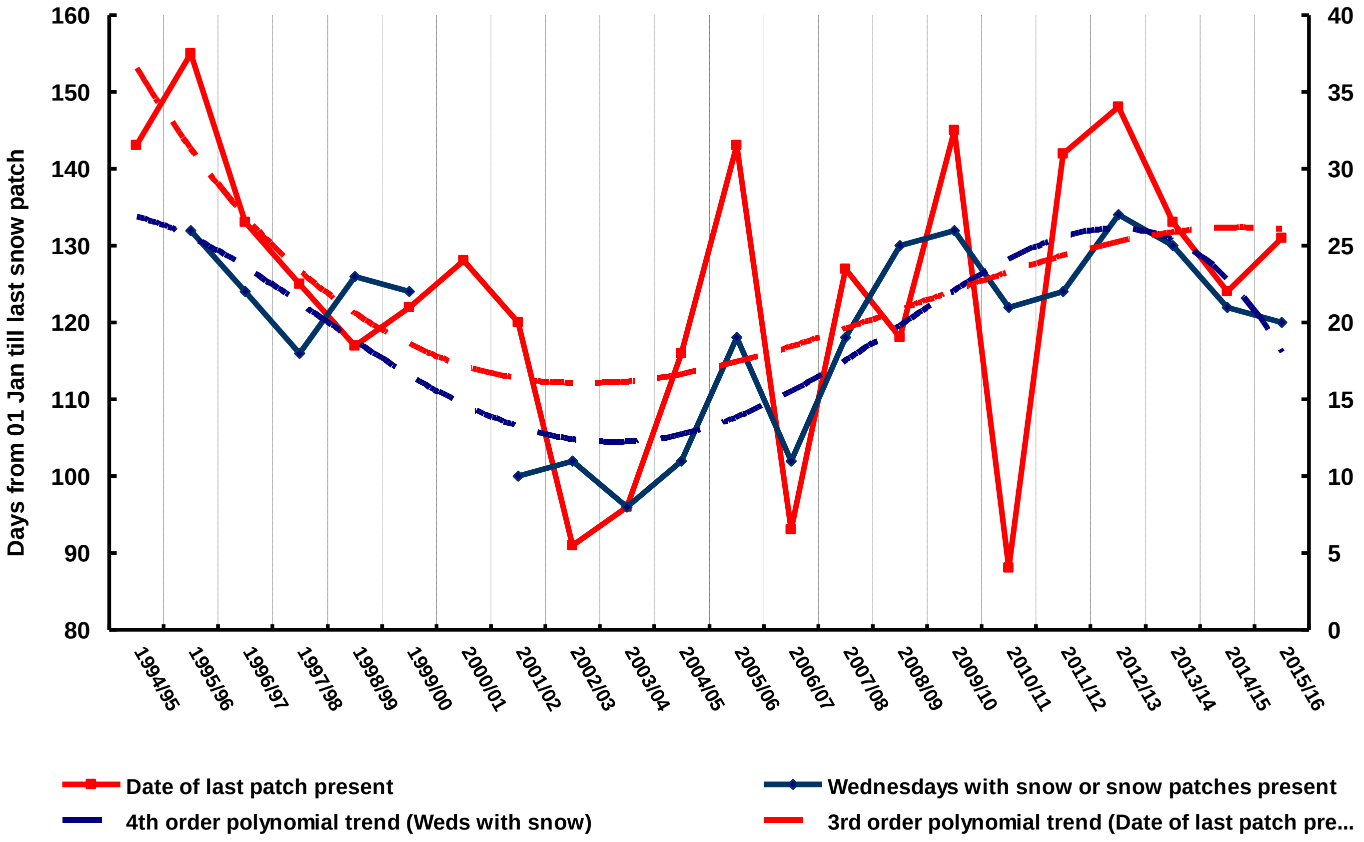


Annual rainfall

Over the duration of the ECN project on Snowdon there has been no significant trend in rainfall. In relation to the rainfall recorded during the IBP project on Snowdon (1966-77), the rainfall over the period 1996-2015 is on average 5.67mm per week higher which translates to 295mm per year. This difference is significant ($p < 0.01$)

Figure 19: Averaged weekly rainfall residuals for the period 1996-2015 in relation to weekly baseline IBP data from 1966-1977.

Terrestrial - snow duration



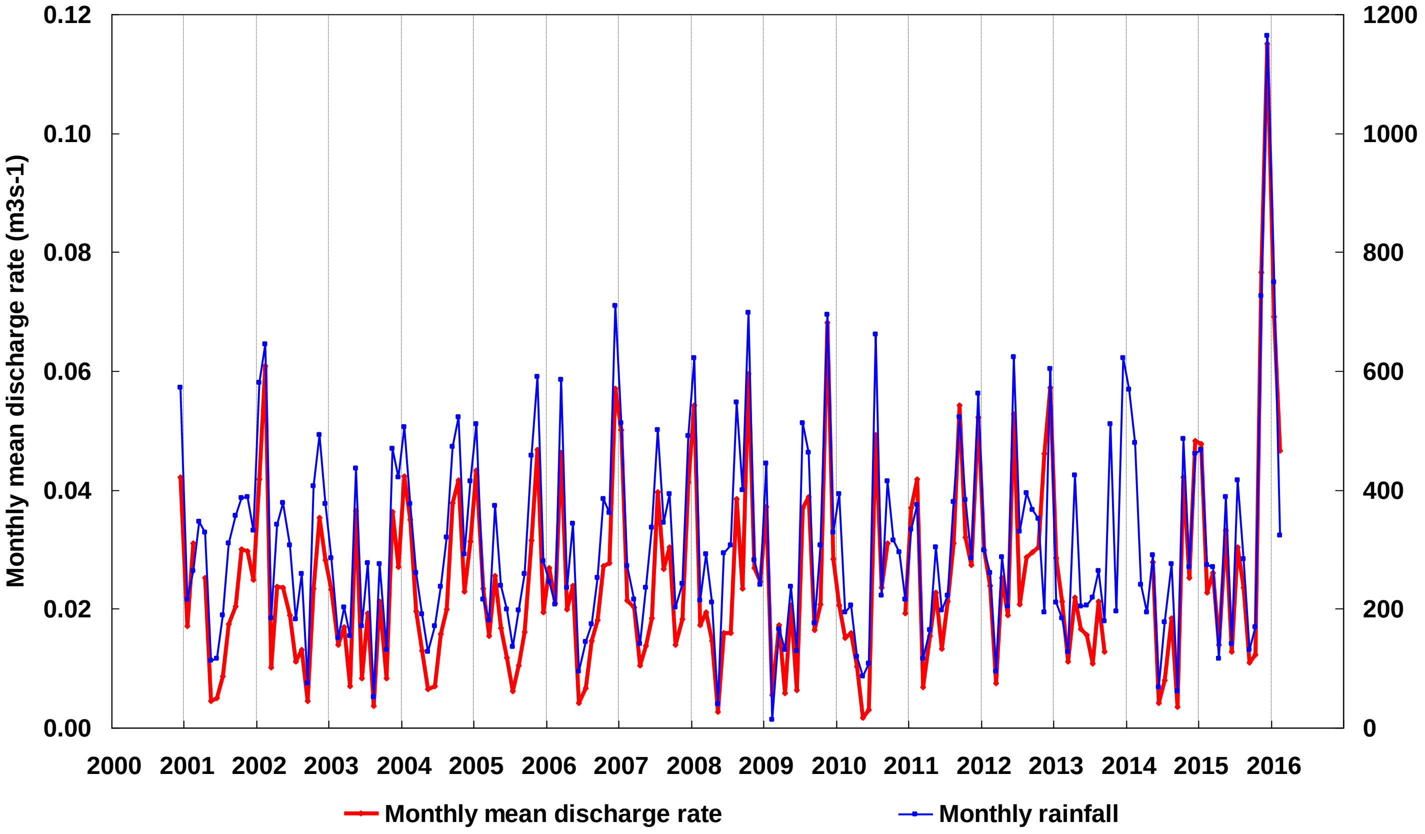
Snow:

Snow duration recording is a non-ECN protocol which has been undertaken since 1995.

The 2014/2015 winter was slightly less snowy than the two preceding years, and perhaps shows a renewed trend towards warming as indicated by the fitted 4rd degree polynomial trend. The date of last snow patch is best fitted with a 3rd degree polynomial which doesn’t yet indicate any change towards earlier melting.

Figure 20: Date of last snow patch present on ECN site and number of Wednesdays with continuous snow or snow patches present somewhere on the site over the period 1996/96 – 2015/16.

Terrestrial - water discharge and rainfall



Nant Teyrn discharge:

Monthly mean discharge rate closely matches monthly rainfall and shows a pronounced seasonal variation with a minimum generally in spring to early summer, and a maximum often in the winter period.

Summer peaks are also seen for the years 2007 to 2012.

Highest flow rates seen over the 15 year period of operation were seen in December 2015 coinciding with unprecedented rainfall on the site.

Figure 21: Monthly mean discharge rate across Nant Teyrn weir and monthly rainfall at ECN weather station.

Freshwater - conductivity and temperature

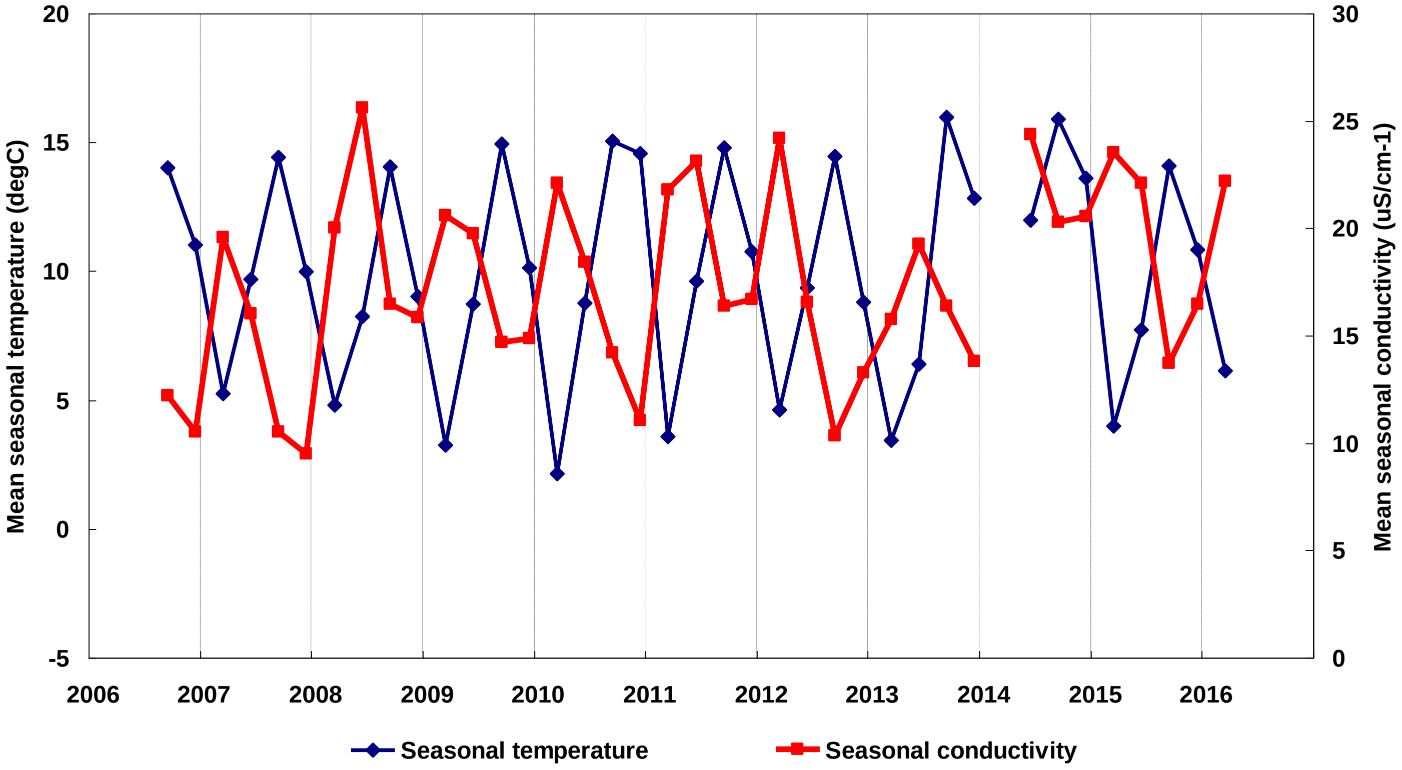


Figure 22: Seasonal mean conductivity and temperature at Nant Teyrn (2006-2016).

Seasonal conductivity and temperature:

Conductivity and temperature are sampled continuously at the Nant Teyrn weir. Both show a strong seasonal pattern but no clear trend with such a short data set.

For conductivity the seasonal pattern has low mean values (10-12 µScm-1) during late summer and early autumn and high values (17-26 µScm-1) during the winter and early spring. The winter temperature is around 3-7 ºC during winter and 12-19 ºC in spring and summer.

Winter temperature in 2015/16 was higher than average reflecting the abundant input of warm sector rainfall associated with a strong and vigorous jet-stream.

3.2 Summary of trends for chemical variables.

The main chemical drivers of change in the upland ecosystem at the Snowdon ECN site all come from atmospheric sources. The main ECN protocols are concentrated on examining changes in the chemistry of precipitation (PC), surface water (WC) and soil water (SS), and samples are all analysed, where volumes allow, for pH, conductivity, alkalinity, anions, cations and Dissolved Organic Carbon (DOC). The soil water samples are collected from suction samplers fortnightly in an area of calcareous grassland while the surface water is collected weekly from the outflow of Llyn Teyrn, a small acidic lake within a catchment with predominantly acidic grassland vegetation and some blanket mire. Hence the soil water is of higher base status generally than the surface water. As has been noted above, the rainfall on the site is high and this has consequences for the deposition of anions in relation to critical loads. In addition to the weekly sampling of surface water, the freshwater chemistry protocol (FWC) is undertaken 4-weekly at the same location as WC but additionally with Biological Oxygen Demand (BOD), a range of heavy metals, arsenic, silicate and solids. Sampling for FWC has been undertaken since 2007, while PC, WC and SS have been sampled since 1997.

For precipitation water, the most marked change has been in terms of base-status with a significant increase in pH ($p < 0.01$). This has been due to highly significant reductions in the concentration of anions such as sulphate (SO_4-S) and nitrate (NO_3-N) (Figures 28 & 30), due to controls on emissions from coal burning and vehicles, starting originally in the 1960s. In seasonal terms, the increase in pH has been most pronounced in spring and autumn ($p < 0.01$ and $p < 0.05$ resp.), which is similar to the significant decreasing trend in sulphate during the same seasons ($p < 0.01$), but also during summer ($p < 0.001$). Nitrate in contrast has only shown a decrease in summer ($p < 0.05$). The other source of nitrogen, ammonium (NH_4-N) whose main source is livestock, has shown a significant annual decrease which is mainly manifested in a decline in summer ($p < 0.05$).

Of the other anions, chloride shown no significant trend and phosphate (PO_4-P) shows an increase in spring. Most of the simple cations (Na, K, Ca or Mg) show no significant annual or seasonal trend with the exception of potassium which shows a significant increase during winter ($p < 0.01$). Iron and aluminium show seasonal increases, the former in summer ($p < 0.001$) and winter ($p < 0.01$), the latter in spring ($p < 0.01$). Finally dissolved organic carbon (DOC), although present at low levels, has shown a decrease both annually and in all seasons.

Levels for critical loads for sulphate and nutrient nitrogen (nitrate + ammonium) for the site were taken from the APIS website (www.apis.ac.uk) and are used in the comparison in Table 7. Levels of deposited sulphur and nutrient nitrogen have decreased significantly, the latter both annually and through all seasons. Table 7 indicates that for nutrient nitrogen, levels are now below the Maximum Critical Load for all habitats, but still above the Minimum Critical Load for seven of the sixteen habitats present on the site. For acidity, out of eleven habitats where levels are available, all but one are above the Minimum Critical Load while all are below the Maximum Critical Load (Figure 35).

For surface water, many of the changes noted above for precipitation water also apply. pH has increased significantly annually and also during the autumn and winter months ($p < 0.05$) and it tracks precipitation water pH fairly closely (Figure 24). Also, levels of sulphate and nitrate have declined ($p < 0.001$), with the former also showing declines through all seasons, while the latter has decreased in all but spring. There has been no appreciable trend for chloride or phosphate.

Small anions show no clear trend in surface waters, either annually or seasonally. Iron shows a decline in the summer months ($p < 0.05$) but no change annually, while aluminium shows a decrease annually ($p < 0.05$) with the major seasonal trend being a decline in the winter ($p < 0.001$).

Ionic Balance Acid Neutralising Capacity (ANC) is a good measure of the acid freshwater status of the nearby Llyn Teyrn. This shows a significant increase over the period ($p < 0.01$) with all the season showing increases except for winter. The increasing trend is caused by the reduction in sulphate and nitrate but with relatively little change in the major cations.

Dissolved organic carbon (DOC) shows an interesting trend, there has been a decrease over the whole period, which is significant both at the annual scale ($p < 0.01$), but also during all four seasons ($p < 0.01$ for all, except autumn, $p < 0.05$). This trend is in sharp distinction to that of other upland sites in the UK Acid Waters Monitoring Network where there have been upward trends (Monteith et al. 2014). The distinction is particularly notable when Llyn Teyrn is compared with Llyn Llagi, only 8 miles away, where the geology, altitude and surrounding habitats are similar, but the trend there is also upward. The difference between the two may be explicable in terms of subtle differences in soils – a greater proportion of deep-peat habitats at Llyn Llagi compared to Llyn Teyrn, and possibly more mineral soil present at the latter.

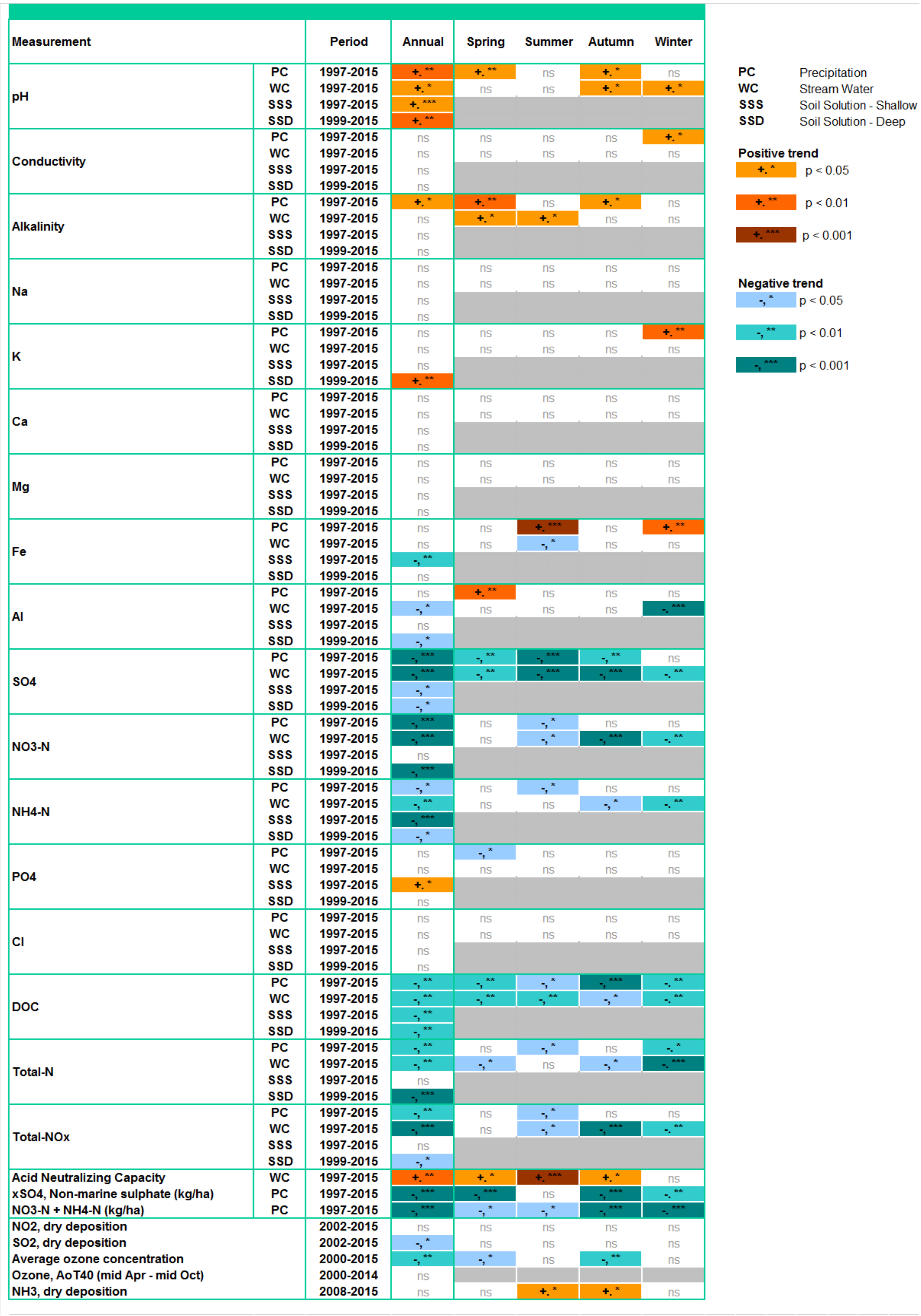
Sampling for freshwater chemistry occurs 4-weekly at the same location as for surface water chemistry, but with the emphasis on a suite of heavy metals as well as BOD, silicate, arsenic and solids. With the heavy metals, there seem to be two patterns, peaks in the winter and peaks in the summer. Of the former, zinc (Zn) is a good example, with summer levels falling below the limit of detection (Figure 42). In contrast iron, manganese and copper all show peaks in the summer. Manganese, iron and zinc show no significant trend over the period of freshwater recording (2007-2015), but copper concentrations show a significantly decreasing trend ($p < 0.05$).

For soil water, some of the trends noted above for rain water and surface water are also apparent, but there are a few differences. pH shows a significant increase both for shallow and deep samplers ($p < 0.001$ and $p < 0.001$). Sulphate also shows a decrease at both levels ($p < 0.05$), but nitrate only shows a decrease at the deep level samplers, there being no clear trend for the shallow ones (Figure 30). Ammonium, shows a decrease at both levels (shallow, $p < 0.001$; deep, $p < 0.01$) (Figure 31). Interestingly, phosphate (PO_4-P) shows an increase at the shallow level samplers, although the graph indicates more of a hump-backed trend with low values in 2014 and 2015. Dissolved organic carbon (DOC) shows a decrease at both levels ($p < 0.01$).

Sampling of dry deposition by NO_2 and SO_2 is undertaken by diffusion tubes. Additionally, the site hosts passive samplers for UKAEAP for ammonia, and a site 8km away at Plas y Brenin is also serviced. NO_2 is sampled fortnightly, and deposited levels are low (Figure 36). In contrast to the decrease seen in nitrate in rainfall, there is no trend in NO_2. SO_2 sampling is done on a 4-weekly basis, and this does show a significant decreasing annual trend ($p < 0.05$) (Figure 37). Ammonia, sampled on a monthly basis, shows no trend in annual concentration, but does show a seasonal trend with an increase during the spring and summer months ($p < 0.05$).

Continuous monitoring of ground-level ozone and nitrogen oxides at Marchlyn Mawr, has been a part of the Snowdon ECN project since 1999. Levels through the year vary with greater concentrations during spring and the lowest concentrations during summer and autumn (Figure 39). Over the period of recording, annual, spring and autumn concentrations have decreased significantly ($p < 0.01$, $p < 0.05$ and $p < 0.01$ resp.). This declining trend is in contrast to other remote sites (Figure 40) which show a relatively level trend. High levels of ozone have been implicated in damage to plants, and AoT40, the accumulated dose over 40ppb during daylight hours from mid-April to mid-October is a measure of the effect with exceedance of the critical level of 5000 ppb.h (parts per billion hour) indicating damage to semi-natural vegetation (APIS 2016). Figure 41 shows a recalculated AoT40 taking in all daylight hours and extended to mid-October, previously the calculation was made from 6am to 6pm, from May to July and the critical level was set at 3000 ppb.h. The trend is apparently downward (Figure 41), but is not significant although the peaks seen in the mid-2000s appear to have gone.

Table 5: **Summary of trends for chemical variables**



Measurement		Period	Annual	Spring	Summer	Autumn	Winter
pH	PC	1997-2015	+. **	+. **	ns	+. *	ns
	WC	1997-2015	+. *	ns	ns	+. *	+. *
	SSS	1997-2015	+. ***				
	SSD	1999-2015	+. **				
Conductivity	PC	1997-2015	ns	ns	ns	ns	+. *
	WC	1997-2015	ns	ns	ns	ns	ns
	SSS	1997-2015	ns				
	SSD	1999-2015	ns				
Alkalinity	PC	1997-2015	+. *	+. **	ns	+. *	ns
	WC	1997-2015	ns	+. *	+. *	ns	ns
	SSS	1997-2015	ns				
	SSD	1999-2015	ns				
Na	PC	1997-2015	ns	ns	ns	ns	ns
	WC	1997-2015	ns	ns	ns	ns	ns
	SSS	1997-2015	ns				
	SSD	1999-2015	ns				
K	PC	1997-2015	ns	ns	ns	ns	+. **
	WC	1997-2015	ns	ns	ns	ns	ns
	SSS	1997-2015	ns				
	SSD	1999-2015	+. **				
Ca	PC	1997-2015	ns	ns	ns	ns	ns
	WC	1997-2015	ns	ns	ns	ns	ns
	SSS	1997-2015	ns				
	SSD	1999-2015	ns				
Mg	PC	1997-2015	ns	ns	ns	ns	ns
	WC	1997-2015	ns	ns	ns	ns	ns
	SSS	1997-2015	ns				
	SSD	1999-2015	ns				
Fe	PC	1997-2015	ns	ns	+. ***	ns	+. **
	WC	1997-2015	ns	ns	-, *	ns	ns
	SSS	1997-2015	-, **				
	SSD	1999-2015	ns				
Al	PC	1997-2015	ns	+. **	ns	ns	ns
	WC	1997-2015	-, *	ns	ns	ns	-. ***
	SSS	1997-2015	ns				
	SSD	1999-2015	-, *				
SO4	PC	1997-2015	-, ***	-, **	-, ***	-, **	ns
	WC	1997-2015	-, ***	-, **	-, ***	-, ***	-. **
	SSS	1997-2015	-, *				
	SSD	1999-2015	-, *				
NO3-N	PC	1997-2015	-, ***	ns	-, *	ns	ns
	WC	1997-2015	-, ***	ns	-, *	-, ***	-. **
	SSS	1997-2015	ns				
	SSD	1999-2015	-, ***				
NH4-N	PC	1997-2015	-, *	ns	-, *	ns	ns
	WC	1997-2015	-, **	ns	ns	-, *	-. **
	SSS	1997-2015	-, ***				
	SSD	1999-2015	-, *				
PO4	PC	1997-2015	ns	-, *	ns	ns	ns
	WC	1997-2015	ns	ns	ns	ns	ns
	SSS	1997-2015	+. *				
	SSD	1999-2015	ns				
Cl	PC	1997-2015	ns	ns	ns	ns	ns
	WC	1997-2015	ns	ns	ns	ns	ns
	SSS	1997-2015	ns				
	SSD	1999-2015	ns				
DOC	PC	1997-2015	-, **	-, **	-, *	-, ***	-. **
	WC	1997-2015	-, **	-, **	-, **	-, *	-. **
	SSS	1997-2015	-, **				
	SSD	1999-2015	-, **				
Total-N	PC	1997-2015	-, **	ns	-, *	ns	-. *
	WC	1997-2015	-, **	-, *	ns	-, *	-. ***
	SSS	1997-2015	ns				
	SSD	1999-2015	-, ***				
Total-NOx	PC	1997-2015	-, **	ns	-, *	ns	ns
	WC	1997-2015	-, ***	ns	-, *	-, ***	-. **
	SSS	1997-2015	ns				
	SSD	1999-2015	-, *				
Acid Neutralizing Capacity	WC	1997-2015	+. **	+. *	+. ***	+. *	ns
xSO4, Non-marine sulphate (kg/ha)	PC	1997-2015	-, ***	-, ***	ns	-, ***	-. **
NO3-N + NH4-N (kg/ha)	PC	1997-2015	-, ***	-, *	-, *	-, ***	-. ***
NO2, dry deposition		2002-2015	ns	ns	ns	ns	ns
SO2, dry deposition		2002-2015	-, *	ns	ns	ns	ns
Average ozone concentration		2000-2015	-, **	-, *	ns	-, **	ns
Ozone, AoT40 (mid Apr - mid Oct)		2000-2014	ns				
NH3, dry deposition		2008-2015	ns	ns	+. *	+. *	ns

PC	Precipitation
WC	Stream Water
SSS	Soil Solution - Shallow
SSD	Soil Solution - Deep

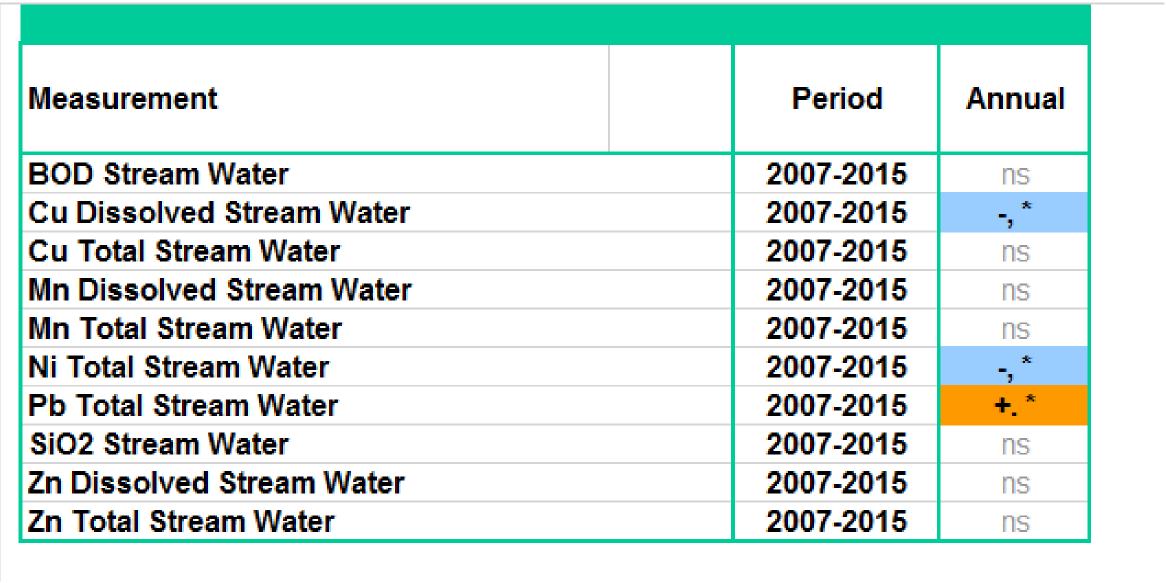
Positive trend

+. *	$p < 0.05$
+. **	$p < 0.01$
+. ***	$p < 0.001$

Negative trend

-, *	$p < 0.05$
-, **	$p < 0.01$
-, ***	$p < 0.001$

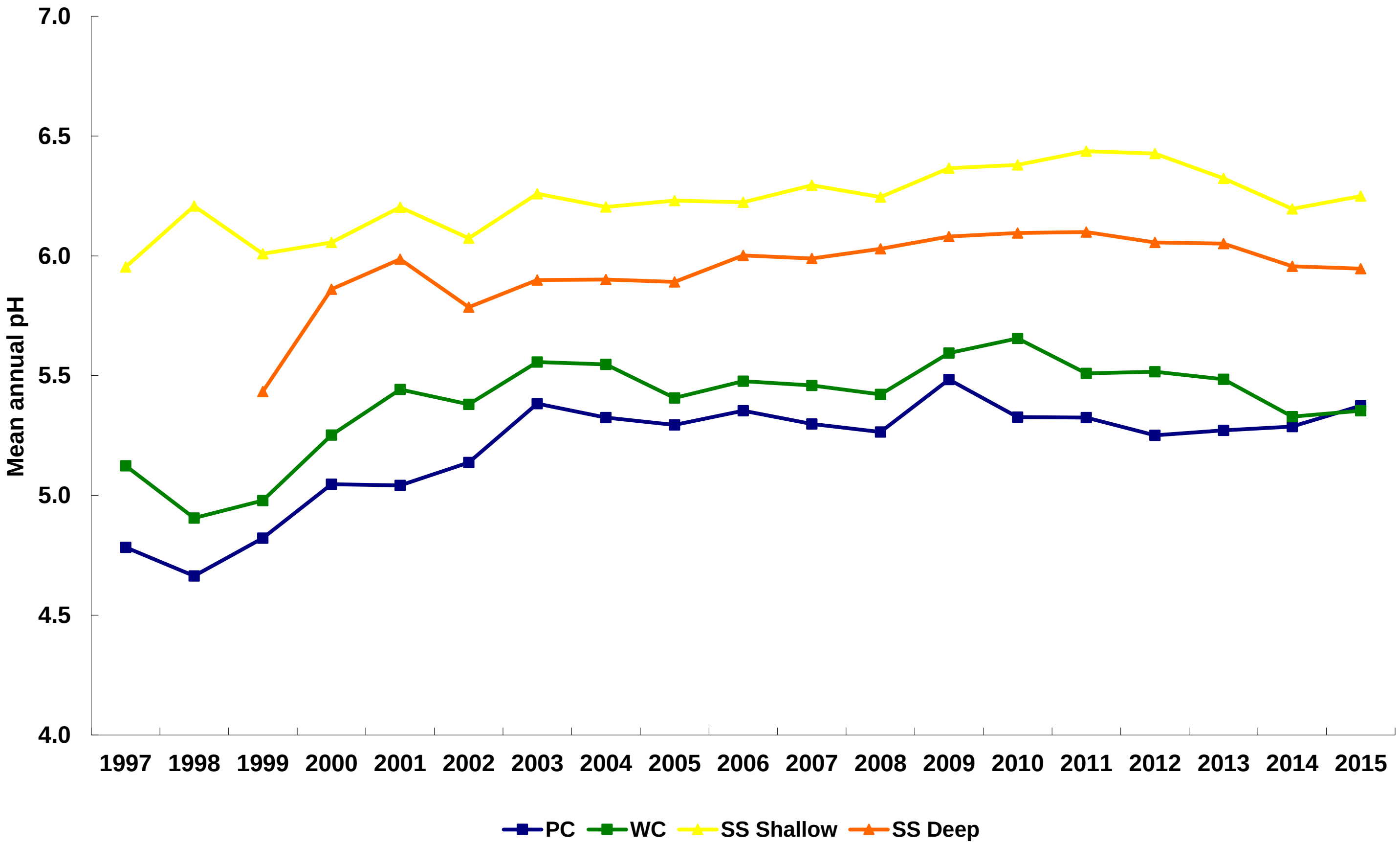
Table 6: Summary of trends for freshwater chemical variables



Measurement	Period	Annual
BOD Stream Water	2007-2015	ns
Cu Dissolved Stream Water	2007-2015	-, *
Cu Total Stream Water	2007-2015	ns
Mn Dissolved Stream Water	2007-2015	ns
Mn Total Stream Water	2007-2015	ns
Ni Total Stream Water	2007-2015	-, *
Pb Total Stream Water	2007-2015	+, *
SiO2 Stream Water	2007-2015	ns
Zn Dissolved Stream Water	2007-2015	ns
Zn Total Stream Water	2007-2015	ns

Figure 23: Collecting soil water for analysis under winter conditions.

Water chemistry - pH



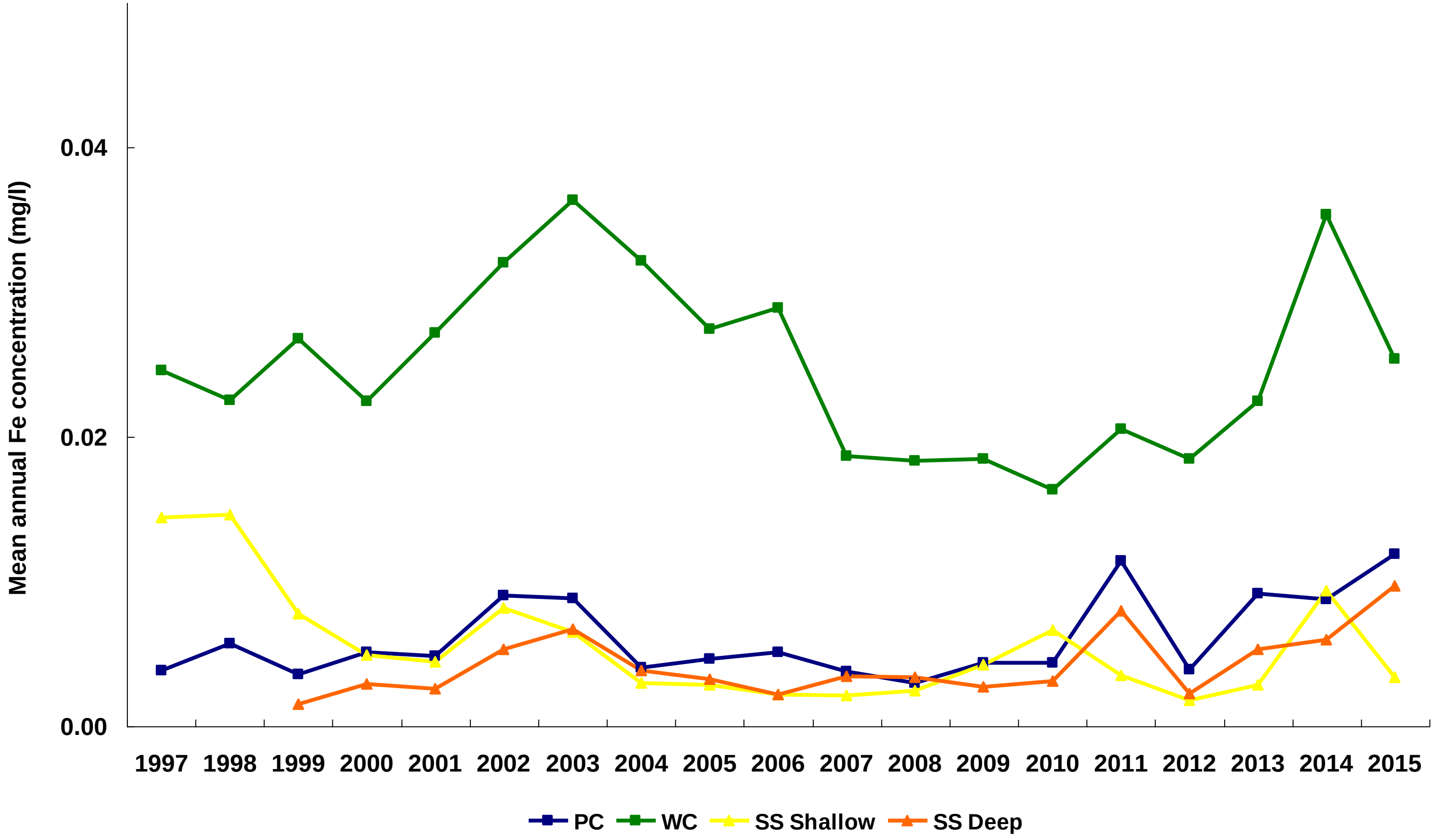
pH:

Acidity of precipitation is continuing to decline across the UK (1986-2007) (RoTaP, 2012) due to the cumulative effect of emission controls.
On Snowdon, surface and shallow soil water pH levels have all continued to increase significantly in line with the significant rise in rainfall pH ($p < 0.01$), the rise being steeper from 1997-2003, followed by a more gradual increase to 2015.

At a seasonal level, the increasing trend for surface waters is significant for Autumn and Winter ($p < 0.05$), while for precipitation the increase has been most marked for Spring ($p < 0.01$) and Autumn ($p < 0.05$)

Figure 24: Mean annual pH for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Water chemistry – dissolved iron (Fe)



Iron:

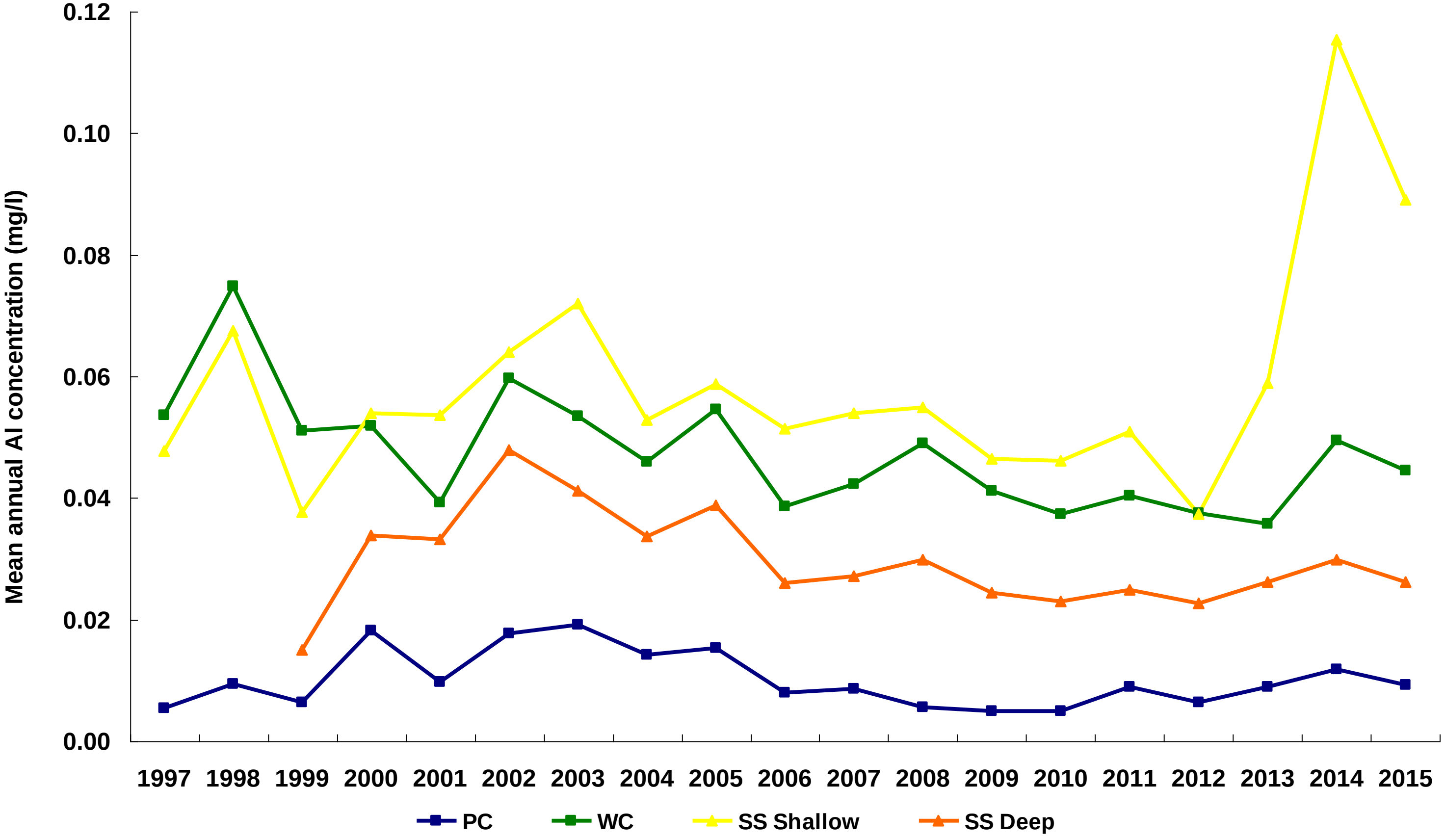
Higher levels of soluble iron in surface water from Nant Teyrn occurred during the period 2002-2006 and 2013-14 when the summers and autumns were drier and warmer, whereas from 2007-2010, with cooler wetter summers, the concentrations were much lower.

Iron concentrations in shallow level soil water show a significant decline since 1997 ($p < 0.01$).

Iron concentrations in rain water, stream water and deeper level soil water do not show significant trends.

Figure 25: Mean annual concentration of dissolved iron (Fe) for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Water chemistry – dissolved aluminium (Al)



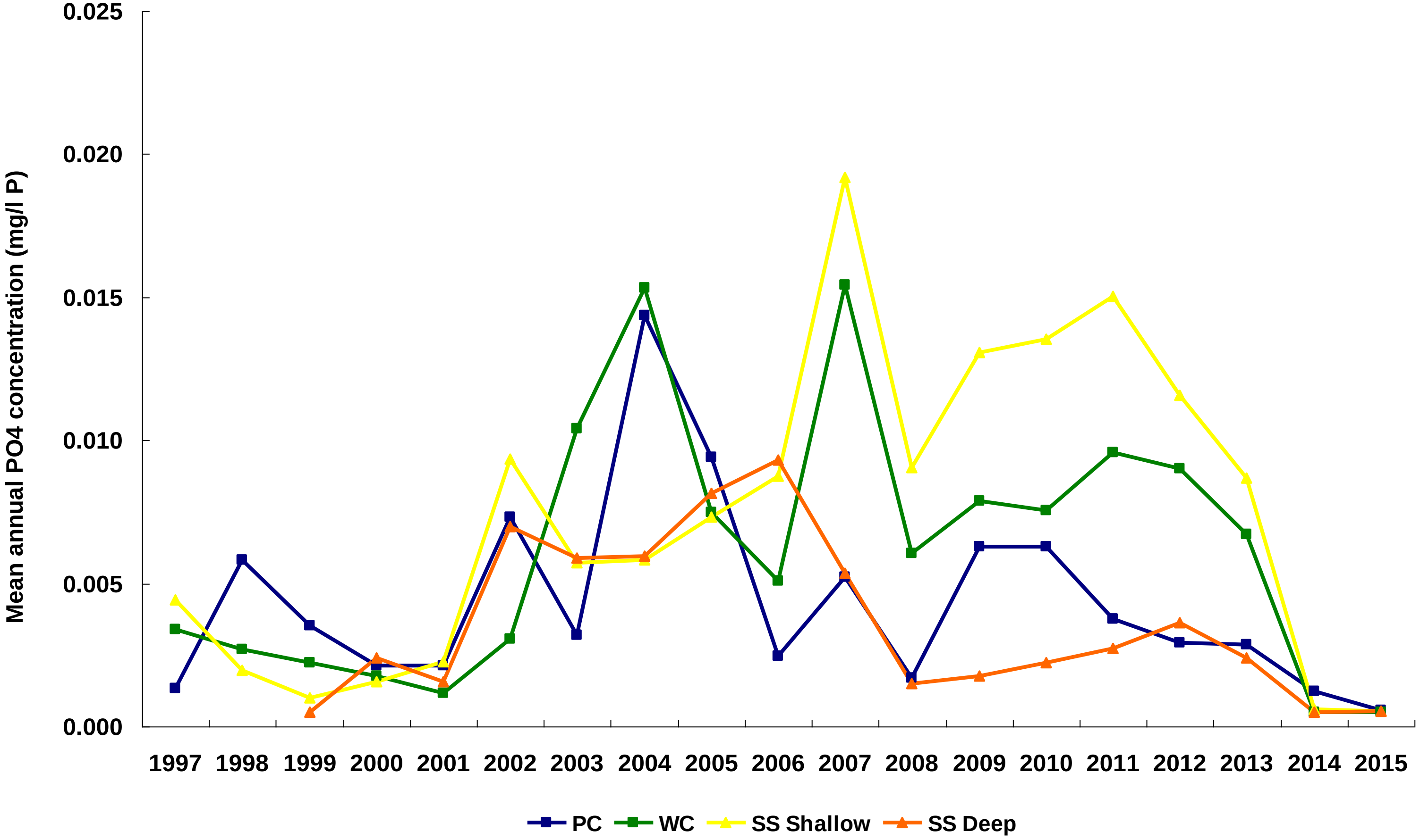
Aluminium:

Acid deposition can result in an increase in dissolved Al when soil buffering capacity is exceeded. Falls in levels of acid deposition should be associated with falls in mobile aluminium which is seen to fall in surface waters, where the declining trend is significant ($p < 0.05$). On a seasonal level, the winter surface water Al concentrations show a very significant decline ($p < 0.001$)

For the calcareous grassland soil samplers, the decreasing trend in the deep level samplers is significant ($p < 0.05$).

Figure 26: Mean annual concentration of dissolved aluminium (Al) for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Water chemistry – phosphate (PO_4-P)



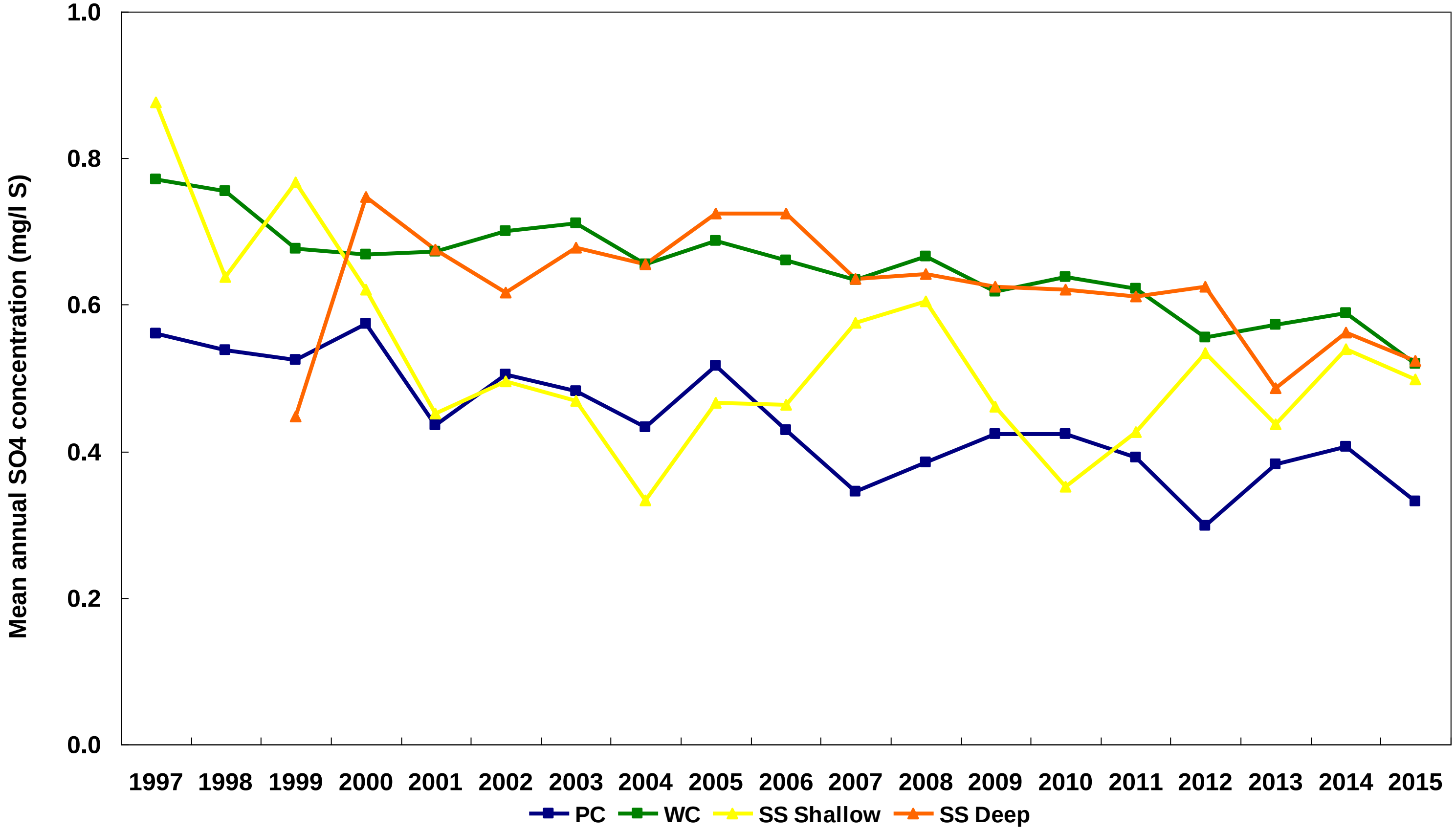
Phosphate:

Trends in phosphate levels on Snowdon show few significant linear trends, apart from for the shallow soil solution which indicates an increasing trend ($p < 0.05$).

The recent low values indicate against this, and the Mann-Kendall τ value has been decreasing over the last 4 years to the point where it only just exceeds the critical value for $p = 0.05$.

Figure 27: Mean annual concentration of phosphate (PO_4-P) for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Water chemistry – sulphate (SO_4-S)



Sulphate:

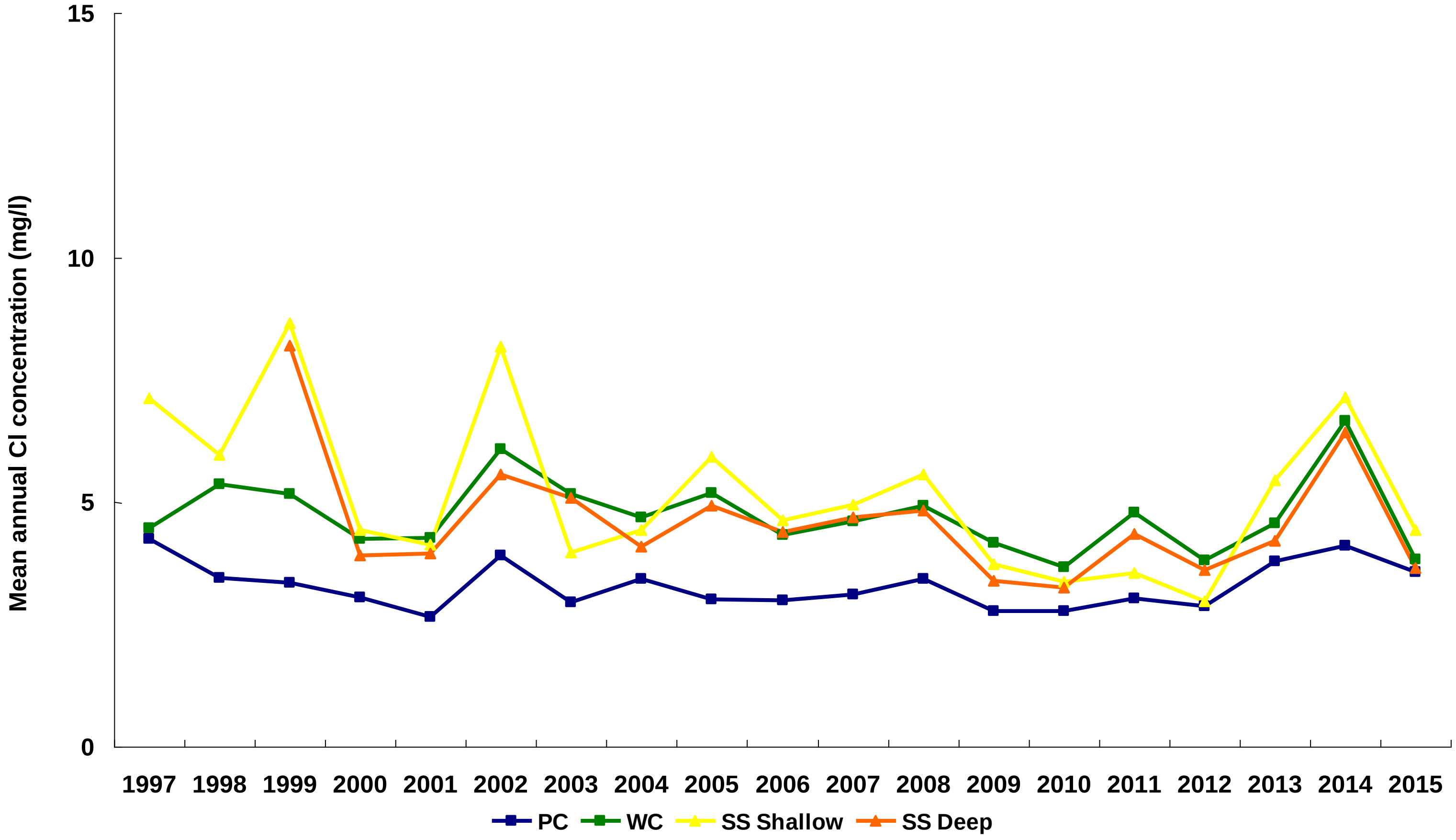
UK sulphur emissions have decreased by 90% since the 1970s (RoTAP, 2012).

As a consequence, highly significant falls in deposition have been noted on Snowdon in rainwater and surface water concentrations ($p < 0.001$). The decline in SO_4 levels in soil water is also significant at shallow and deep levels ($p < 0.05$).

At a seasonal level for precipitation and surface waters, significant decreases have been noted in all seasons, except for precipitation in winter.

Figure 28: Mean annual concentration of dissolved sulphate (SO_4) for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Water chemistry – chloride (Cl)



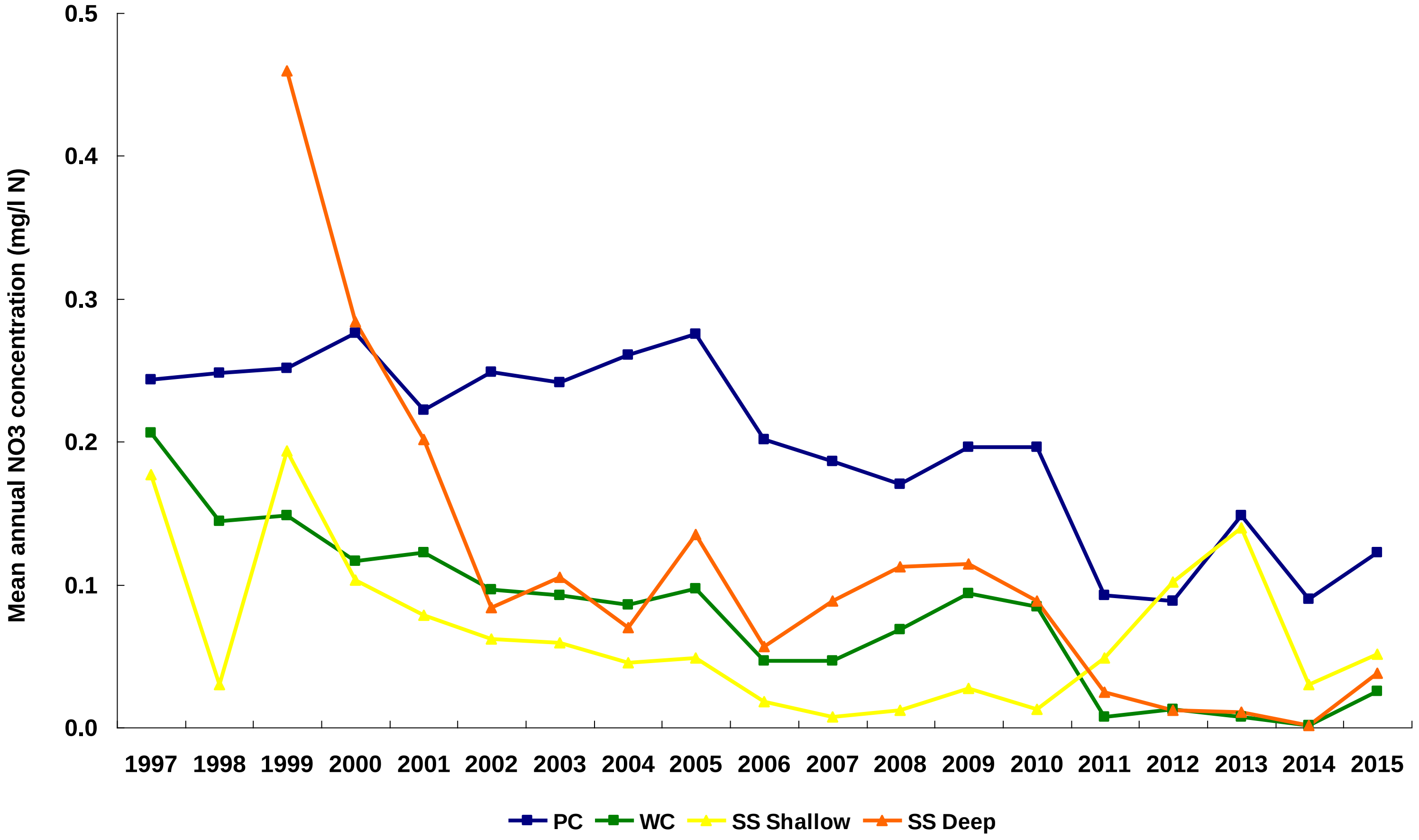
Chloride:

Chloride deposition mainly results from marine inputs associated with vigorous low pressure systems with strong westerly or south-westerly winds.

Overall mean input concentrations from rainfall and outputs to stream water and soil water have fallen slightly, but not significantly, since 1997. The increase in 2014 was due to large input from November 2013 to February 2014 which lead to a record concentration of 512 µEq/l in stream water following on from a series of very vigorous storms.

Figure 29: Mean annual concentration of chloride (Cl) for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Water chemistry – nitrate (NO_3-N)



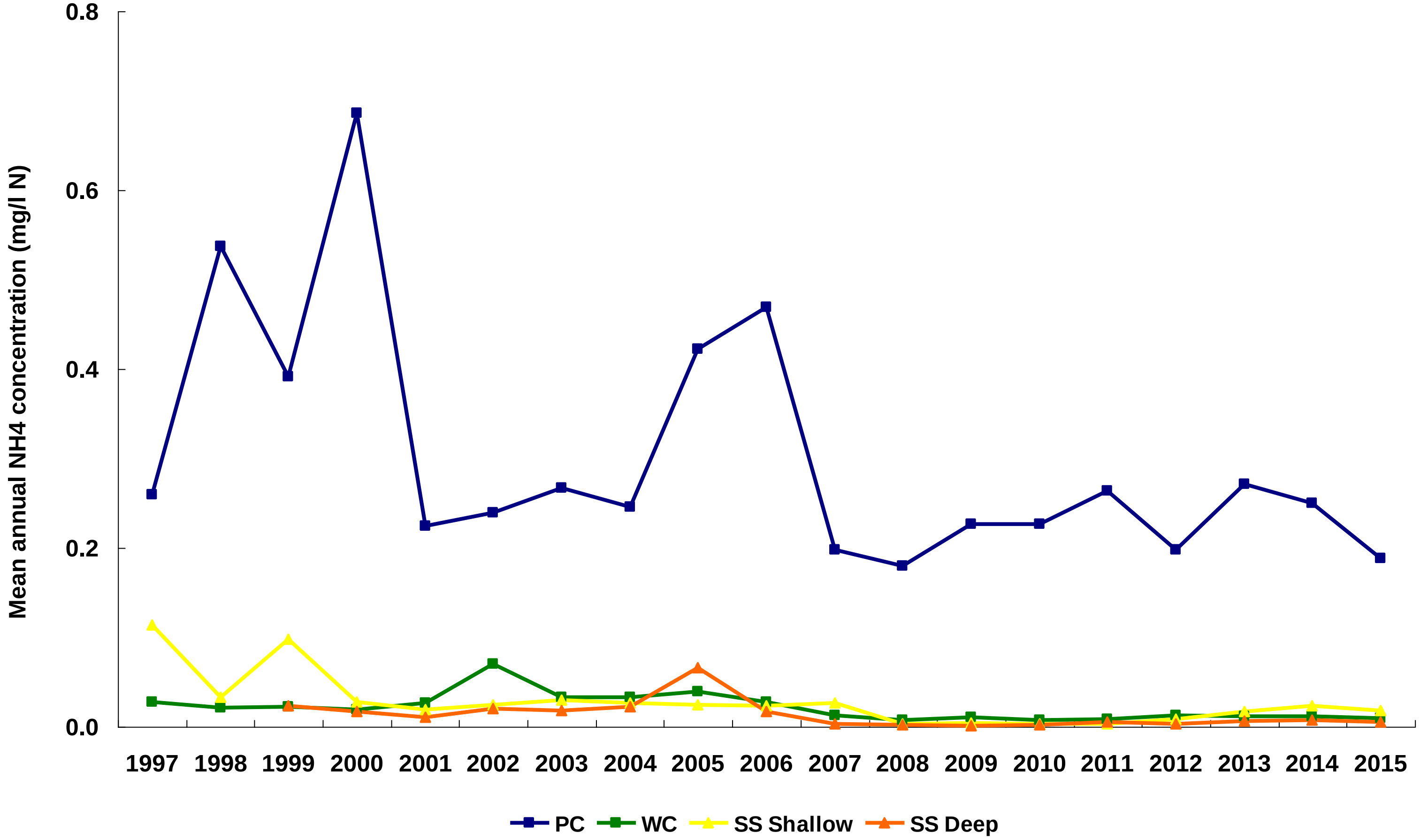
Nitrate:

Highly significant downward trends in concentrations of Nitrate (NO_3-N) in rain water, deep layer soil water and surface water can all be seen ($p < 0.001$). These falls agree with falls in emissions of NOx in the UK (RoTAP, 2012) although the trend for dry deposition of NO_2 on the site is not significant (Figure 34).

The deep-level NO3-N concentration shows a rapid fall to 2002 and from then mirrors the precipitation levels fairly closely perhaps indicating some change in soil process around 2002-03.

Figure 30: Mean annual concentration of nitrate (NO_3-N) for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Water chemistry – ammonium (NH_4-N)



Ammonium:

The declines in concentrations of ammonium in rainfall, surface water, shallow- and deep-level soil waters are significant ($p < 0.05$, < 0.01, < 0.001, < 0.05 respectively).

Most of the ammonium falling in rainfall is quickly taken up by vegetation with levels in surface water and soils much lower in concentration.

On a seasonal level, there are significant declines in concentrations in Autumn and Winter for surface waters ($P < 0.05$ and < 0.01 respectively), which may reflect similar significant decreases in sheep numbers during those seasons.

Figure 31: Mean annual concentration of ammonium (NH_4-N) for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Surface water chemistry – Acid Neutralising Capacity (ANC)

Acid Neutralizing Capacity:

Acid neutralizing capacity (ANC) of Nant Teyrn stream water is a good measure of the acid freshwater status of Llyn Teyrn (the lake adjacent to the sample station). The increasing trend is caused by the steep reduction in SO_4^{2-} and NO_3^- but with relatively little change in the major cations and is very significant ($p < 0.01$).

On a seasonal level the trends are significant for spring and autumn ($p < 0.05$) and highly significant for summer ($p < 0.001$).

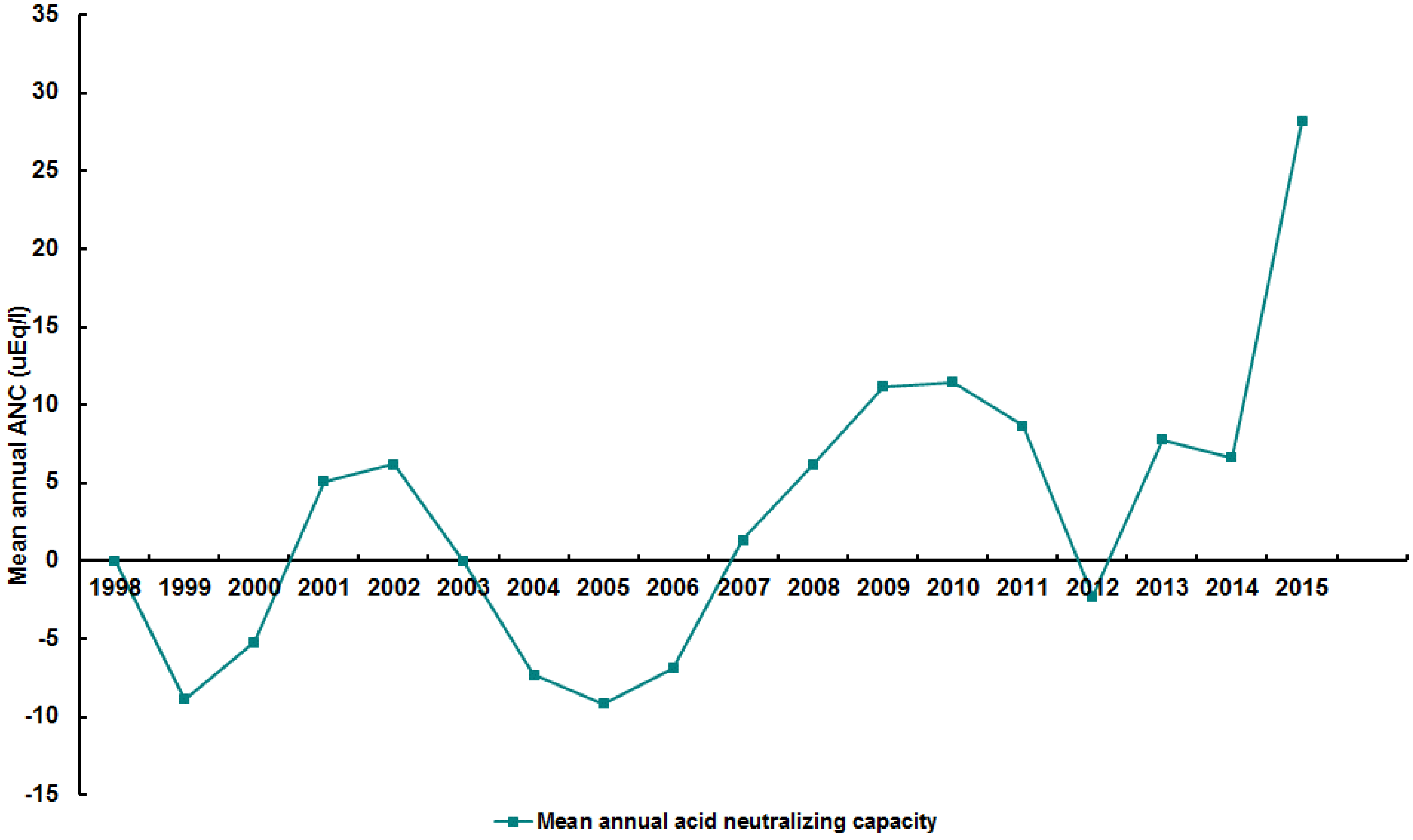
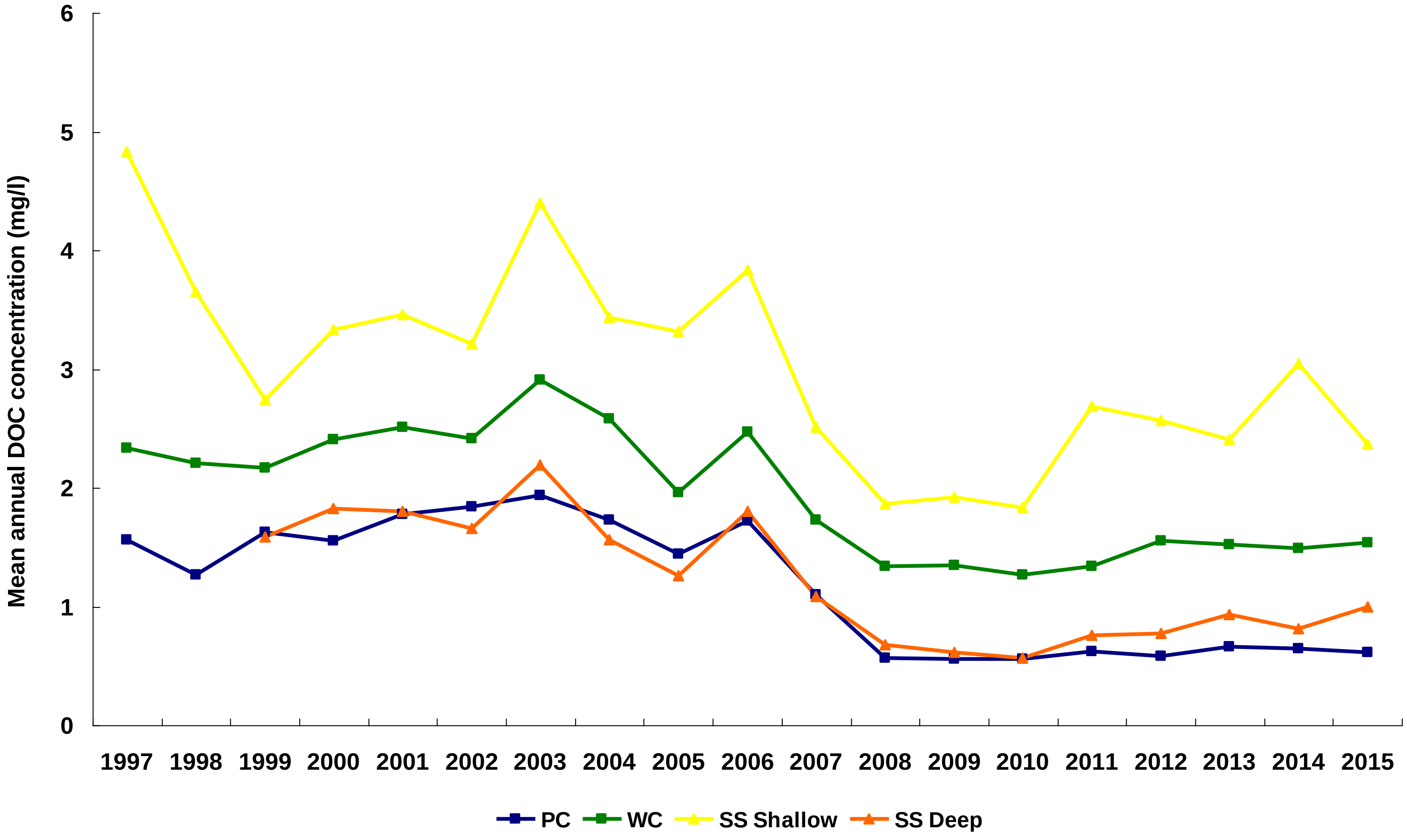


Figure 32 Ionic Balance Acid Neutralizing Capacity for Nant Teyrn for the period 1997-2015.

Water chemistry – Dissolved Organic Carbon (DOC)



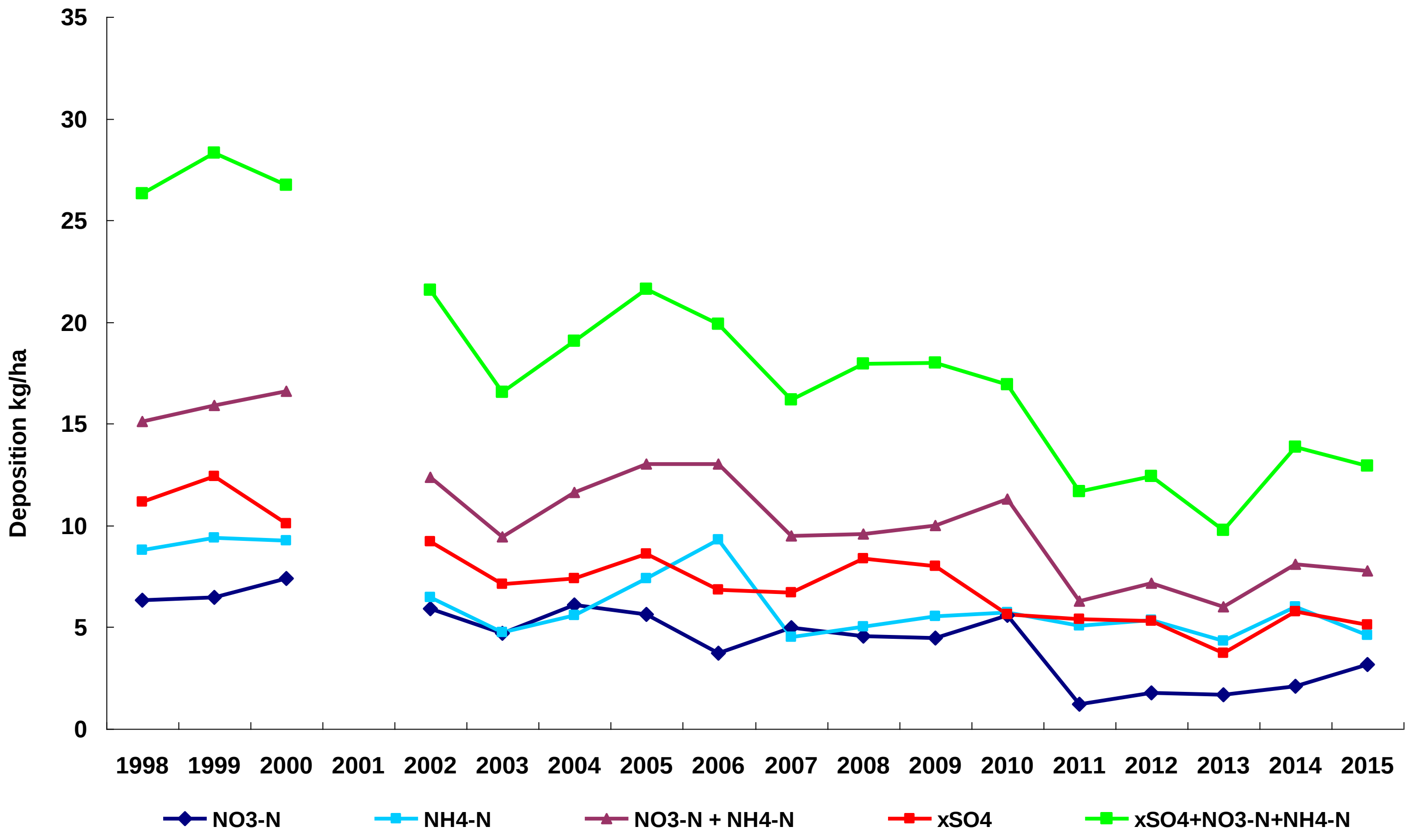
Dissolved Organic Carbon:

Trends for Nant Teyrn, the outflow and hence a proxy for Llyn Teyrn, show significantly declining concentrations in rainfall, surface water, shallow-level and deep level soil waters ($p < 0.05$ for all). The decrease primarily occurs from 1997 to 2008 and values are relatively stable after that date. There have been significant declines during all seasons ($p < 0.01$ except Autumn, $p < 0.05$)

The downward trend in concentration of surface water DOC is in stark contrast to results reported by UK Acid Waters Monitoring Network which found a rising trend at many other sites including at Llyn Llagi, the adjacent freshwater ECN site to Nant Teyrn (Monteith *et al.*, 2007, Sawicka et al 2016).

Figure 33: Mean annual concentration of dissolved organic carbon (DOC) for precipitation (PC), surface water (WC), and soil solution (SS=shallow, SD=deep) for the period 1997-2015.

Water chemistry – critical loads, acidity and nutrient nitrogen



Critical loads:

Combined NH_4-N, and NO_3-N inputs give a good indication of nutrient nitrogen loading and show a highly significant decline ($p < 0.001$).

Despite the decreasing trend, 2015 values still exceed maximum CL limits for nutrient nitrogen for alpine heath, blanket bog and scree and rock habitats and for the minimum CL for almost all habitats found on the site (Table 6).

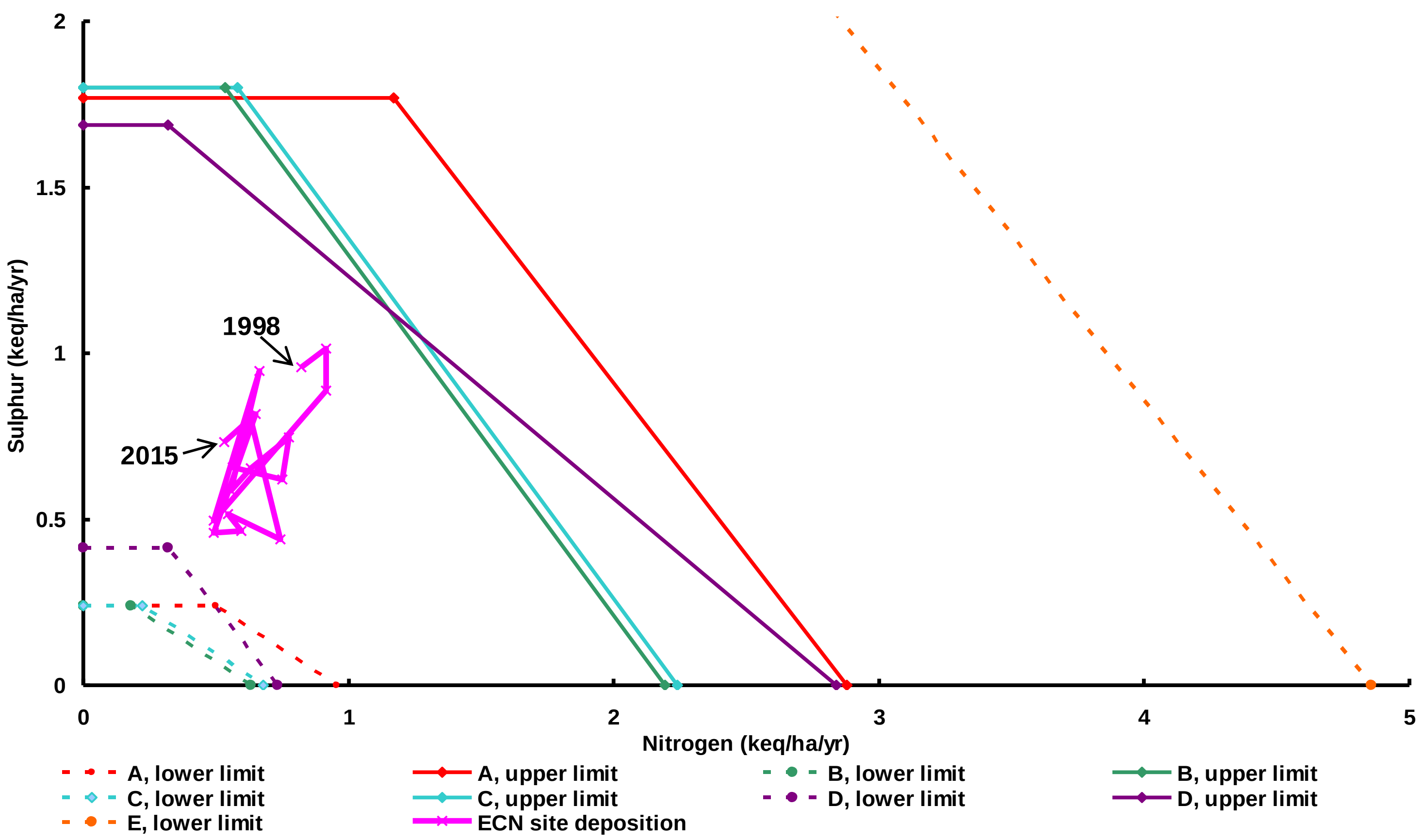
Acidity, as measured by combined nutrient nitrogen and non-marine sulphate (xSO_4^{2-}), also shows a highly significant decline ($p < 0.001$).

Figure 34: Annual deposition of non-marine sulphate (xSO_4^{2-}), nitrate (NO_3-N) and ammonium (NH_4-N) for the period 1998-2015. Missing data from 2001 due to Foot and Mouth restrictions.

Table 7: Critical Loads status for nutrient nitrogen and acidity for Annex 1 habitats occurring on the Yr Wyddfa/Snowdon ECN site. Values from APIS website (http://www.apis.ac.uk/overview/issues/overview_Noordwijkerhout_text.html. (Bobbink & Hettelingh, 2011)) and Evans *et al.* (2007) (*)

Annex I Code	**Annex I Habitat**	**Equivalent EUNIS habitat code**	**Critical Load nutrient N range (kgN/ha/yr)**	**Exceedence of nutrient N minimum CL in 2015**	**Exceedence of nutrient N maximum CL in 2015**	**Exceedence of acidity minimum CL in 2015**	**Exceedence of acidity maximum CL in 2015**
H3130	Oligotrophic to mesotrophic waters with standing vegetation	C1.1	3 - 10	**Y**	N	-	-
H4010	North Atlantic wet heaths (*Erica tetralix*)	F4.1	10 - 20	N	N	**Y**	N
H4030	European dry heaths	F4.2	10 - 20	N	N	**Y**	N
H4060	Alpine and boreal heaths	F2.2	5 - 15	**Y**	N	**Y**	N
H6150	Siliceous alpine and boreal grasslands	E4.3	10 - 15	N	N	**Y**	N
H6170	Alpine and subalpine calcareous grasslands	E4.4	10 - 15	N	N	N	N
H6230	Species-rich Nardus grassland	E1.72	10 - 15	N	N	**Y**	N
H6430	Hydrophilous tall-herb fringe communities (plains, mountains)	E5.5	10 - 15*	N	N	**Y**	N
H7130	Blanket bogs	D1.2	5 - 10	**Y**	N	**Y**	N
H7230	Alkaline fens	D4.1	15 - 35	N	N	-	-
H7240	Alpine pioneer formations (*Caricion bicoloris-atrofuscae*)	D4.2	15 - 25	N	N	-	-
H8110	Siliceous scree of montane to snow levels	H2.3	5 - 15*	**Y**	N	**Y**	N
H8120	Calcareous and calcschist screes of montane/alpine levels	H2.4	5 - 15*	**Y**	N	-	-
H8210	Calcareous rocky slopes with chasmophytic vegetation	H3.2	10 - 15*	N	N	**Y**	N
H8220	Siliceous rocky slopes with chasmophytic vegetation	H3.1	5 - 15*	**Y**	N	**Y**	N

Water chemistry – critical loads, acidity



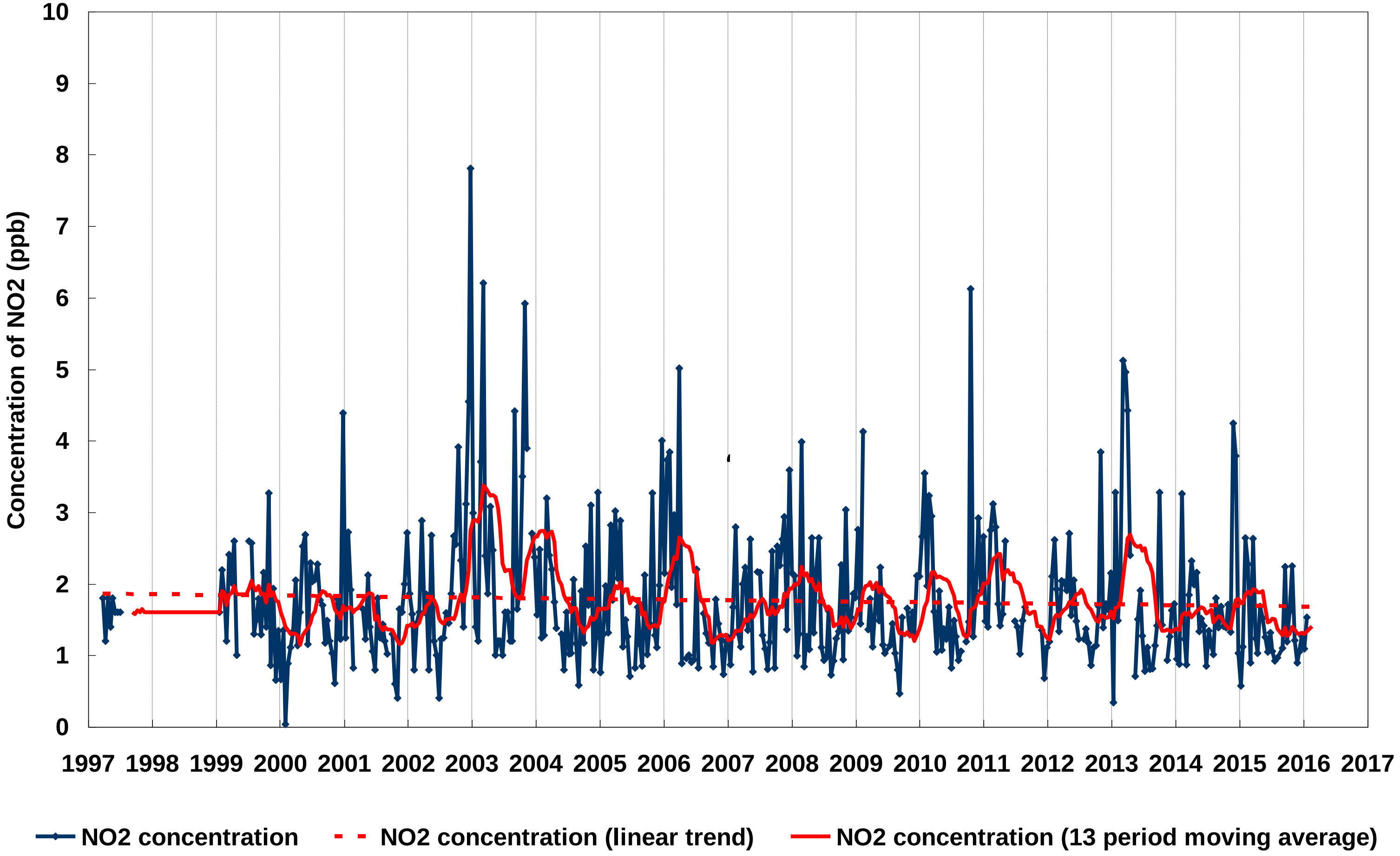
Critical loads: acidity

Envelopes for different habitats for the Yr Wyddfa/Snowdon site are taken from the APIS website (www.apis.ac.uk). For most habitats, the sulphur and nitrogen deposition lies between the maximum and minimum critical loads, with the exception of Group E which contains Alpine and sub-alpine grassland which lies below the minimum critical load for acidity..

A number of habitats are not represented as there is insufficient information – these are shown in Table 7.

Figure 35: Critical loads diagram for acidity at Yr Wyddfa/Snowdon site over the period 1998-2015. The envelopes cover the following Annex 1 habitats: Group A - North Atlantic wet heaths with *Erica tetralix*, and European dry heaths; Group B – Alpine and boreal heaths, Siliceous alpine and boreal grassland, Hydrophilous tall herb fringe communities, Siliceous scree, Calcareous rocky slopes and Siliceous rocky slopes; Group C – Species-rich Nardus grassland; Group D – Blanket Bogs; Group E – Alpine and sub-alpine calcareous grasslands.

Dry deposition - nitrogen dioxide (NO_2)



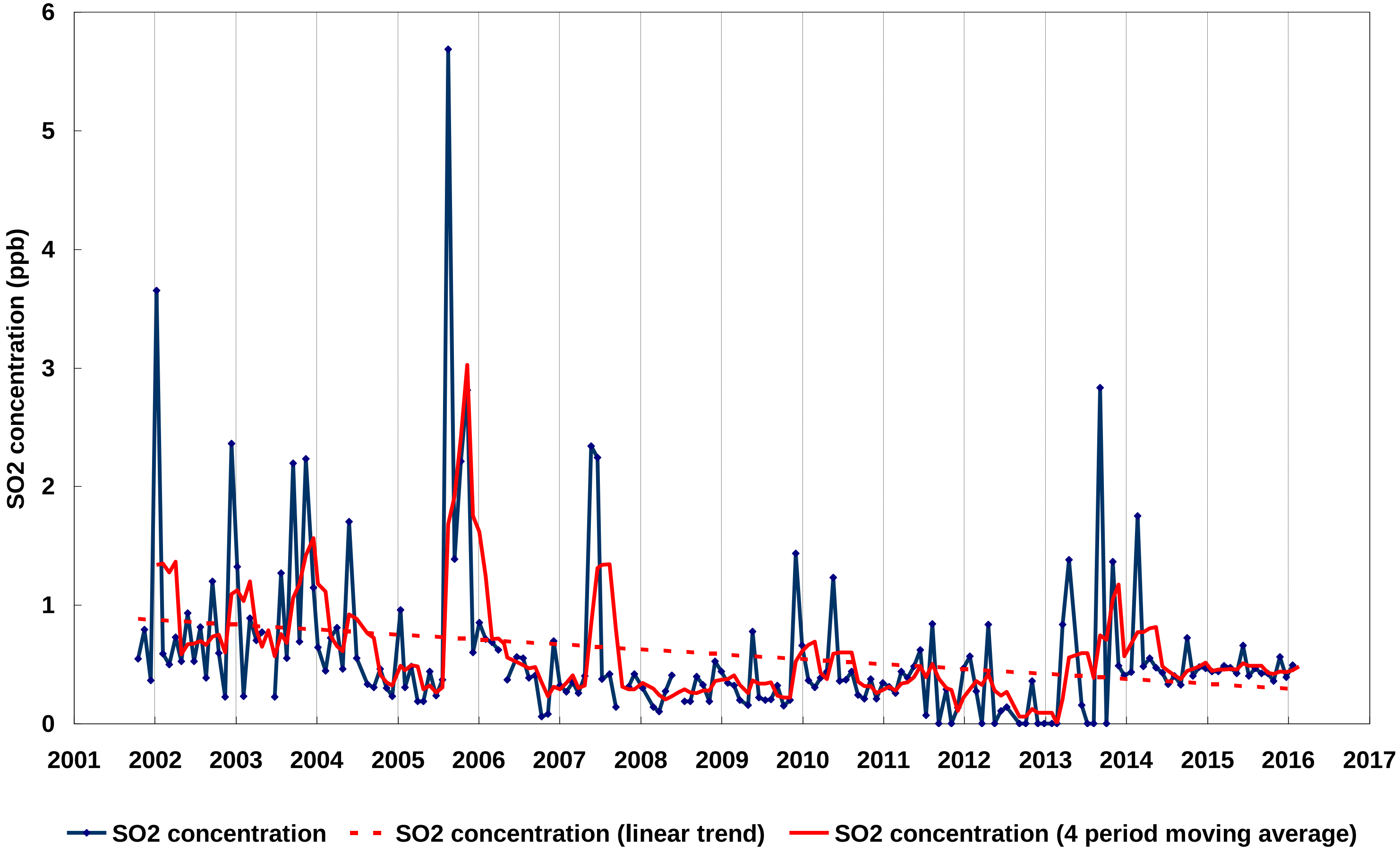
Nitrogen dioxide:

Deposited levels of dry NO_2 are low at Snowdon and despite a degree of variability, there is very little change in the average over the recording period, in contrast to the significant decline in wet deposited NO_3-N.

A 3-month moving average reveals an annual cycle, with a maximum in late winter and spring and a minimum in summer and early autumn. Highest levels were seen in late 2003. There is no significant trend at a seasonal level, however, within the data.

Figure 36: Fortnightly concentration of NO_2 at Yr Wyddfa/Snowdon ECN site over the period 1997-2014.

Dry deposition - sulphur dioxide (SO_2)



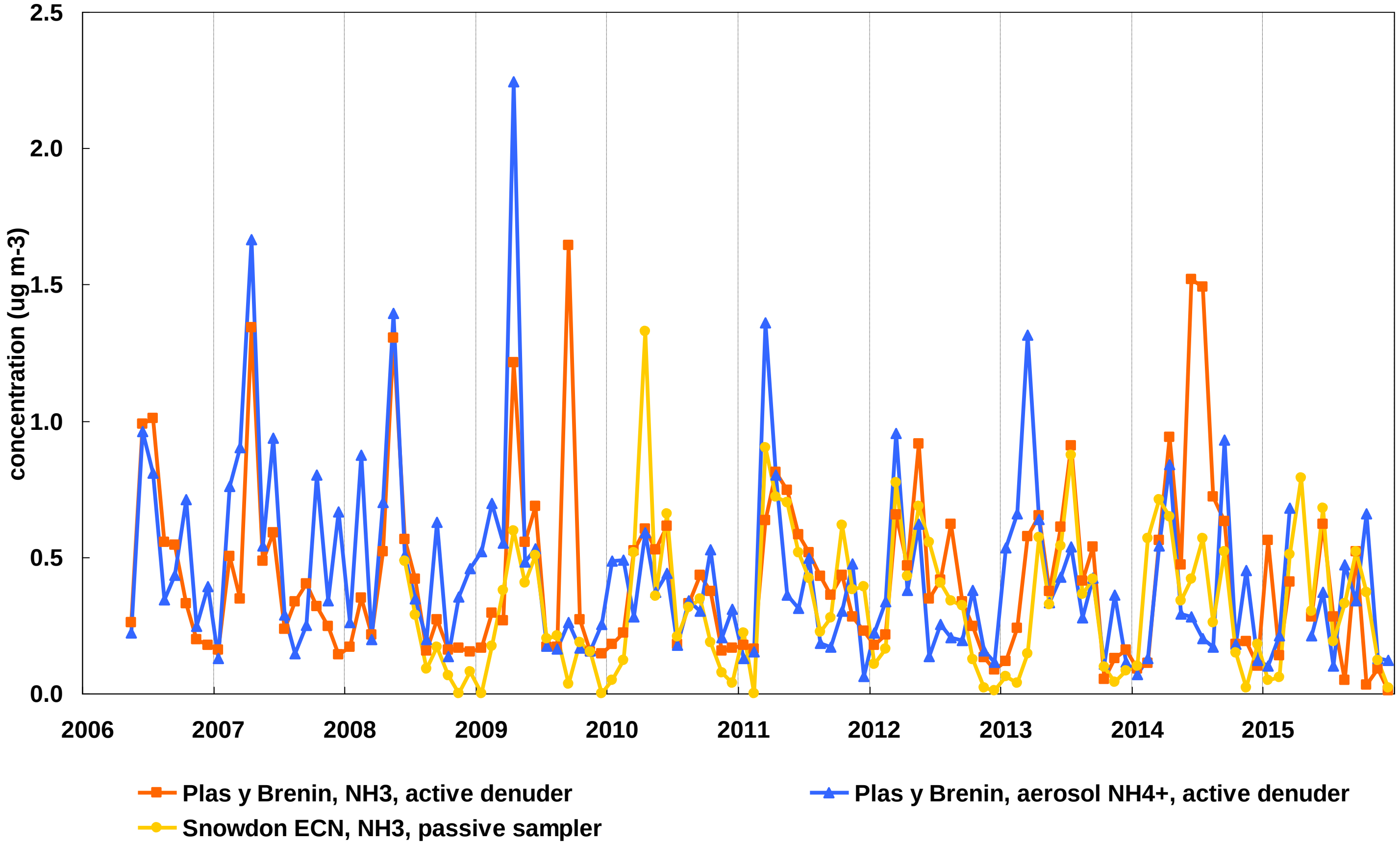
Sulphur dioxide:

Dry deposited levels of SO_2 on Snowdon shows a clear and significant decline over the recording period ($p < 0.05$).

Concentrations over 2013-15 have risen slightly in comparison to 2008-12, possibly as a result of reduced precipitation. The year with the highest concentration also had the lowest summer rainfall.

Figure 37: Monthly concentration of SO_2 at Yr Wyddfa/Snowdon ECN site over the period 2001-2016.

Dry deposition - ammonia (NH_3) at Plas y Brenin and Yr Wyddfa/Snowdon ECN site, 2006-2012



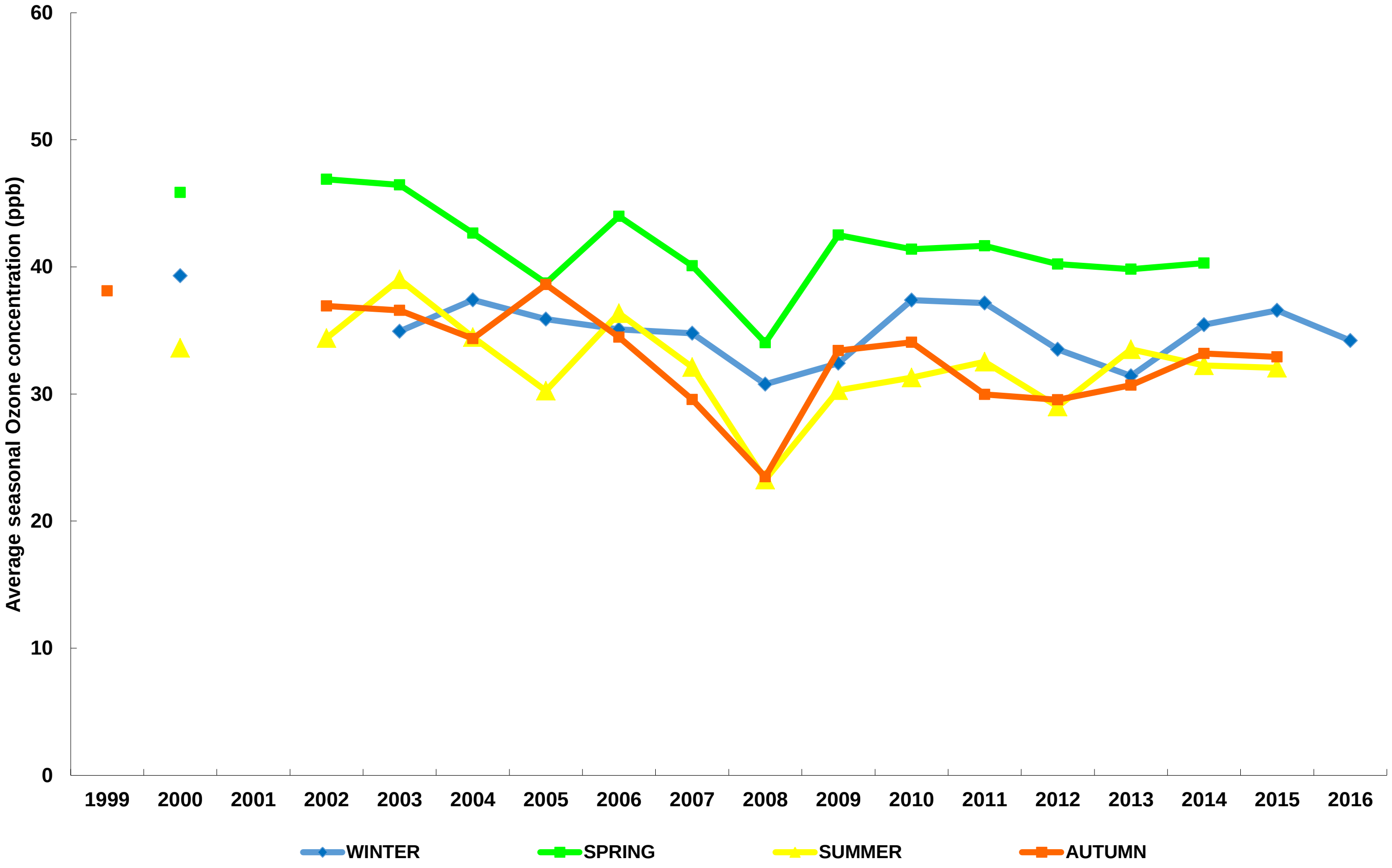
Ammonia:

NRW acts as a local site operator for passive diffusion tubes for NH3 at the ECN site and an active denuder for NH_3 and NH_4^+ at Plas y Brenin on behalf of UKEAP.

Levels at both sites show very similar annual variation with a peak during the drier part of the spring to early summer, and a minimum in winter. There is no significant trends in the annual data for the ECN site, but at a seasonal level, there has been a significant increase in summer and autumn ($p < 0.05$)

Figure 38: Four-weekly concentration of NH_3 and NH_4^+ at Plas y Brenin and NH_3 at Yr Wyddfa/Snowdon ECN site over the period 2006-2013. Data courtesy of Sim Tang, CEH Edinburgh.

Ozone (O_3)



Ozone:

Continuous ground-level O_3 and NO_x sampling is undertaken at Marchlyn Mawr.

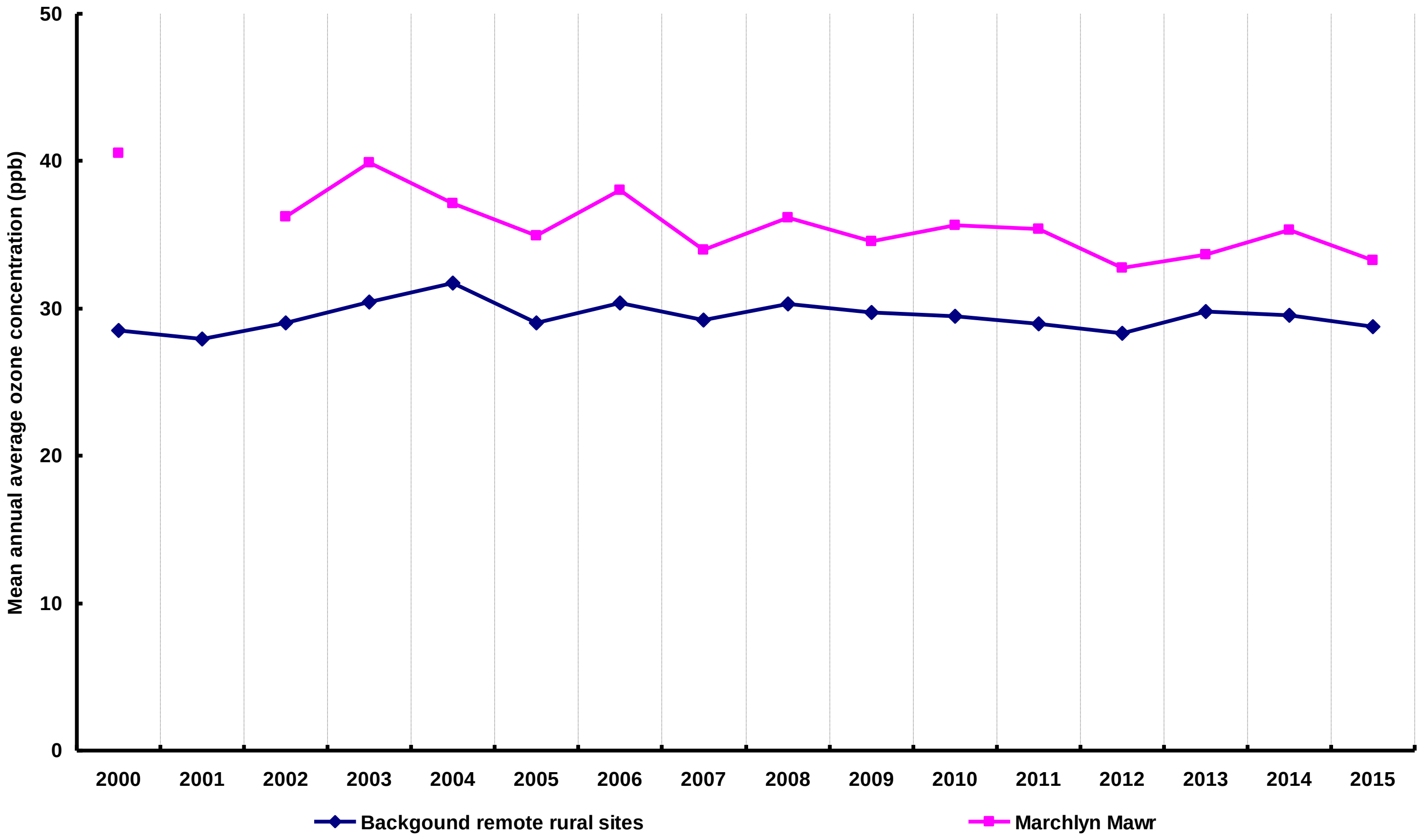
Spring ozone concentrations are significantly higher than those for summer, autumn and winter ($p < 0.001$). Spring and autumn concentrations show significant declines over the period 1999-2015 ($p < 0.05$ and $p < 0.01$ respectively).

Data missing for Jan - Apr 2015 due to instrument malfunction and repair.

Data is ratified by Ricardo-AEA on behalf of the Welsh Air Quality Forum (www.welshairquality.co.uk/).

Figure 39: Seasonal mean ozone concentration at Marchlyn Mawr over the period 1999-2016.

Ozone (O_3)



Ozone:

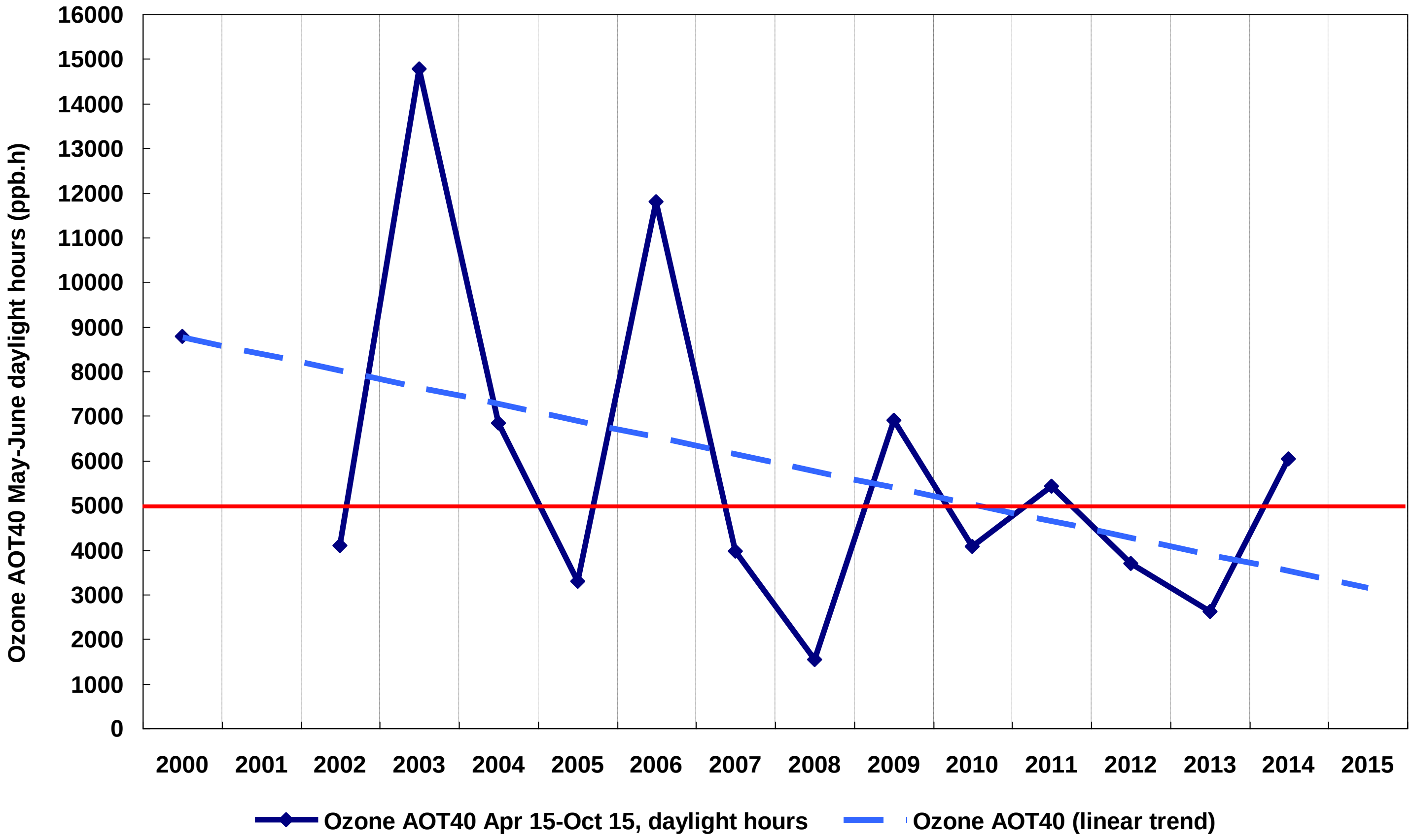
Annual average ground-level ozone concentrations have fallen significantly over the period 2000-2015 ($p < 0.01$).

A comparison with annual average ozone levels from other generally upland Rural Background Natural sites (uk-air.defra.gov.uk/data), classed as remote, shows that the levels at Marchlyn are higher and the decline seen is atypical.

The other sites are: Strathvaich, Eskdalemuir, Great Dun Fell, High Muffles, Ladybower Reservoir and Yarner Wood (2000-11) and all are part of the Automatic Urban and Rural Network (AURN).

Figure 40: Average annual ozone concentration at Marchlyn Mawr over the period 2000-2013 in comparison with remote Rural Background Network sites in the UK uplands.

Ozone (O_3)



Ozone:

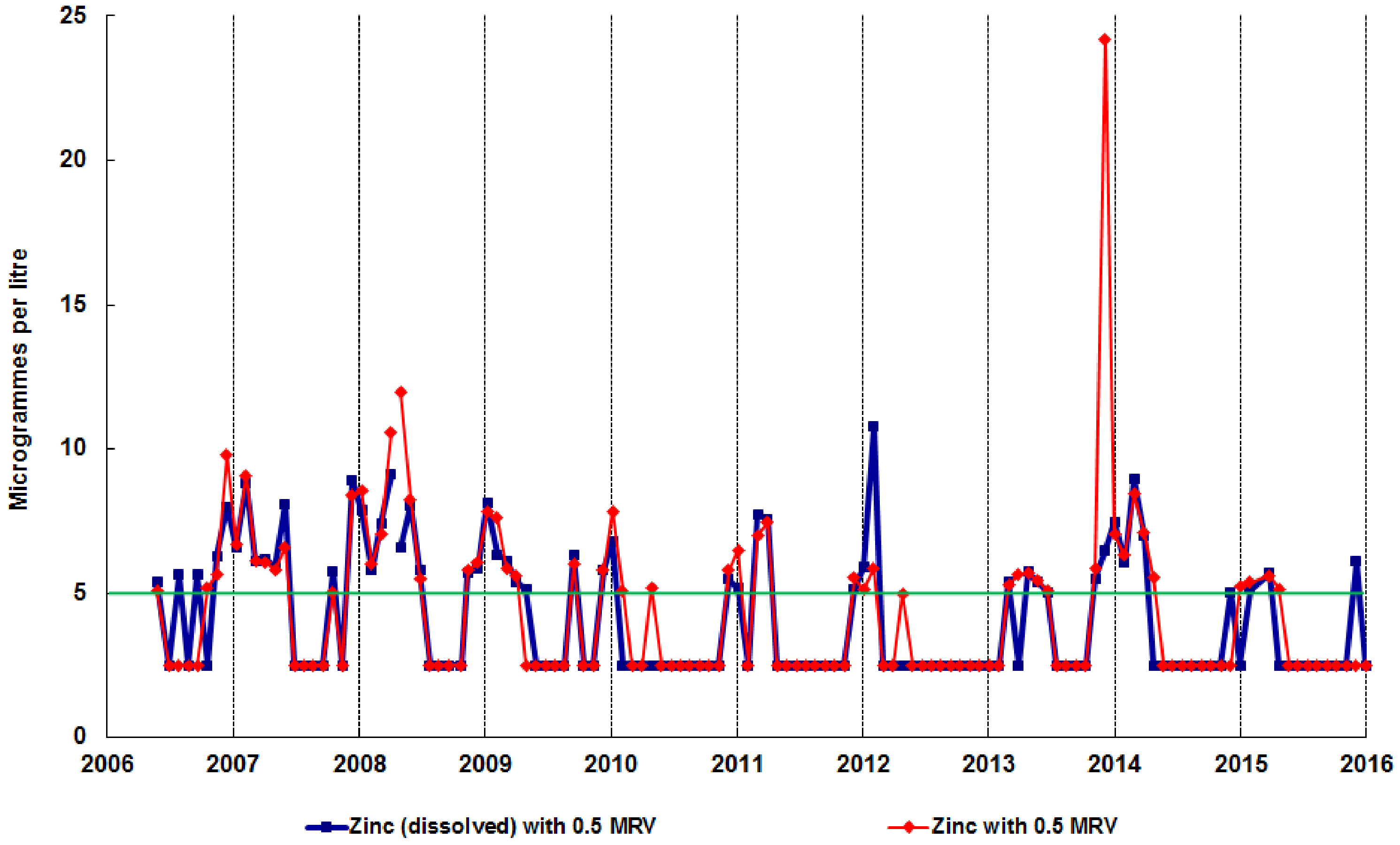
High concentrations of ground-level ozone have been implicated in damage to vegetation. AOT40, the accumulated dose over 40ppb during daylight hours from mid-April-mid October is a measure of the potential harmful effect of ozone on vegetation. The critical level for semi-natural vegetation is 5000 ppb.h (APIS 2016). In general the highest monthly AOT values are seen in May, and can be exceptional e.g. in May 2000, the AOT40 was 5000 ppb.h

There is a gentle downward trend over the recording period, but it is not significant.

The 2000 data point is an underestimate as the Sept and Oct values were not recorded.

Figure 41: Accumulated dose over the threshold concentration of 40ppb (AOT40) during daylight hours between April 15th and Oct 15th at Marchlyn Mawr over the period 2000-2015.

Freshwater chemistry – dissolved and total zinc (Zn)



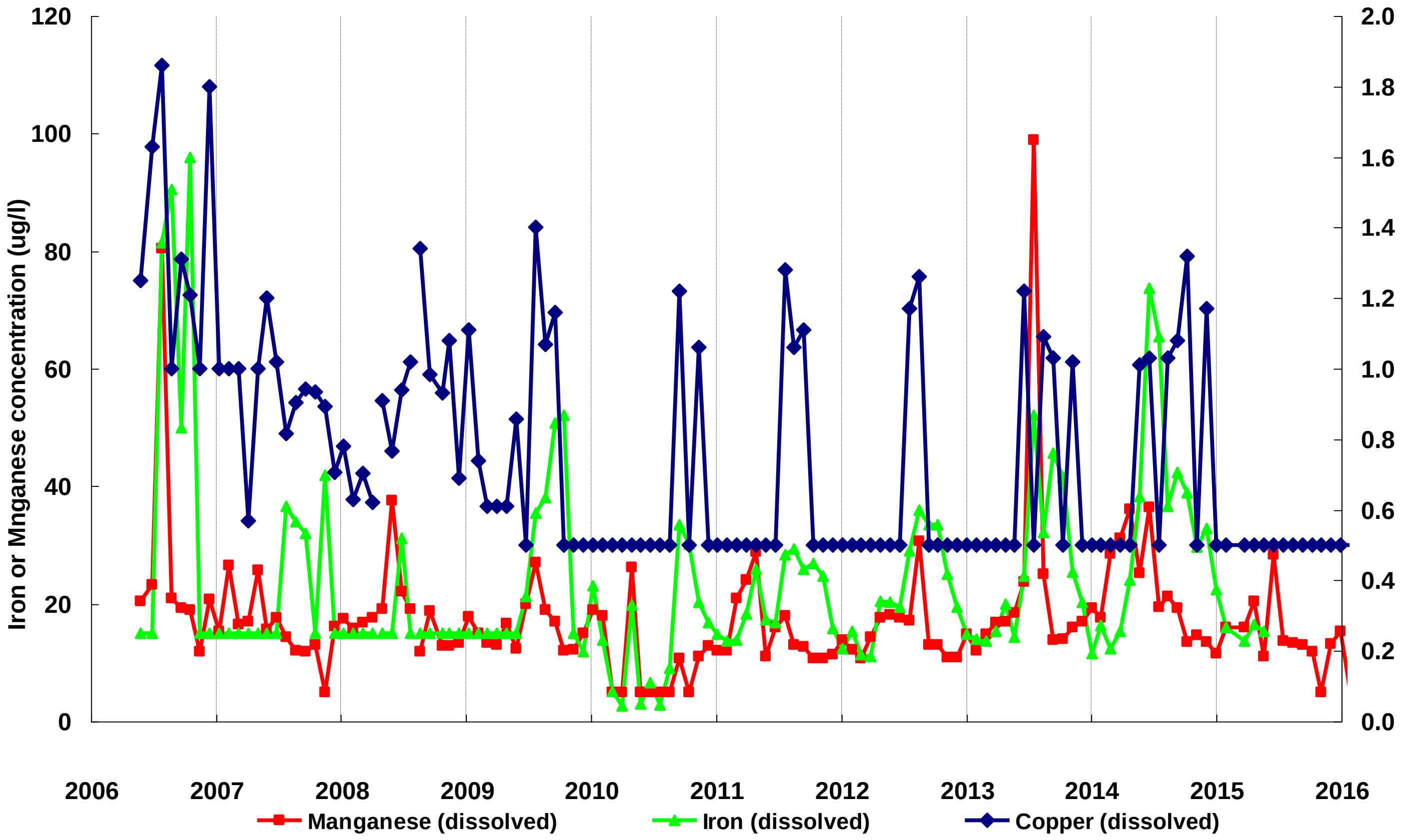
Zinc:

Zinc exhibits a fairly strong seasonality with peaks in the winter and spring periods followed by low values (below the limit of detection) during late summer and autumn. The peaks are possibly caused by small-scale erosion events within the catchment over the winter period. The 2013 peak occurred with a similar peak in copper, nickel, silicate and calcium so could possibly reflect sedimentary input to Llyn Teyrn triggered by heavy precipitation.

There is no significant trend.

Figure 42: 4-weekly concentrations of dissolved and total zinc in Nant Teyrn 2006-15. Horizontal green line is the limit of detection. Values below this have been set at 0.5 MRV.

Freshwater chemistry – dissolved and total copper (Cu), manganese (Mn) and iron (Fe)



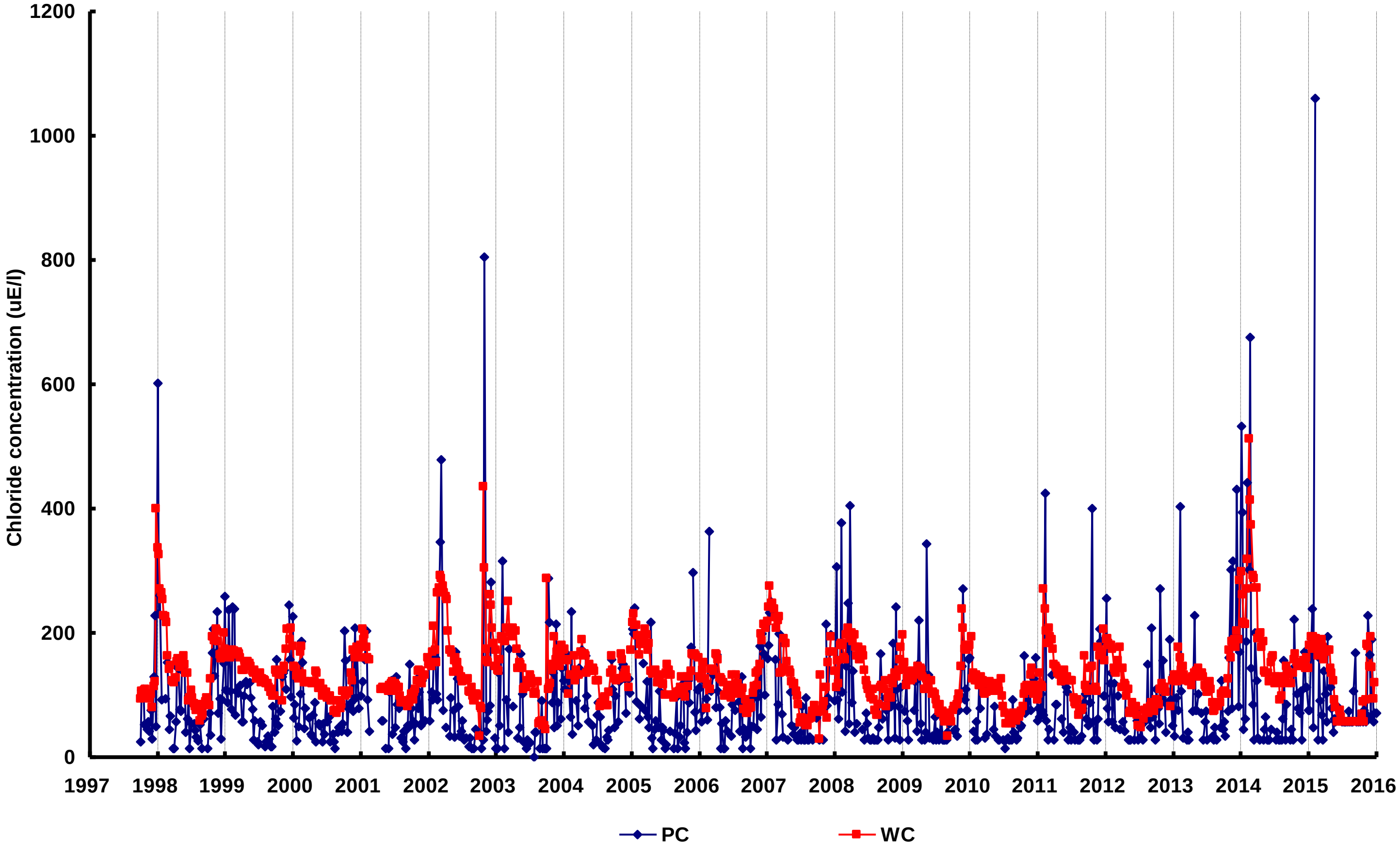
Manganese, iron and copper:

Annual concentrations for dissolved iron from 1997 are shown in Figure 26. Over the shorter period of running freshwater ECN protocols, summer peaks in manganese and iron concentrations follow similar trends, with both decreasing but not significantly.

Annual mean dissolved copper concentrations have significantly decreased ($p < 0.05$) from a peak in 2006, and 50% of the samples in 2010-2015 fell below the limit of detection. Some of the peaks in copper concentration coincide with elevated levels in dissolved iron.

Figure 43*:* 4-weekly concentrations of dissolved manganese, iron and copper in Nant Teyrn 2006-15. Values below the limits of detection have been set at 0.5 MRV (Mn MRV = 10µg/l, Fe MRV = 15µg/l, Cu MRV = 0.5 µg/l)

Freshwater chemistry – chloride (Cl), weekly



Chloride:

Annual chloride concentrations in surface waters (WC) generally peak during the winter months as a result of strong westerly or south-westerly winds associated with vigorous Atlantic depressions. Concentrations occasionally exhibit very high peaks (e.g. 512 μEql^{-1} in February 2014) which are the cumulative result of at multiple rainfall events often with PC concentrations exceeding 300 μEql^{-1} including one with 675 μEql^{-1} .in 2014.

By contrast, the extreme rainfall events in November and December 2015 had average chloride concentrations and raised the WC chloride concentration little above the monthly norm.

Figure 44: Weekly chloride concentrations in precipitation (PC) and surface water (WC) from Nant Teyrn from 1997 to 2015.

3.3 Summary of trends for biological variables.

Biological monitoring undertaken on the site includes that for vertebrates (birds, bats and frog spawning), invertebrates (ground beetles, spiders and spittle bugs) and vegetation (fine- and coarse-grain). Additional non-ECN protocols cover pollinators and phenology (bird returns and first flowering).

Breeding birds are monitored using Breeding Bird Survey protocols (BTO 1995), twice during the breeding season along 10 200m sections of two transects within a 1km grid-square. Total numbers of birds recorded are strongly influenced by the numbers of Meadow Pipits (*Anthus pratensis*) which have exhibited an irregular cyclic abundance over the period of recording (Figure 46), and which hasn't been, as yet, linked with any obvious climatic variable(s). None of the species recorded show any increasing or decreasing trend. The pattern in the numbers of long-distance migrants (Ring Ouzel (*Turdus torquatus*), Common Sandpiper (*Actitis hypoleucos*) and Wheatear (*Oenanthe oenanthe*)) mirrors the numbers of Meadow Pipits, indicating that variation in numbers is controlled by local factors, rather than factors in the wintering areas of these species. There has been no change in Shannon diversity for birds.

Timing of return of long distance migrant birds has been recorded since 1999 (Figure 47), but shows no obvious trend, although in some years there appears to be a link to spring temperature.

Bat recording takes place during a sequence of 4 3-week recording windows from mid-June to early September along two 1km transects which for health and safety reasons were chosen to follow sections of the miners Track and the Pyg Track on Snowdon. The predominant species found are Common Pipistrelles (*Pipistrellus pipistrellus*) and Daubenton's bats (*Myotis daubentonii*), and they probably roost in the stonework of old mine buildings and mine entrances on the site. Figure 48 shows the trend since the start of recording in 1996, and there is quite substantial year-to-year variation, and no obvious increasing or decreasing trends. The two transects differ in altitude, with the lower ranging from 440-590m while the upper ranges from 565-675m. The lower transect also passes Llyn Llydaw and ends at Glaslyn, while the upper has no water bodies. Because of these factors, the number of bats recorded along the lower transect greatly exceeds those from the upper.

Work done at Moor House ECN site using continuous recording indicated that (a) in the uplands the 4 3-week recording periods are probably missing significant numbers through starting too late and finishing too early and (b) that bat activity is bimodal (Rob Rose, pers. comm.). The dip midway through the season is explained by the need for lactating females to have a steady and assured supply of insects, which is often not possible in the uplands due to poor weather. As a result, sampling was increased at Snowdon from the beginning of May until the end of September in 2012. Figure 49, showing the average numbers per recording period through the season, confirms that a bimodal activity curve occurs at Snowdon as well.

Monitoring of frog spawning is carried out in two ponds – a spring fed pond at 565m altitude, with average pH 5.71 and a rain-fed pond at 545m altitude with average pH 4.90. The two ponds have very different success rates with the second pond often failing to get tadpoles to the metamorphosis stage. For the first frog pond, there is no clear trend in timing of spawning, but the developmental period from spawning to metamorphosis has shown a significant shortening ($p < 0.01$) over the period of recording (Figure 50).

Butterfly species recorded on the site can be grouped as residents and migrants. The resident species are Small Heath (*Coenonympha pamphilus*) and Green-veined White (*Pieris napi*), while the commoner migrants include Small Tortoiseshell (*Aglais urticae*), Peacock (*Inachis io*), Red Admiral (*Vanessa atalanta*) and Painted Lady (*Cynthia cardui*). The residents form the majority of individuals recorded (Figure 52). There has been no significant increasing or decreasing trend in numbers - the most notable feature being the higher numbers recorded during 2004-2006 when the summers were relatively dry and warm. During this period, Gatekeeper (*Pyronia tithonus*) and Meadow Brown (*Maniola jurtina*) were both recorded, but disappeared when the summers became wetter from 2007 onwards. In terms of diversity, there has been a significant decrease in Shannon diversity, H', over the period of recording ($p < 0.05$).

Ground beetles are collected in traps set out in 3 transects of 10 traps placed 10m apart and sampled fortnightly from the beginning of April until the end of November. The three transects are located in calcareous (transect A), slightly acid (transect B) and moderately acid (transect C) grassland vegetation. Trapping has been undertaken since 1999, and numbers of beetles in all three transects have shown a significant decrease over this period ($p < 0.001$.$p < 0.01$ and $p < 0.05$ resp.). The change has been most pronounced in the calcareous vegetation and least so in the more acid grassland. Over the shorter period 2005-2015, transect A shows a significant decline ($p < 0.05$), while transect C shows some recovery with a significant increase ($p < 0.05$). Excluding the dominant species on the site *Pterostichus madidus*, which forms over 90% of catches, the differences in numbers between the transects become much less and Transect C doesn't show a downward trend over the whole recording period, and shows an increase over 2005-2015.

Spiders are collected from the same traps as ground beetles and have been identified in catches since 2000. The numbers are much closer between transects and there is no significant difference between transects A and B, but catches for both are consistently higher than transect C (Figure 54). The spider fauna also are not dominated by one species as in the ground beetles. There are no significant trends except for transect B which shows an increase over the recording period ($p < 0.05$). To what degree there is an interaction with spiders is unknown, but the increase could be at the expense of the decrease in ground beetle numbers.

Spittle bugs or froghoppers (*Homoptera)* have been monitored on the site since 1998 and there are two plots, one in blanket mire dominated by monocotyledons, the other in a base-rich exclosure with a high proportion of dicotyledons. The protocol involves counting nymphs and spittle in mid-late June, followed by sampling for colour morphs of adults of *Philaenus spumarius* in August. The rationale behind the decision to monitor spittle bugs originally was that the colour polymorphism is the result of a set of closely linked genes and the proportions of morphs are environmentally determined (Whittaker 1968). There are no significant trends, either amongst colour morphs or amongst the proportion of melanic or non-melanic types.

Pollinator sampling was started on the site as a trial of the Open Farm Sunday Pollinator Survey (CEH 2012), and this was extended to a weekly recording between the beginning of April and the end of September when weather conditions allowed. The two locations which were chosen were two of the grazing exclosures, one on an acid podzolic soil and the other on a brown earth. After almost three years of recording (Figure 56), some preliminary conclusions can be drawn. The most abundant pollinators are flies (Diptera), followed by bees and finally butterflies coming a distant third. No ladybirds, ants or beetles were observed on open flowers. The number of pollinators was greater in the basic exclosure, reflecting the greater floristic diversity of the vegetation there compared with the acidic exclosure. Bees formed a greater proportion in the acidic exclosure, with greatest activity in August and September when heather was flowering.

There are two protocols for vegetation monitoring on the site - coarse-grain (VC) and fine-grain (VF) protocols. The coarse-grain recording is undertaken every 9 years and has only been completed twice, so is not included here. The fine-grain consists of 9 pairs of 10 x 10m plots in different vegetation types, each plot with 10 fixed 50 x 50cm quadrats which are recorded on a 3-year cycle. Five of these plots are additionally recorded annually. The first recordings were made in 1999 and a few extra plots were added in 2000. All vascular plants, mosses and lichens are recorded as present/absent, together with bare rock, bare soil, litter, dung etc. Trends are examined below for 8 vegetation types listed with their corresponding NVC communities (Rodwell el al., 1991 et seq.): calcareous grassland (CG10), acid grassland (U4 and U5), Vaccinium heath (H18), Calluna heath (H21), Juniper heath (H15), acid flush (M6), wet heath (M15) and blanket mire (M17). Trends are also examined for Grassland (calcareous and acid), Heath (Vaccinium, Calluna and Juniper heath) and Wetland (acid flush, wet heath and blanket mire). Trends are also disaggregated into those for the vascular plant layer and those for the vascular plant + moss layers. Differences are evident between the two due to varying responses to the drivers of rainfall, nutrient input and acidity input.

Rose et al. (2016, in press) looked at fine-grain vegetation plots across the network over the period 1993-2012, and found a significant increase in species-richness of the vascular plant layer in open uplands, open lowlands and woodlands. Also, a comparable increase in Ellenberg R, an index of acidity, was noted. Over the period 1999-2015, on the Snowdon ECN site, similar changes were observed with increases in species richness in grasslands (Figure 57) not only in the vascular plant layer, but also in the vascular + moss layers and in all layers ($p < 001$, except for all layers, $p < 0.05$). In addition, species richness was observed to have increased for wetland vegetation for the vascular plant layer and for all layers ($p < 0.01$). Broken down into Broad habitats, the changes are most pronounces in acid grassland with increases in all three combinations of layers. In addition, calcareous grassland shows an increase in species-richness for the vascular plant layer ($p < 0.05$). For wetter vegetation, acid flush (M6) shows increases in species-richness for the vascular plant layer and all layers ($p < 0.001$).

Ellenberg Indicator Values can act as a proxy for directly measured soil properties when well calibrated. Figure 58 shows changes for EbF, the Ellenberg index for moisture for the vascular plant layer. Increases in EbF, which correspond to increases in soil moisture, were noted for acid grassland, acid flush and juniper heath for the vascular plant layer alone ($p < 0.05$, except for juniper heath, $p < 0.01$). In contrast, decreases in EbF, corresponding to drier soil conditions were noted for blanket mire for the vascular plant layer and also for vascular plant + moss layers ($p < 0.05$).

Changes to Ellenberg's index for nutrient, EbN, shown in Figure 59, show increases for wet heath and blanket mire ($p < 0.05$), and for wetland vegetation as a whole ($p < 0.01$) for the vascular plant layer. Grassland also shown an increase for EbN ($p < 0.05$) for the vascular plant layer. Looking at the vascular plant layer plus the moss layer, wetland vegetation shows an increase in EbN ($p < 0.01$), but there is a decrease for acid grassland and *Calluna* heath ($p < 0.05$).

Ellenberg's index of reaction or acidity, EbR, applied to the vascular plant layers, show an increasing trend only for grassland ($p < 0.05$). When the combined vascular plant + moss layer is considered, as well as the increase in grassland EbR, there is an increase for wetland vegetation ($p < 0.05$). Disaggregating down to Broad habitats and below, there are increases for calcareous grassland and *Vaccinium* heath.

Phenological recording of around 80 flowering plant species takes place weekly on the site. Species flowering are assessed on a crude abundance scale, to enable information on when the majority of a particular species is in flower. Of the 80 species, four woodland species, (Primrose (*Primula* vulgaris), Wood Anemone (*Anemone nemorosa*), Lesser Celandine (*Ranunculus ficaria*) and Bluebell (*Hyacnthoides non-scripta*), growing on cliff habitat and which have been monitored since 1999, show more or less parallel trends (Figure 61). Wood Anemone and Primrose show significant trends towards earlier flowering. Of the remaining species, which have been monitored since 2007, Cross-leaved Heath (*Erica tetralix*), Wood Sorrel (*Oxalis acetosella*) and Mouse-eared Hawkweed (*Pilosella officinalis*) show a trend towards later flowering ($p < 0.05$, except for Wood Sorrel, $p < 0.01$). In contrast, Golden Saxifrage (*Chrysosplenium oppositifolium*) and Wood Sage (*Teucrium scorodonia*) show a trend towards earlier flowering.

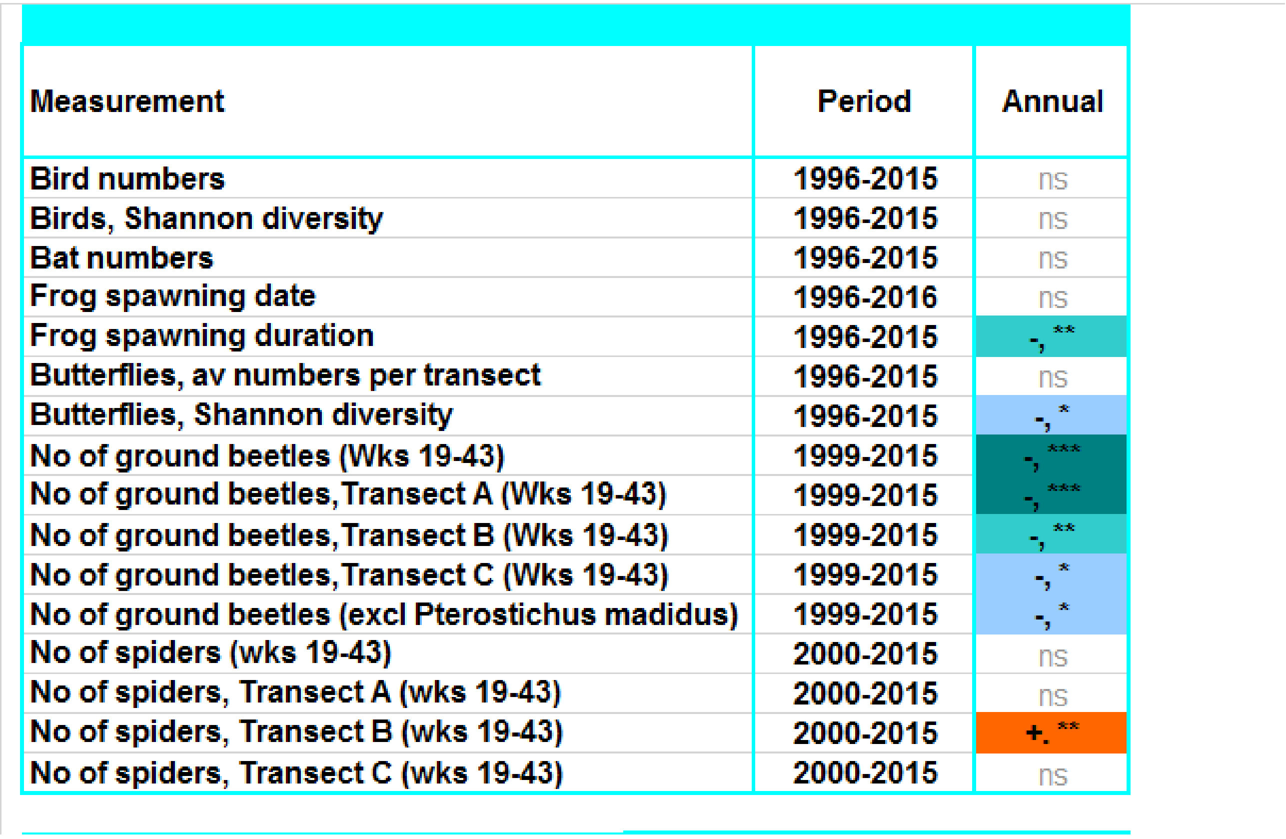
A number of arctic-alpine species occur along the transect used for butterflies and phenological recording, and as these species are considered to be at risk from climate change, simple monitoring of numbers flowering was set up. Monitoring began in 1997 with Purple Saxifrage (*Saxifraga oppositifolia*), which is the earliest flowering species on the ECN site and there is a significant trend towards earlier flowering ($p < 0.05$). Other arctic alpines occurring close to the butterfly transect route which are monitored include Moss Campion (*Silene acaulis*) and Starry Saxifrage (*Saxifraga stellaris*).

Arctic-alpine monitoring plots were set up initially in 2001 under advice from the ECN Advisory Committee for Snowdon. They are located in three areas: Clogwyn y Garnedd, Cwm Glas and Diffwys, the small cliff close to the Target Sampling Site. There are 40 plots in total, of two types - 32 are gridded fixed quadrat locations on more or less vertical rock, and 14 are locations where chasmophytic ferns are monitored, with 6 being both. The full set are monitored according to the same timetable as the fine-grain vegetation plots, but a subset of six on Diffwys are monitored annually. There are no significant increases or decreases for the full set of plots, but for the set of annually monitored plots there has been a significant increase in cell counts of Roseroot (*Sedum rosea*) ($p < 0.05$).

A 30 x 30m plot for fungal monitoring was laid out in 2007 and fortnightly recording commenced in November of that year. The grassland close to the Target Sampling Site has a moderate complement of Waxcap (*Hygrocybe*) and allied species typical of relatively unimproved grassland, and because of interest in this type of grassland, a simple recording method based on that used for survey elsewhere (Griffiths et al. 2006), was instituted. Most species were initially identified by local mycologists until the ECN staff became familiar with them, and now only new species and difficult genera (e.g. *Galerina* and *Entoloma*) are sent for expert identification. There is large year-to-year variation in numbers (Figure 65) and in species fruiting dates. The cumulative species abundance curve (Figure 66) shows little sign of levelling off even after 9 years. Fungal monitoring at this site is unique in the UK.

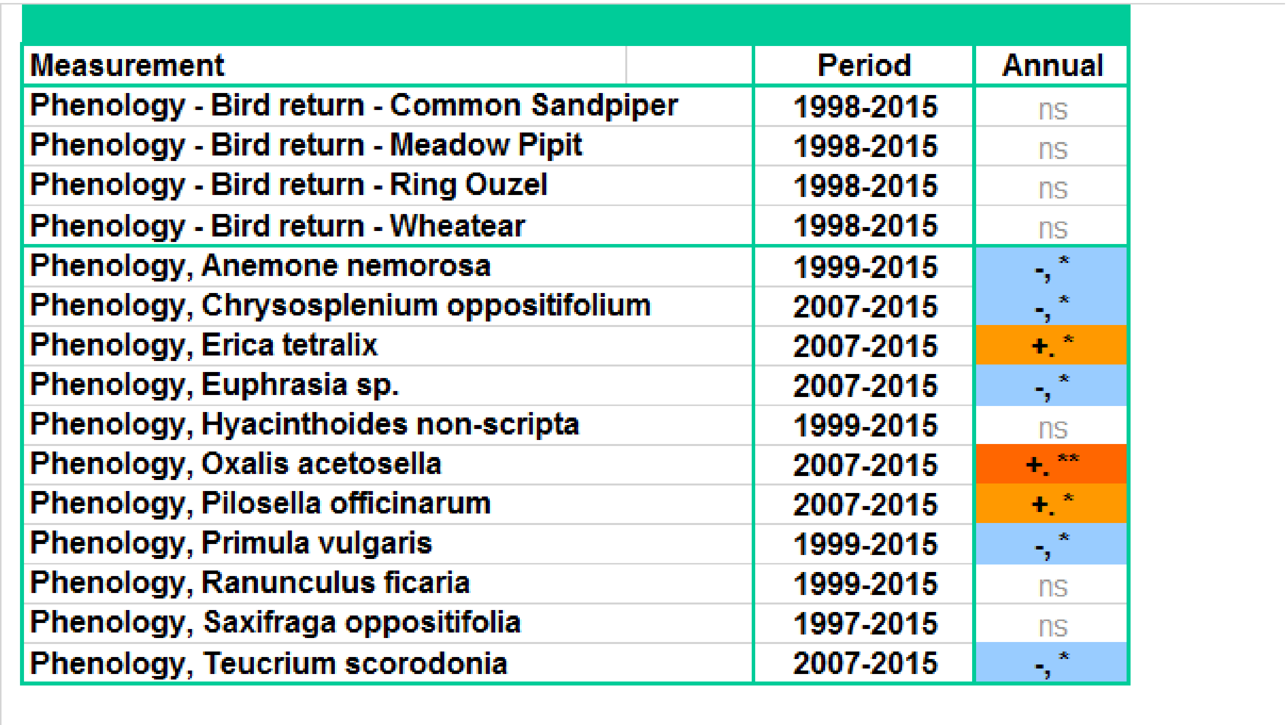
Freshwater phytoplankton monitoring began in 2006 and samples are taken 4-weekly as part of the freshwater chemistry sample. Changes in levels of chlorophyll-a (Figure 67) show large year-to-year variation with summer peaks linked to weather conditions. Freshwater diatoms are scraped from cobbles in 3 locations in Nant Teyrn twice a year. Changes in the Trophic Diatom Index (Kelly 2001, 2007) are shown in Figure 68, but the trend is not significant. Macrophytes are sampled in July of each year with 10 10m lengths of Nant Teyrn, with half above and half below the gauging weir. The two sections differ considerably in morphology with 5m section above the weir cut through deep peat, while the section below is rocky with large boulders. There have been some minor changes in frequency of species with for example a decrease in Water Lobelia (*Lobelia dortmanna*) and an increase in Bog Pondweed (*Potamogeton polygonifolius*) in the peaty upper section. Ellenberg indicator values calculated for the stream vegetation show little trend, except rather surprisingly for a decrease in Ellenberg EbF (moisture). Finally macroinvertebrates are sampled twice-yearly in spring and autumn, but a number of recent samples are still awaiting identification so interpretation of any changes is limited.

Table 8: Summary of trends for biological variables - vertebrates and invertebrates



Measurement	Period	Annual
Bird numbers	1996-2015	ns
Birds, Shannon diversity	1996-2015	ns
Bat numbers	1996-2015	ns
Frog spawning date	1996-2016	ns
Frog spawning duration	1996-2015	-, **
Butterflies, av numbers per transect	1996-2015	ns
Butterflies, Shannon diversity	1996-2015	-, *
No of ground beetles (Wks 19-43)	1999-2015	-, ***
No of ground beetles,Transect A (Wks 19-43)	1999-2015	-, ***
No of ground beetles,Transect B (Wks 19-43)	1999-2015	-, **
No of ground beetles,Transect C (Wks 19-43)	1999-2015	-, *
No of ground beetles (excl Pterostichus madidus)	1999-2015	-, *
No of spiders (wks 19-43)	2000-2015	ns
No of spiders, Transect A (wks 19-43)	2000-2015	ns
No of spiders, Transect B (wks 19-43)	2000-2015	+. **
No of spiders, Transect C (wks 19-43)	2000-2015	ns

Table 9: Summary of trends for biological variables - phenology



Measurement	Period	Annual
Phenology - Bird return - Common Sandpiper	1998-2015	ns
Phenology - Bird return - Meadow Pipit	1998-2015	ns
Phenology - Bird return - Ring Ouzel	1998-2015	ns
Phenology - Bird return - Wheatear	1998-2015	ns
Phenology, Anemone nemorosa	1999-2015	-, *
Phenology, Chrysosplenium oppositifolium	2007-2015	-, *
Phenology, Erica tetralix	2007-2015	+. *
Phenology, Euphrasia sp.	2007-2015	-, *
Phenology, Hyacinthoides non-scripta	1999-2015	ns
Phenology, Oxalis acetosella	2007-2015	+. **
Phenology, Pilosella officinarum	2007-2015	+. *
Phenology, Primula vulgaris	1999-2015	-, *
Phenology, Ranunculus ficaria	1999-2015	ns
Phenology, Saxifraga oppositifolia	1997-2015	ns
Phenology, Teucrium scorodonia	2007-2015	-, *

Table 10: Summary of trends for biological variables – vegetation, fine-grain

	Habitat	Vascular plants only	Vascular plants + mosses	All species
Species richness	Calcareous grassland	+, *	ns	ns
	Acid grassland	+, ***	+, **	+, *
	Vaccinium heath	ns	ns	ns
	Calluna heath	ns	ns	ns
	Juniper heath	ns	ns	ns
	Acid flush	+, ***	ns	+, ***
	Wet heath	ns	ns	ns
	Blanket mire	ns	ns	ns
	Grassland	+, **	+, **	+, *
	Heath	ns	ns	ns
	Wetland	+, **	ns	+, **
Ellenberg F (moisture)	Calcareous grassland	ns	ns	
	Acid grassland	+, *	ns	
	Vaccinium heath	ns	ns	
	Calluna heath	ns	ns	
	Juniper heath	+, **	ns	
	Acid flush	+, *	ns	
	Wet heath	ns	ns	
	Blanket mire	-, *	-, *	
	Grassland	ns	ns	
	Heath	ns	ns	
	Wetland	ns	ns	
Ellenberg N (nutrient)	Calcareous grassland	ns	ns	
	Acid grassland	ns	-, *	
	Vaccinium heath	ns	ns	
	Calluna heath	ns	-, *	
	Juniper heath	ns	ns	
	Acid flush	ns	ns	
	Wet heath	+, *	ns	
	Blanket mire	+, *	ns	
	Grassland	+, *	ns	
	Heath	ns	ns	
	Wetland	+, **	+, **	
Ellenberg R (reaction)	Calcareous grassland	ns	+, *	
	Acid grassland	ns	ns	
	Vaccinium heath	ns	+, *	
	Calluna heath	ns	ns	
	Juniper heath	ns	ns	
	Acid flush	ns	ns	
	Wet heath	ns	ns	
	Blanket mire	ns	ns	
	Grassland	+, **	+, *	
	Heath	ns	ns	
	Wetland	ns	+, *	

Positive trend

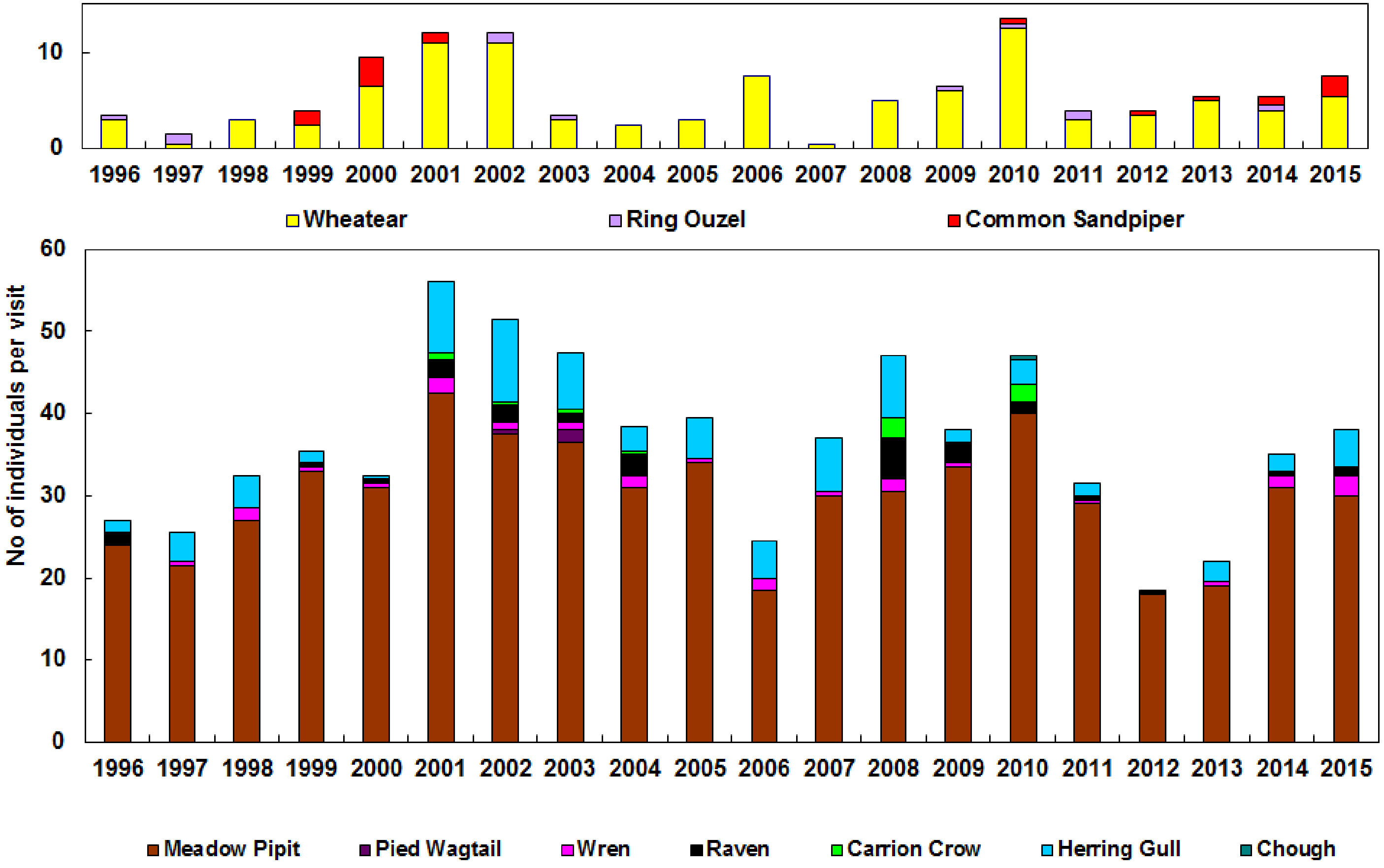
+, *	$p < 0.05$
+, **	$p < 0.01$
+, ***	$p < 0.001$

Negative trend

-, *	$p < 0.05$
-, **	$p < 0.01$
-, ***	$p < 0.001$

Figure 45: Annex 1 habitats on Snowdon: Calcareous Rocky Slope with Chasmophytic Vegetation, Arctic-Alpine plot (top) and Alpine and Boreal Heath, VF plot 904, Juniper heath (bottom).

Vertebrates - breeding birds (BB)



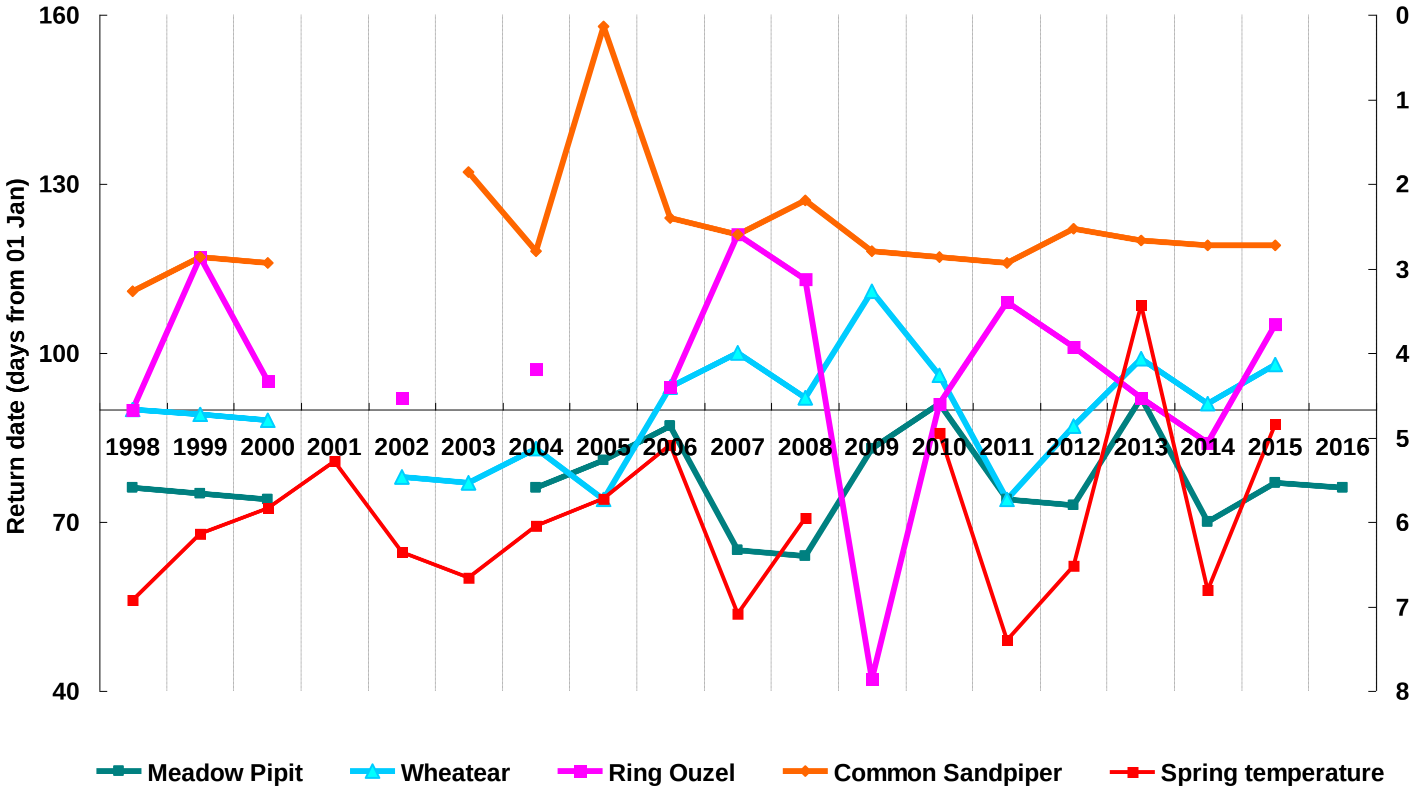
Birds:

The numbers of individual species recorded using the Breeding Bird Survey methodology do not show any significant trend over the recording period, and there has been no significant change in total numbers or diversity.

Meadow Pipits, which are the dominant bird on the site, appears to show an irregularly cyclic abundance curve, with minima in 1997, 2006 and 2012. The combined abundances of the long-distance migrants show a significant correlation with Meadow Pipit numbers, indicating that the origin of the variation is to be found in the environmental conditions on the ECN site rather than in conditions of the migrant’s wintering grounds.

Figure 46: Numbers of bird species recorded on BBS survey over the period 1996-2015. Long range migrants, above, residents and shorter range migrants and below.

Vertebrates - breeding birds, phenology



Bird returns:

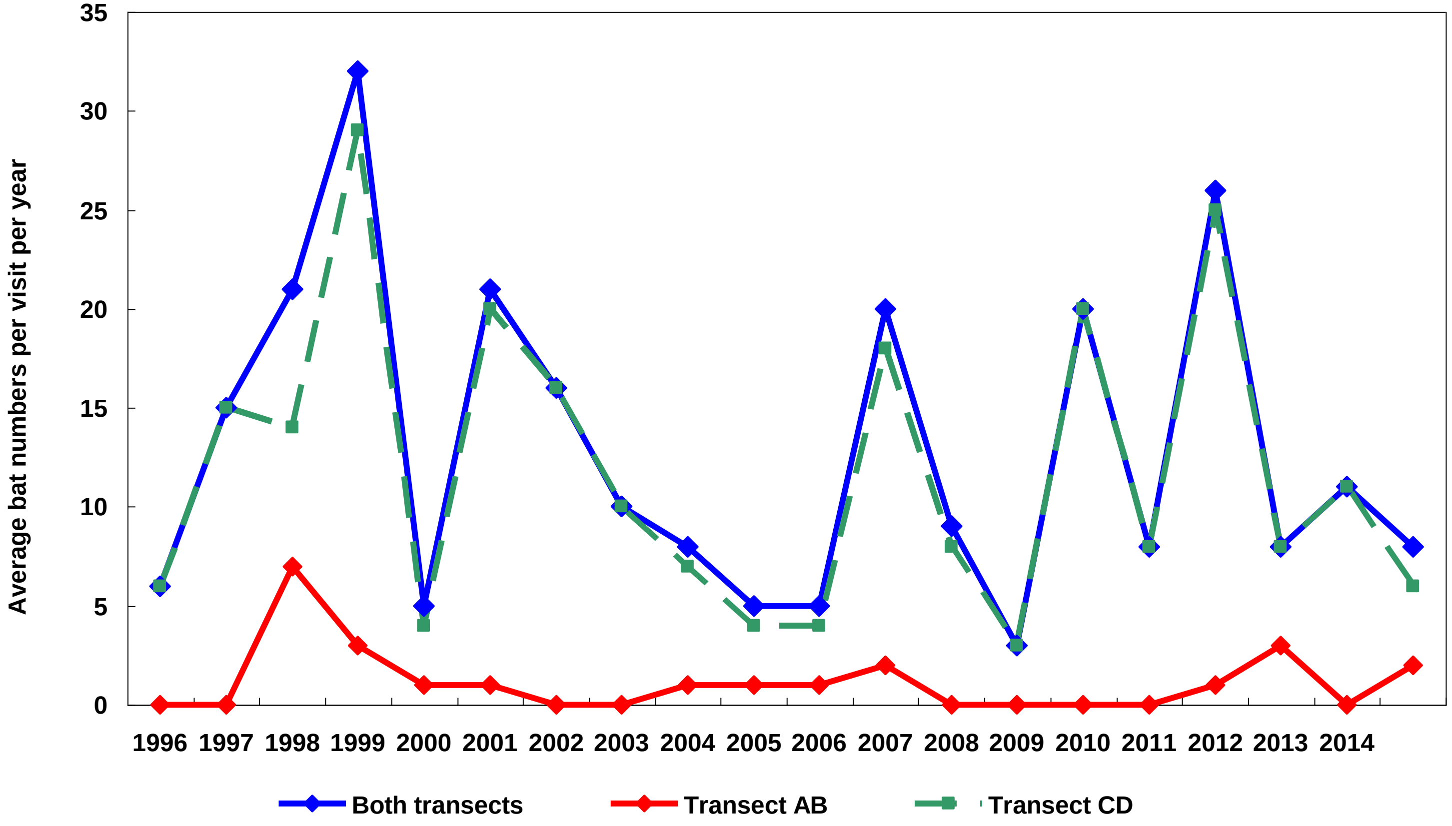
There is little real change in the dates of return of the species shown in the figure.

The date of return of Meadow Pipit, short-distance migrants, is moderately strongly correlated with spring temperature (R2 = 0.57)

Wheatear, Ring Ouzel and Common Sandpiper are all long-distance migrants and show little correlation with local spring temperatures. Timing with these species is probably dictated by a complex of changes in weather patterns across the whole of Europe and North Africa.

Figure 47: Changes in the timing of bird returns 1999-2016.

Vertebrates - bats



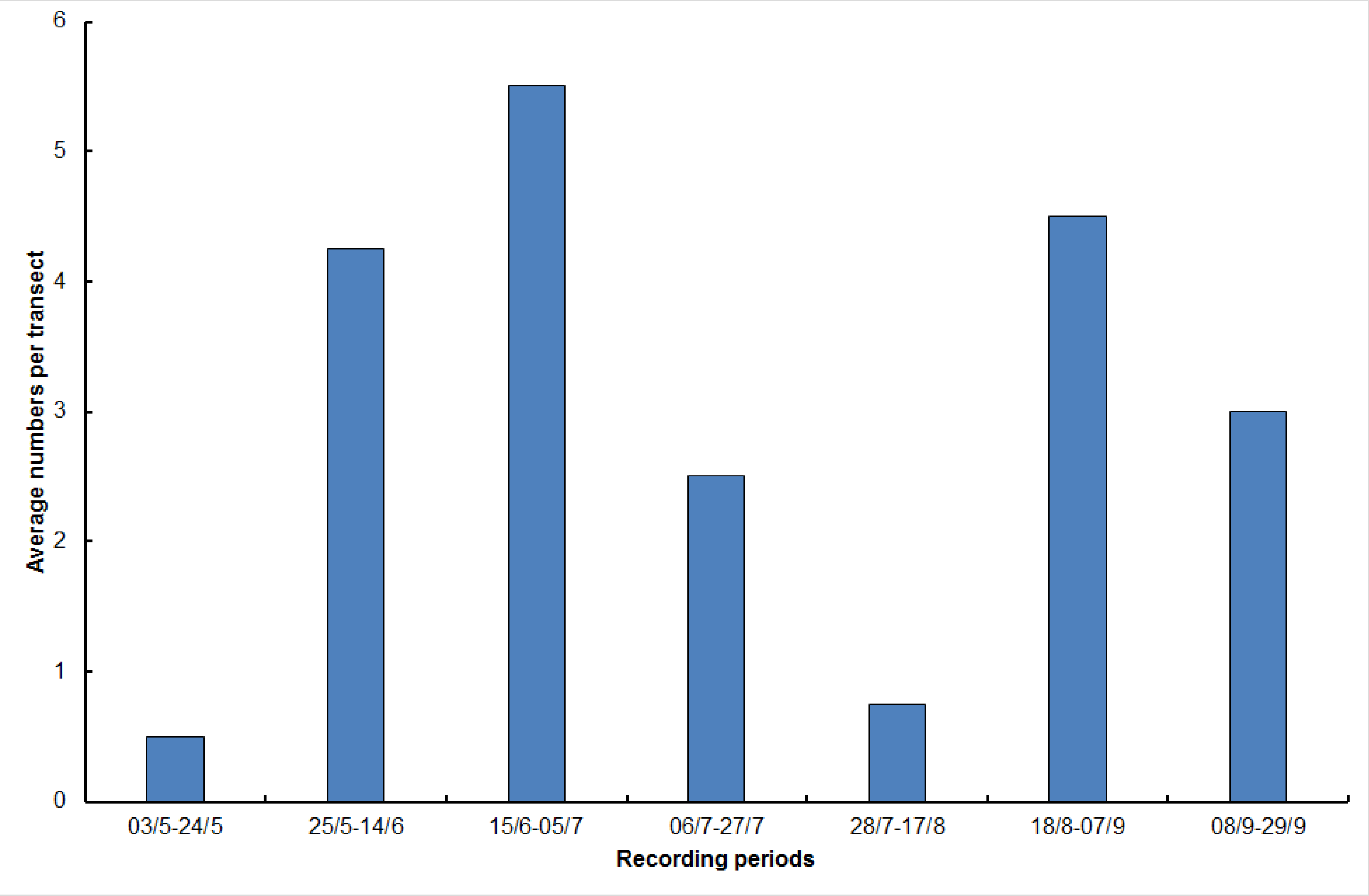
Bats:

Bat numbers at moderate altitude sites are sensitive to even slightly extended periods of rainfall in spring and summer when females need daily food for young. For this reason, bat activity on Snowdon can be very variable and on average is highest later in the recording season once young bats have become more independent.

The annual pattern seen shows no significant monotonic trend for either of the two altitudinally separated transects or for each of the sampling periods.

Figure 48: Mean number of bats per transect per year 1996 – 2013.

Vertebrates – bats, seasonal activity



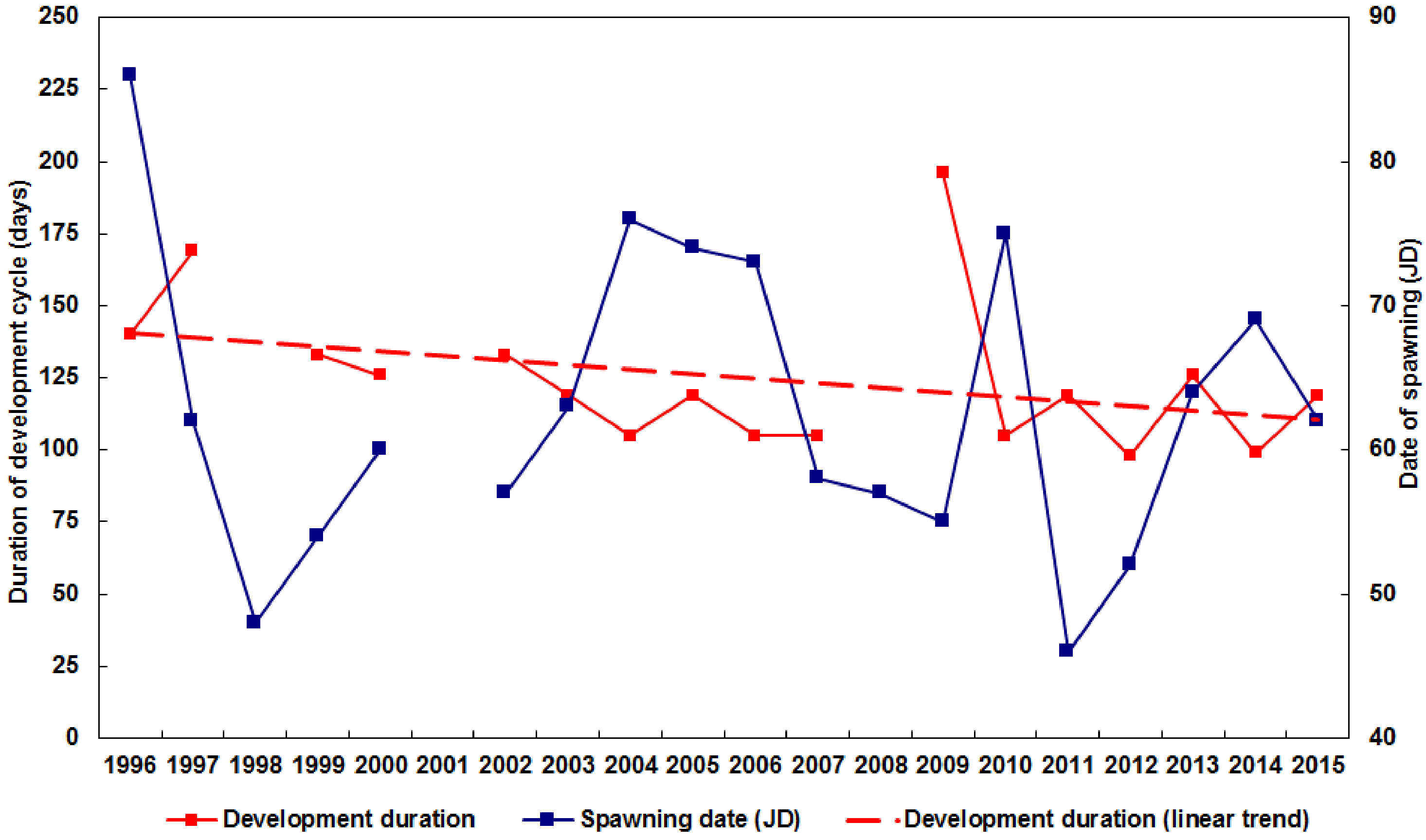
Bats: seasonal activity

Work done at Moor House ECN site using continuous recorders has indicated that upland bat activity may be bimodal (Rob Rose, pers. comm.), and that the 4 3-week recording periods may not be capturing all the activity. The mid-range dip is accounted for by the need for lactating females to be able to feed every day - something which is often not possible in the uplands due to poor weather, and hence females are obliged to move to lower altitudes where the likelihood of feeding is higher.

At the Snowdon site, we started undertaking extra transects in 2012, and this has confirmed that a similar pattern is also found here.

Figure 49: Seasonal activity of all bat species by recording period for the years 2012-2015.

Vertebrates - frog spawning



Frogs:

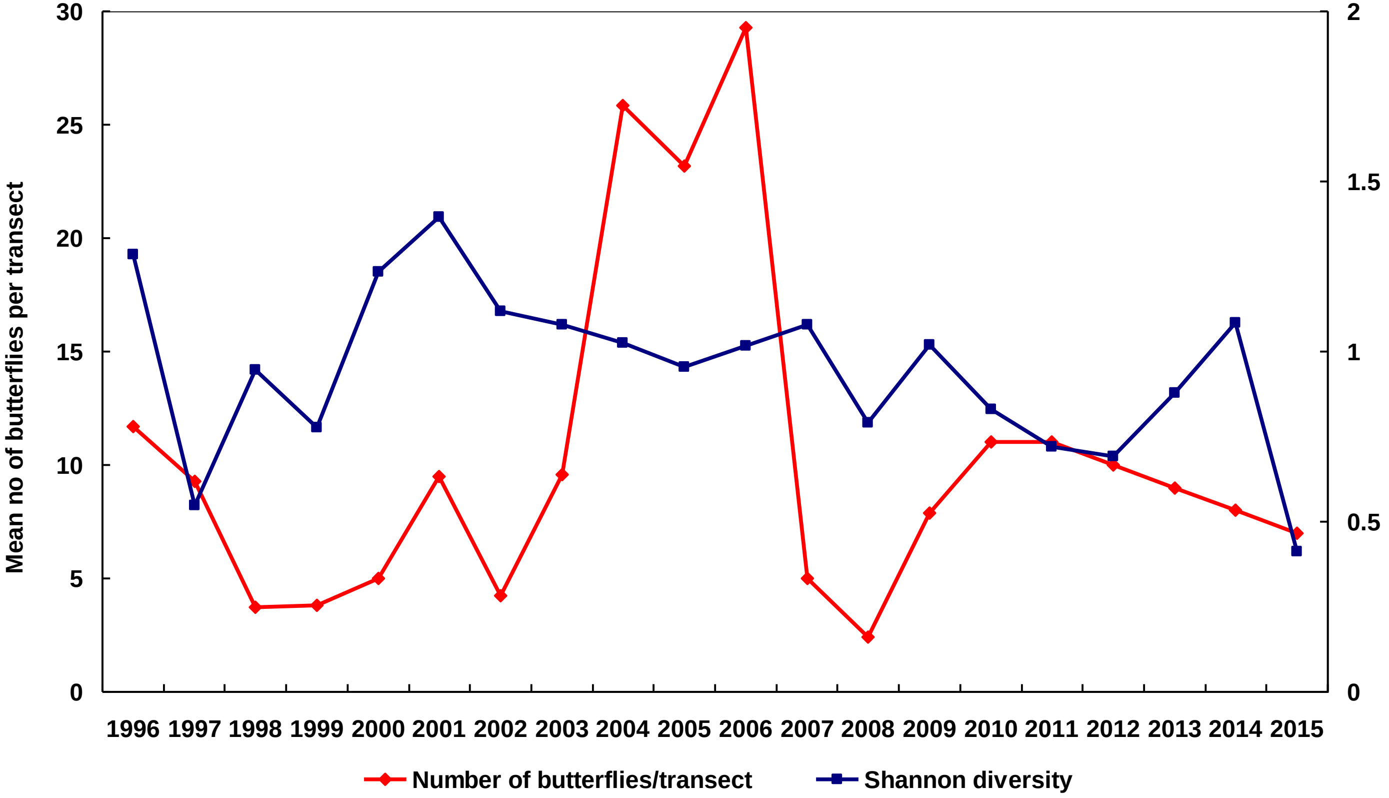
Frog spawning dates can be quite variable depending on spring weather. Late snowfall persisting for more than a couple of days can induce mass mortality if spawning happens too early as for example in 1998 and 2008.

Duration of the period from spawning to metamorphosis is much less variable and shows a significant trend (p < 0.01) towards shorter development times.

There is a difference in success between spring-fed and rain-fed ponds with the latter being successful much less frequently than the former.

Figure 50: Changes in development duration (spawning to adult metamorphosis) and first spawning dates from 1996-2013 for Frog Pond 1 (spring-fed).

Invertebrates – butterflies, species richness and diversity



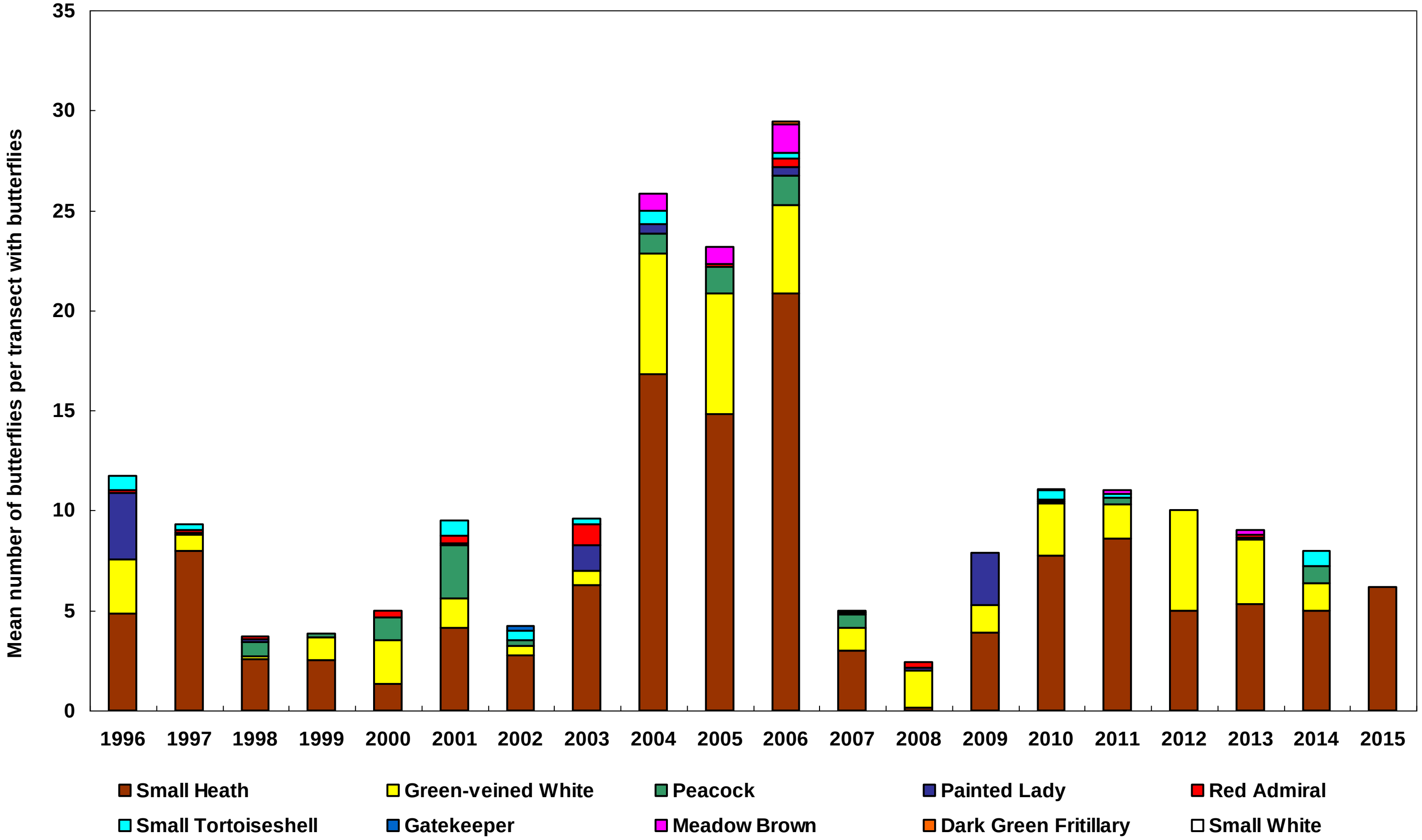
Butterfly numbers and diversity:

During the drier and warmer summers of 2004 to 2006, butterfly numbers increased dramatically when there were large numbers of Small Heath in June and July. Since then numbers per transect have fallen back to levels seen prior to the increase.

There has been a fairly steady decline in the Shannon diversity index, H', of the butterflies recorded, from around 2000 to the present, which is significant ($p < 0.05$).

Figure 51: Average number of butterflies per transect and Shannon diversity, H', on Snowdon over the period 1996-2015.

Invertebrates - butterflies, species

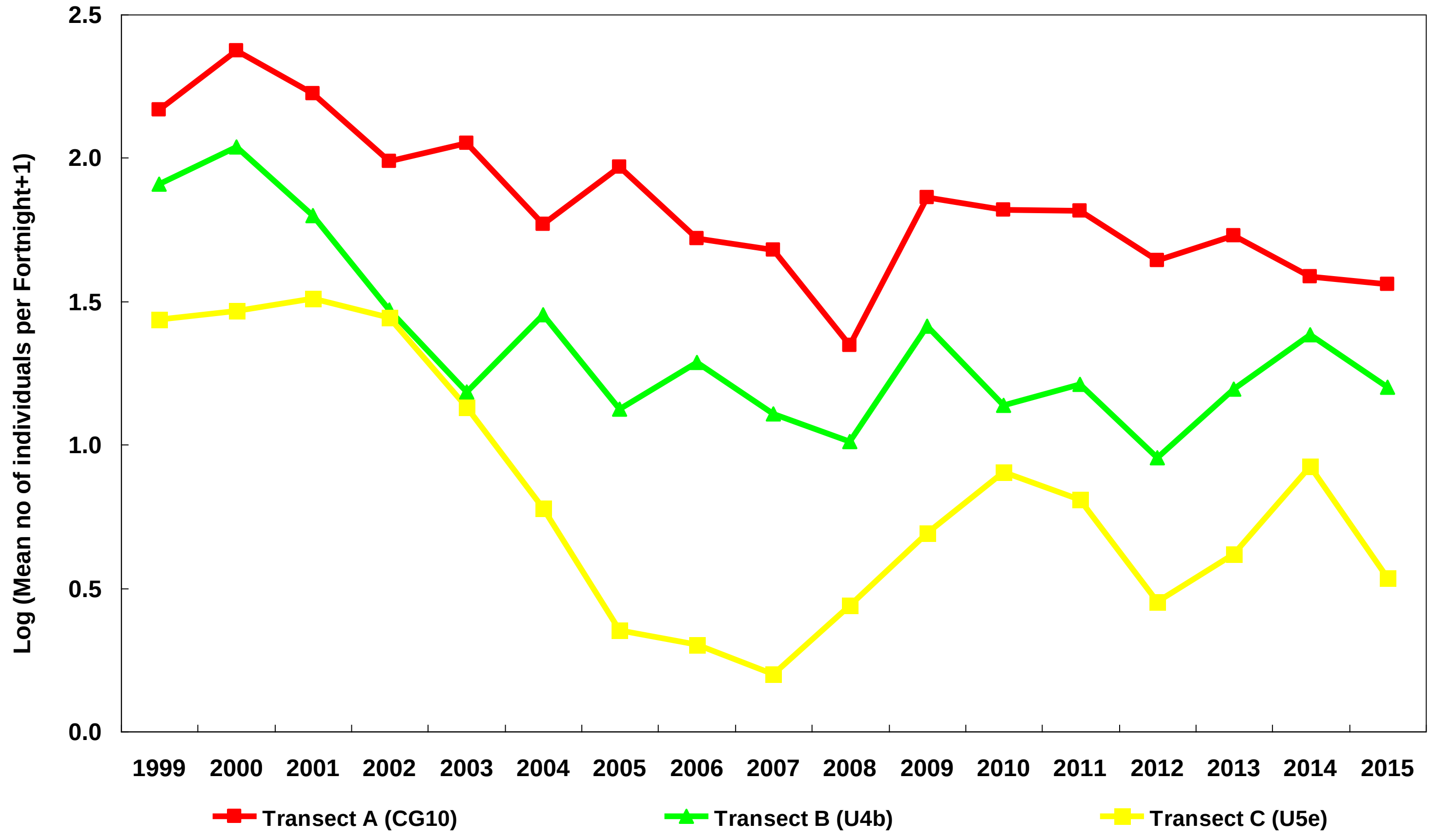


Butterfly species:
The drier and warmer summers in the mid-2000s produced larger numbers of butterflies on the site, and new migrant species were recorded such as Meadow Brown, *Maniola jurtina* and Gatekeeper, *Pyronia tithonus*. The migrant proportion of the total number during these warm summers was, however, relatively low.

With the wetter summers from 2007 onwards lower numbers were seen with lower diversity and the virtual disappearance of the migrants.

Figure 52: Average numbers of individual species of butterflies per transect for Yr Wyddfa/Snowdon over the period 1996-2015.

Invertebrates - ground beetles (Carabidae), total numbers



Ground beetles:

Ground beetle numbers combined across all three transects at the site have decreased significantly ($p < 0.001$) over the full period of sampling (1999-2015).

For the different grassland types, the decrease is most pronounced in calcareous grassland (Transect A, $p < 0.001$) and least in the most acid grassland (Transect C, $p < 0.05$)

Over the shorter period 20005-2015, Transect A still shows a significant decline ($p < 0.05$) while Transect C has shown a slight but significant increase ($p < 0.05$).

Figure 53: Log of mean number of Carabid beetles per fortnightly transect for transects A to C on Snowdon for the period 1999 to 2015. (May – October).

Invertebrates – spiders, total numbers

Spiders:

Spider numbers have changed less over the 16 years of sampling than ground beetles. Transect B, which is effectively neutral grassland, shows a slight but significant increase ($p < 0.05$).

All three transects show a minimum in species numbers in 2005, and over the following years, all display a significant increasing trend ($p < 0.05$) with transects A and B reaching a maximum in 2015.

Figure 54: Log of mean number of spiders per trap per transect for transects A-C on Snowdon for the period 2000-2015.

Invertebrates – spittle Bugs, colour morph numbers

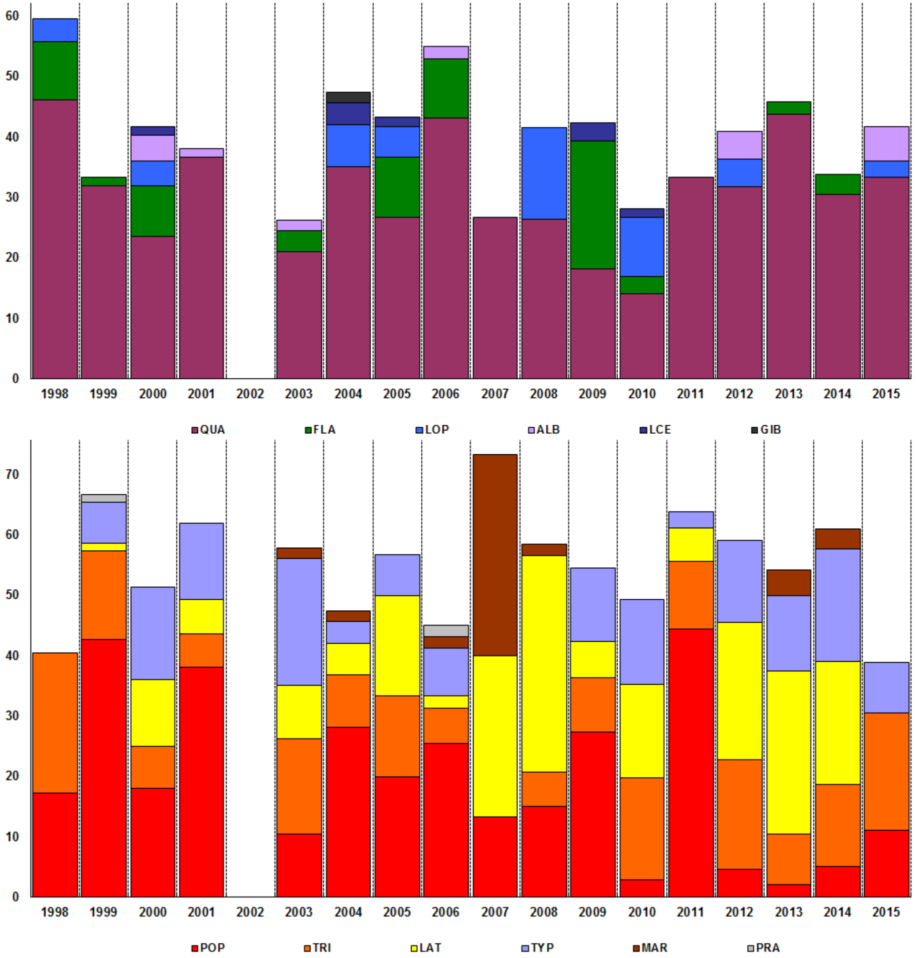
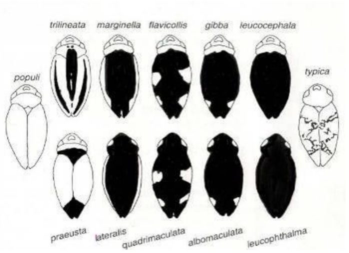


Figure 55: Proportions of different colour morphs of *Philaenus spumarius* separated into melanic, above, and non-melanic, below, over the period 1998-2015. Data missing for 2002.

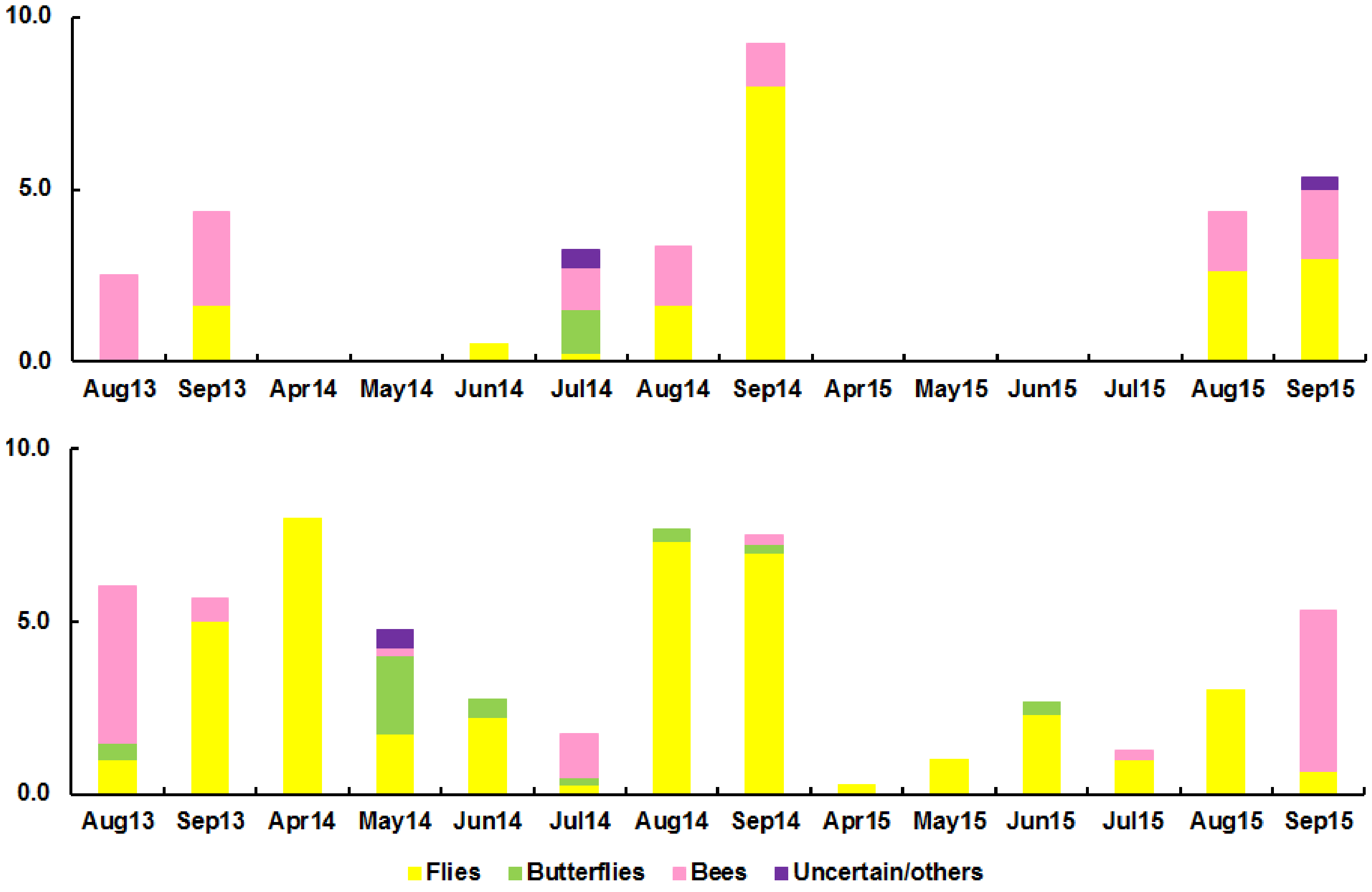
Key: Names and abbreviations of colour morphs found on the ECN site.

Abbrev.	Full name	Melanic/non-melanic
ALB	*albomaculata*	MELAN
FLA	*flavicollis*	MELAN
GIB	*gibba*	MELAN
LAT	*lateralis*	MELAN
LCE	*leucocephala*	MELAN
LOP	*leucopthalma*	MELAN
MAR	*marginella*	MELAN
POP	*populi*	NON-M
PRA	*praeusta*	NON-M
QUA	*quadrimaculata*	MELAN
TRI	*trilineata*	NON-M
TYP	*typica*	NON-M



Colour morphs of *Philaenus spumarius*.

Invertebrates - pollinators



Pollinators

Pollinator sampling was started in August 2013 on the site as an extension of a trial of the Open Farm Sunday Pollinator Survey (CEH, 2012)

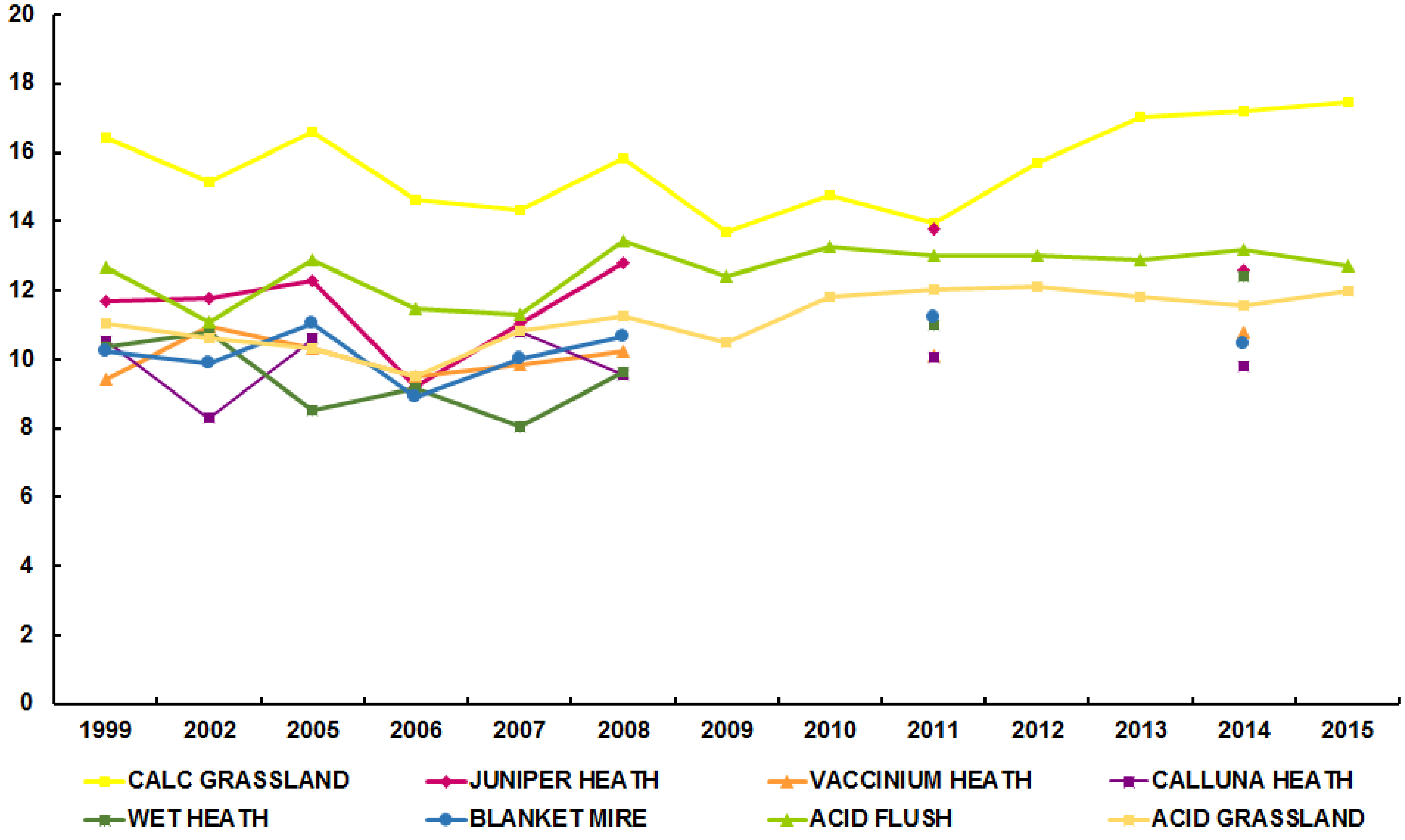
The two areas chosen were the long-term acidic and basic exclosures which have been ungrazed since the early-1980s.

In the species-poor acidic exclosure, the flowering of heather in August and September can be seen with increased visits by bees and flies.

The pattern in the basic exclosure is more varied, reflecting the greater botanical diversity but visits are dominated by visits by flies

Figure 56: Average numbers of pollinators in 2 minute counts per weekly visit on vegetation in an acidic (top) and a basic (bottom) exclosure on Snowdon for the period August 2013 - September 2015. Zero counts of ladybirds, beetles and ants excluded.

Vegetation, fine-grain - species richness



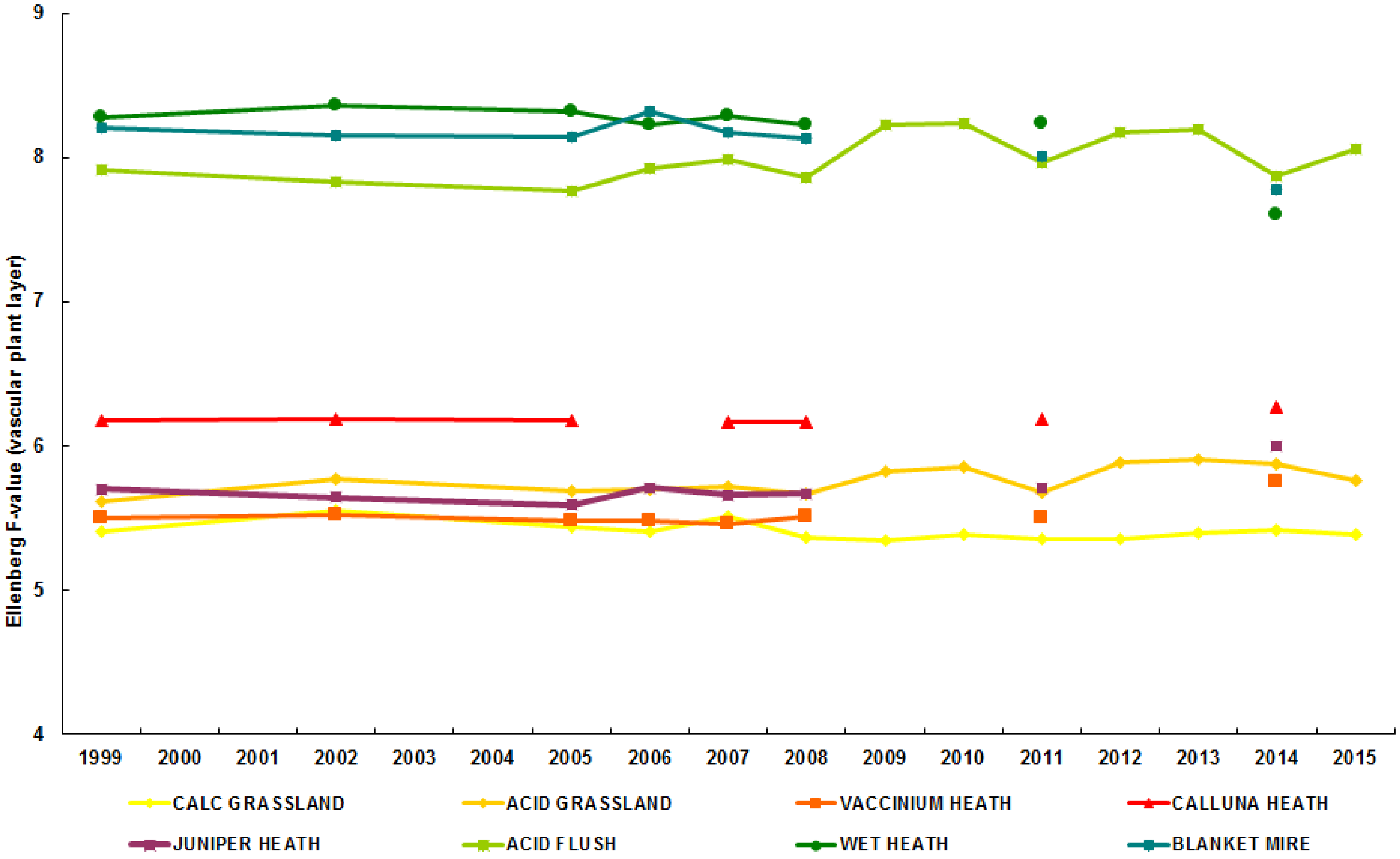
Species richness:

Species richness has increased significantly across a number of vegetation types. Grassland species richness has increased for all species ($p < 0.05$) and for vascular plants only ($p < 0.01$). Considering vascular plants only, there have been increases in both acid ($p < 0.001$) and calcareous grassland ($p < 0.05$).

Wetland vegetation has also shown a significant increase for all species and also for vascular plants only ($p < 0.01$). The increase is mainly accounted for by acid flush vegetation ($p < 0.001$).

Figure 57: Species richness for the vascular plant layers of fine-grain (VF) plots 1999-2015.

Vegetation, fine-grain – Ellenberg F (moisture), EbF



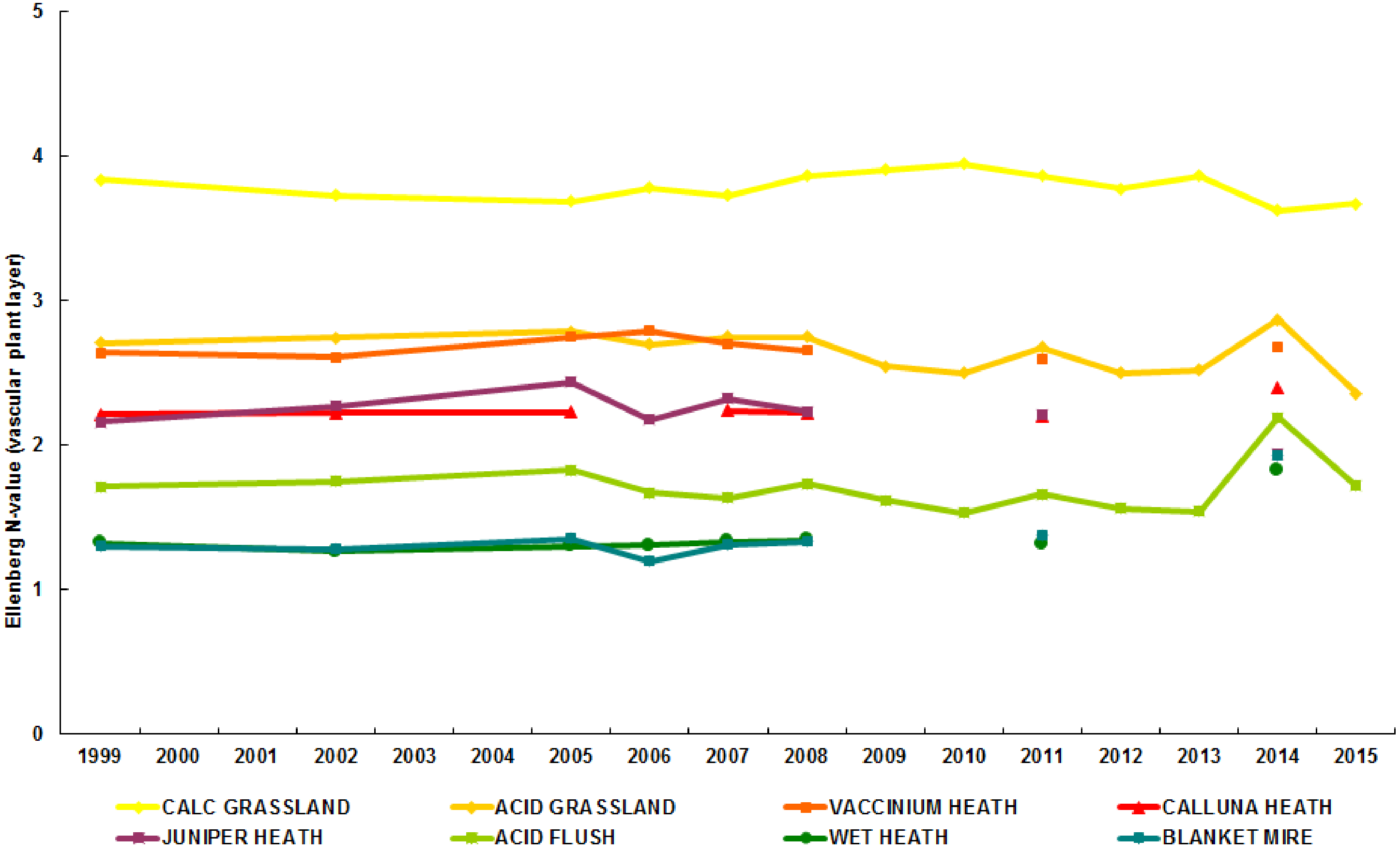
Ellenberg F (moisture), EbF

Hill's modified Ellenberg indicator value for moisture, EbF (Hill *et al.* 1999), clearly separates wet heath, flush and bog habitats (NVC M15, M6 and M17) from the remaining heath and grassland habitats on the site.

Changes in EbF have been most marked in the vascular plant layer, with significant increases seen in acid grassland and acid flush ($p < 0.05$), and juniper heath (NVC H15, $p < 0.01$). Conversly, there has been a decline in EbF for blanket mire ($p < 0.05$), and this decline is the only significant change seen when vascular plants and mosses are combined ($p < 0.05$).

Figure 58: Weighted mean Hill's modified Ellenberg indicator value F (moisture), EbF, for the vascular plant layers of VF plots 1999-2015. NVC community codes from Rodwell et al (1999 et seq.)

Vegetation, fine-grain – Ellenberg N (nutrient), EbN



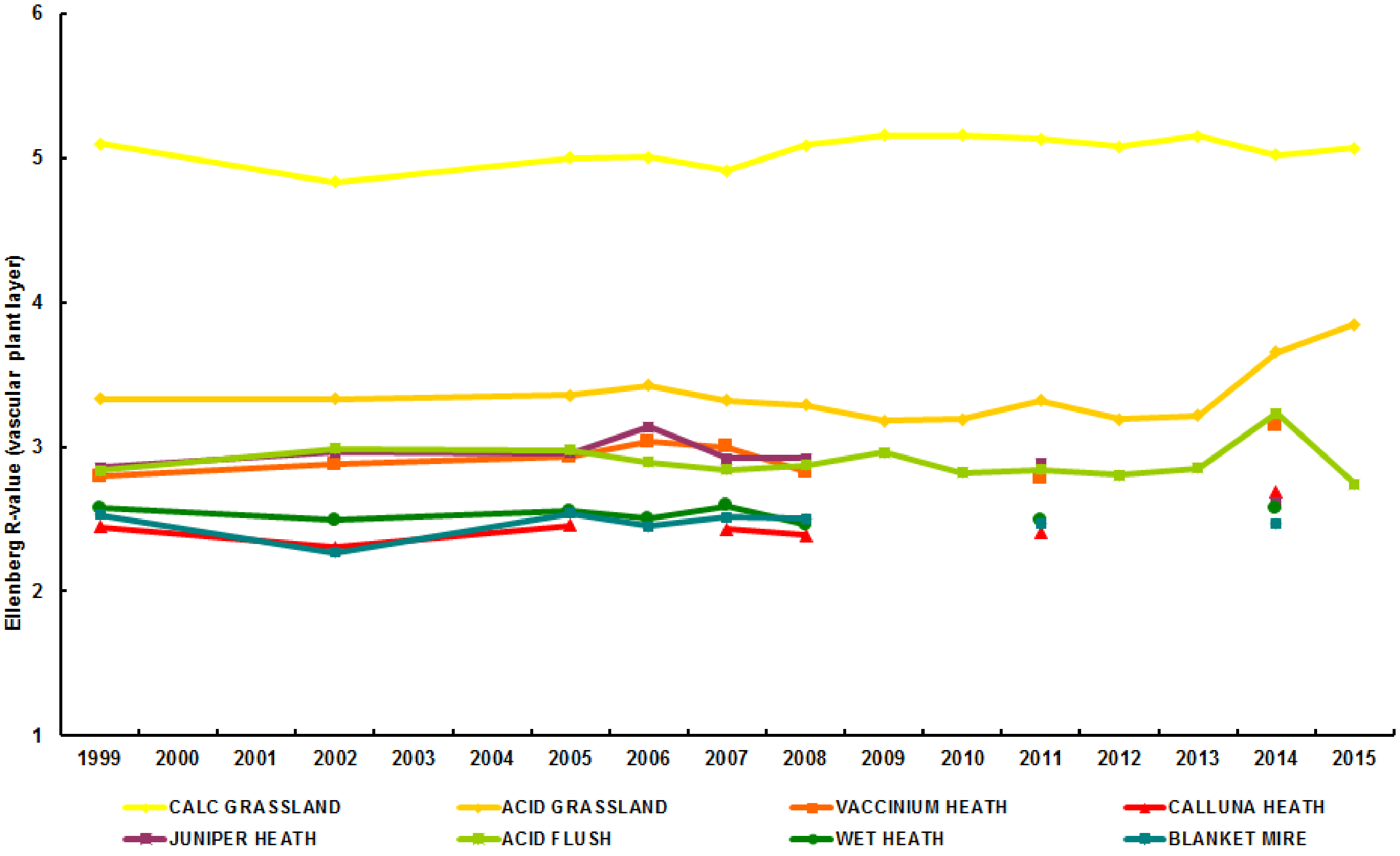
Ellenberg N (nutrient), EbN

Calcareous grassland (CG10) is the most heavily grazed habitat on the site, and is clearly separated from other habitats in Figure 58. The wettest habitats with the lowest grazing intensity, acid flush (M6), wet heath (M15) and blanket bog (M17), have the lowest value of EbN indicating their extreme infertility.

Significant trends differ between the vascular plant layer and the combined vascular plant and moss layer. In the latter, the only habitats exhibiting significant change and showing a decrease in EbN are acid grassland and *Calluna* heath ($p < 0.05$). Conversly, using just the vascular plant layer, there have been increases in EbN for blanket mire and wet heath ($p < 0.05$).

Figure 59: Weighted mean Hill's modified Ellenberg indicator value, EbN, (Nutrient or Nitrogen) for the vascular plant layers of VF plots 1999-2015. NVC community codes from Rodwell et al (1999 et seq.)

Vegetation, fine-grain – Ellenberg R (acidity), EbR



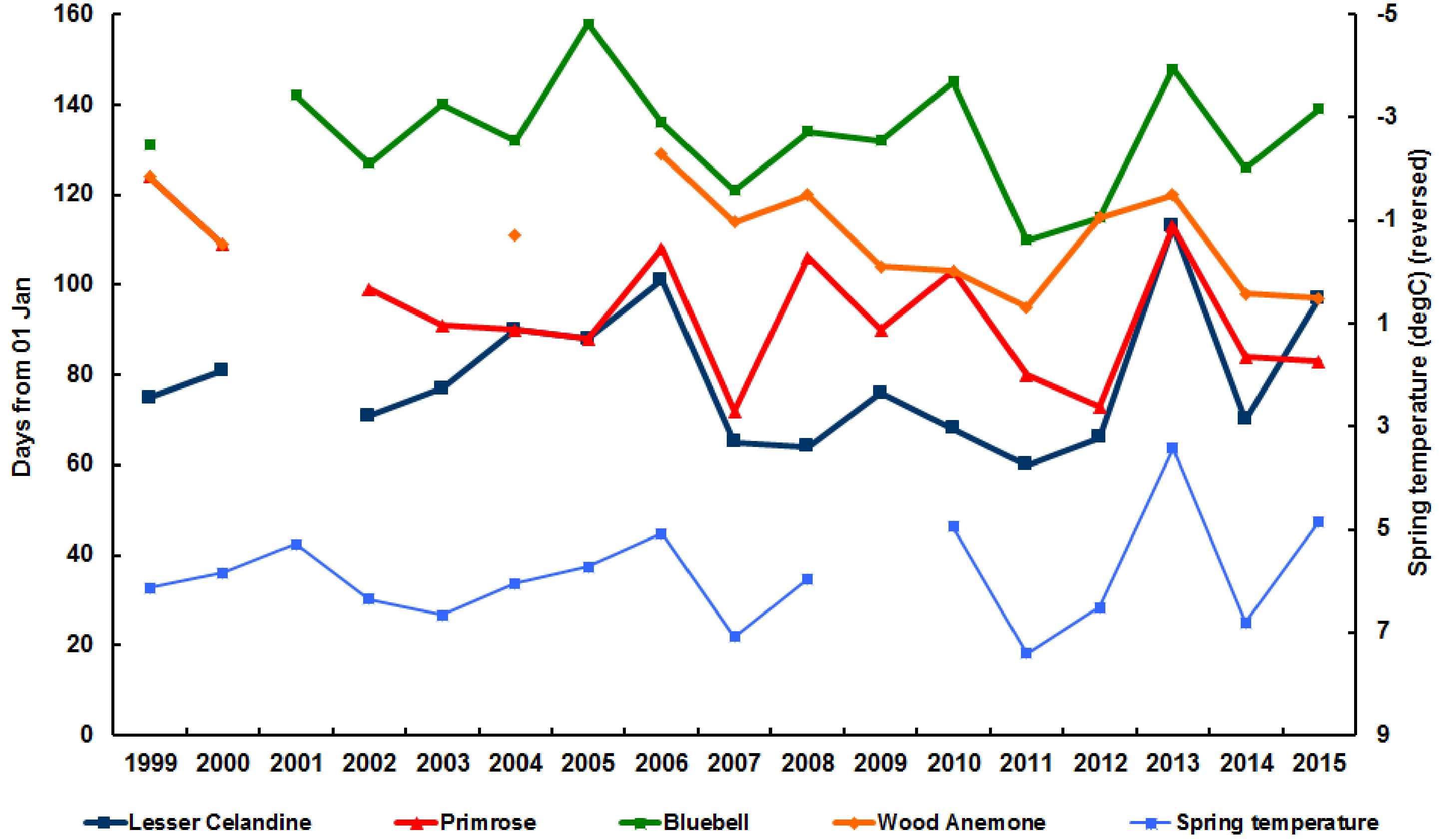
Ellenberg R (acidity), EbR:

Hill's modified Ellenberg indicator value R (reaction) is correlated with soil acidity. As in Figure 50, calcareous grassland EbF stands well apart from the other habitats monitored, with *Calluna* heath and blanket mire being the most acidic.

As with EbN, there are differences between the vascular plant layer and the combined vascular plant and moss layer. Amongst the former, there are no individually significant trend at the broad habitat level, but when all the grassland samples are combined, there is an increasing trend ($p < 0.05$). In the combined layer, there are increasing trends for calcareous grassland and *Vaccinium* heath ($p < 0.05$). Combining habitats also gives increasing trends for grassland and wetland ($p < 0.05$).

Figure 60: Weighted mean Hill's modified Ellenberg indicator value, EbR, (Reaction or Acidity) for the vascular plant layers of VF plots 1999-2015.

Vascular plants – phenology, first flowering



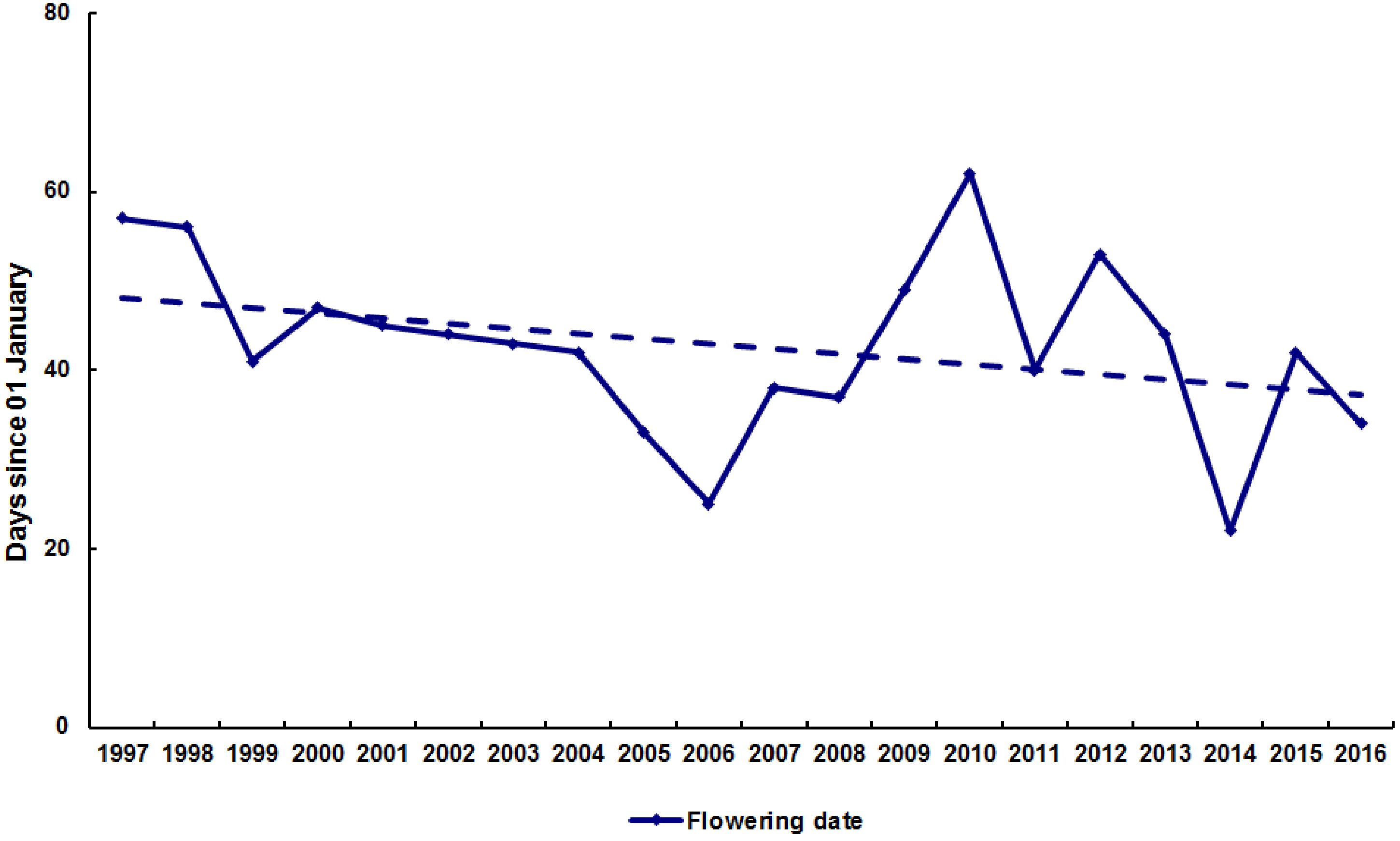
Phenology:

Of the 81 species currently monitored, a number of nominally woodland species have been monitored since 1999. Four of the commonest of these appear to show more or less parallel trends towards earlier flowering, with *Primula vulgaris* (Primrose) and *Anemone nemorosa* (Wood anemone) having a significant trend towards earlier flowering ($p < 0.05$). The Snowdon trends match UK trends for these species from data collated by the UK Phenology Network (http://www.naturescalendar.org.uk/) but with an obvious delay due to the lapse rate.

Timing of first flowering is partly determined by average spring temperature.

Figure 61: Changes in the timing of first flowering of the woodland species Lesser Celandine (*Ranunculus ficaria*), Bluebell (*Hyacinthoides non-scripta*), Primrose (*Primula vulgaris*) and Wood Anemone (*Anemone nemorosa*), in relation to mean spring temperature, on the ECN site over the period 1999-2015.

Vascular plants – phenology, Purple saxifrage (*Saxifraga oppositifolia*) first flowering

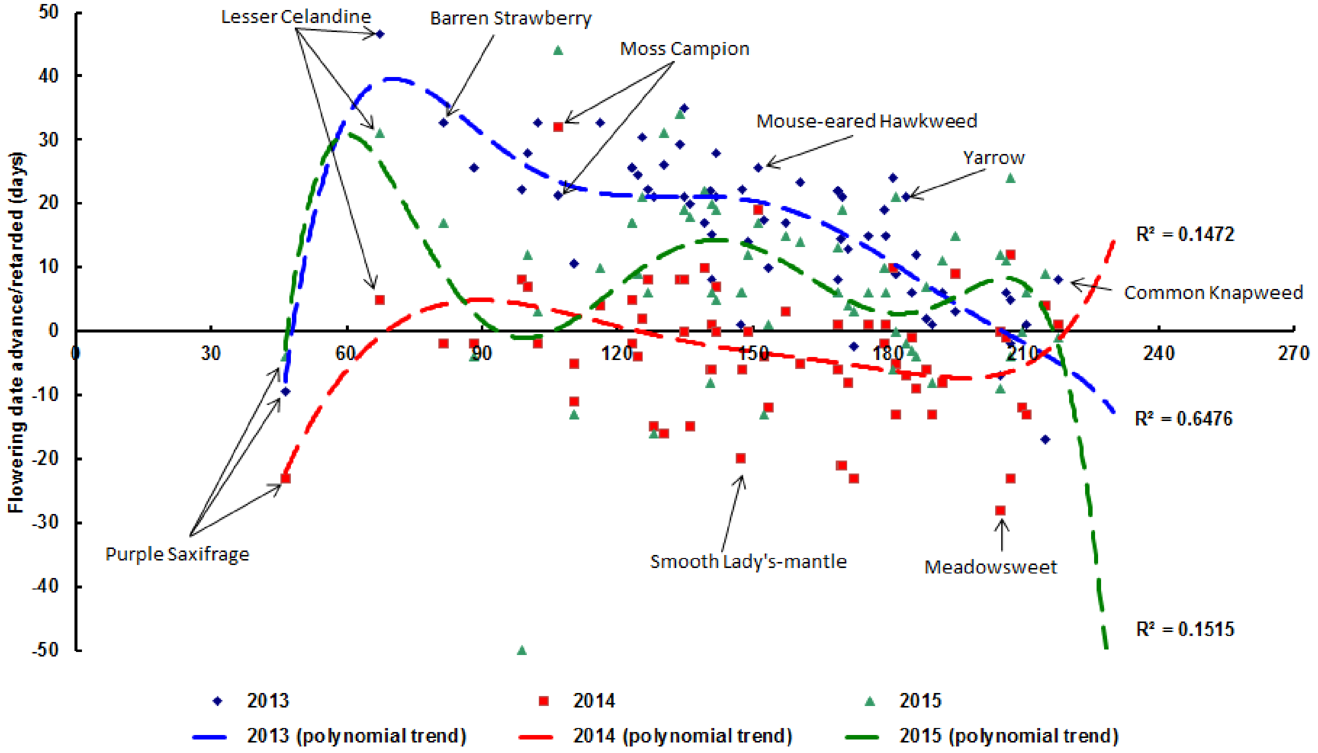


Purple saxifrage:

Purple saxifrage (*Saxifraga oppositifolia*), an arctic-alpine species occurring on the ECN site, has a very early flowering period. Over the period 1997-2008, first flowering dates had generally been getting earlier, but from 2009-13 later flowering occurred due to colder winters. Mild winter from 2014 onwards, however, have lead to earlier first flowering. The apparent downward trend towards earlier flowering is significant ($p < 0.05$).

Figure 62: Purple Saxifrage (*Saxifraga oppositifolia*) date of first flowering on all sites over the period 1997-2015.

Vascular plants, first flowering - comparison between 2013, 2014 and 2015



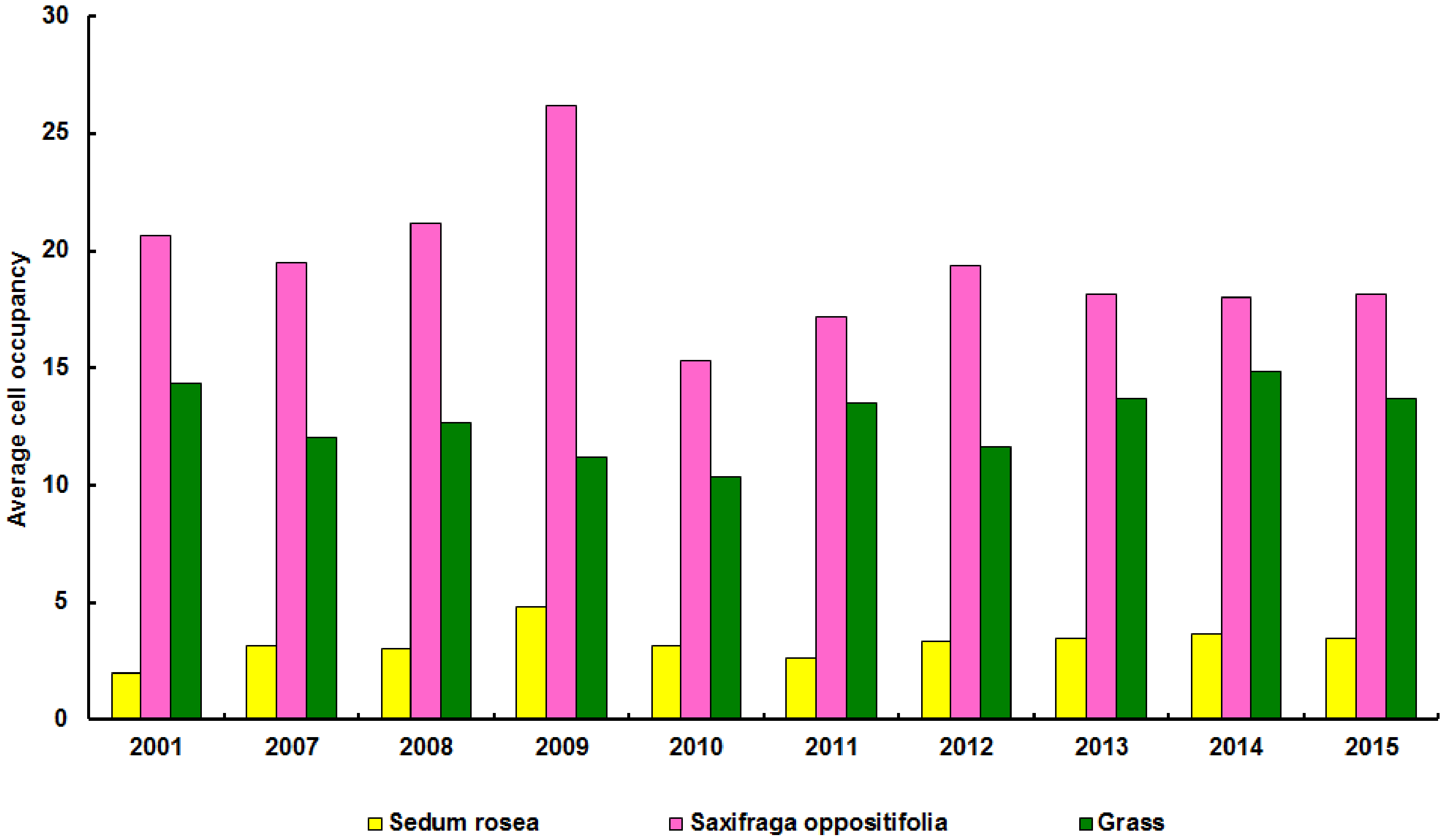
Phenology - Year-to-year changes

Phenological changes (e.g. first flowering) are very sensitive to changes in climate, and large changes are seen from year-to-year. Over 80 species are monitored for flowering status, 65 are used in Figure 56. A 6th degree polynomial fitted to the data for each year shows the differing patterns.

In 2013, a cold spring led to retarded flowering, and despite warmer weather later, the delay persisted until mid-summer. In 2014, spring and summer were closer to average temperatures, while in 2015, despite a cold spring, the delay in flowering was less pronounced

Figure 63: Differences in date of first flowering for 66 species for the years 2013, 2014 and 2015. The flowering date is shown relative to the average flowering date from 2007-2012, negative values are for earlier flowering, positive for later.

Arctic-alpine plants – plant cover



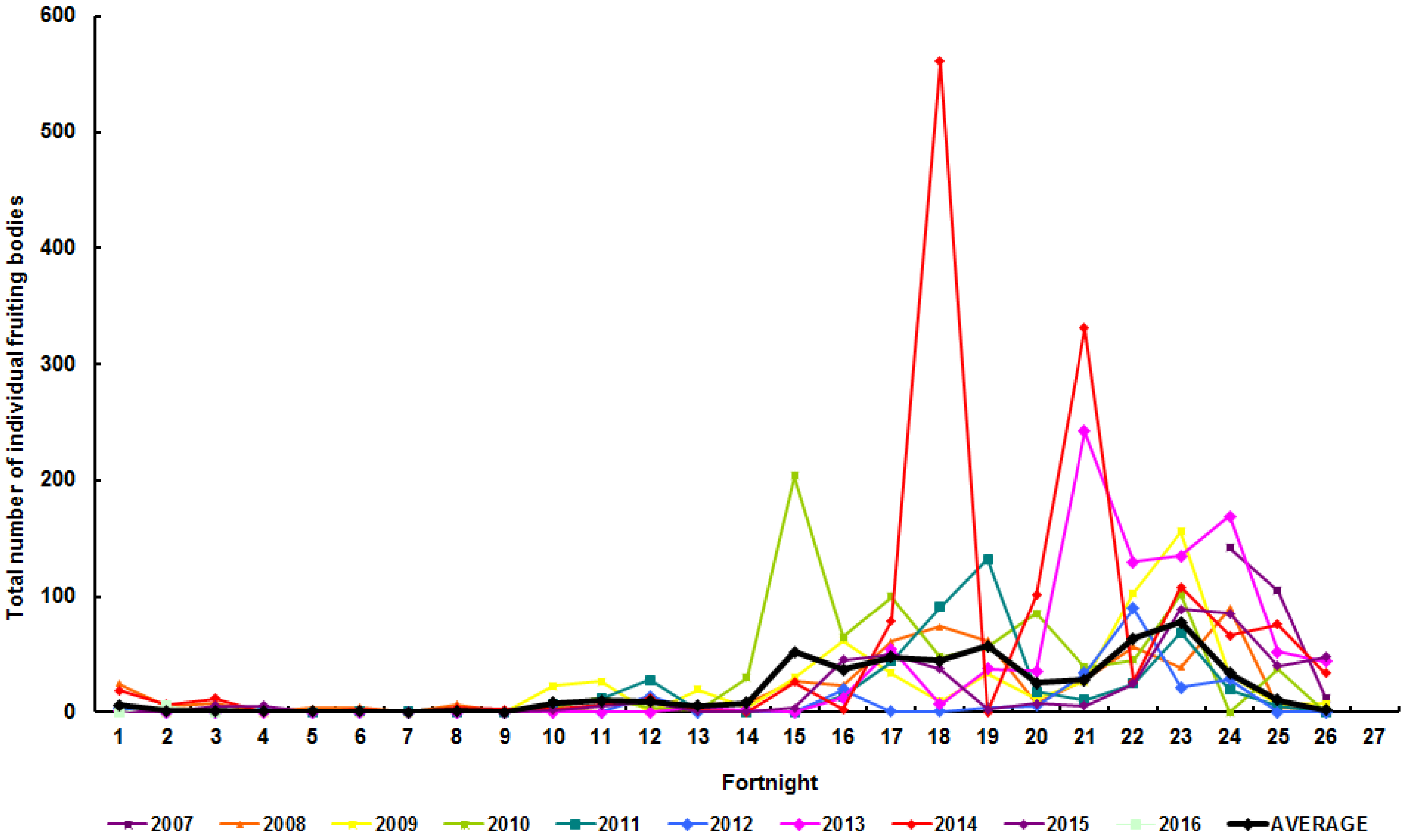
Arctic-alpines:

Arctic-alpine plant species, found on cliffs on the ECN site are relict species surviving since the last Ice Age. Monitoring is a non-ECN protocol which has been carried out since 2001. Every three years, all the plots are re-recorded while a subset of 6 plots on Diffwys are recorded annually.

There are no clear trends among the species recorded as part of the full survey. Amongst the species recorded during the annual survey, only that for *Sedum rosea* (Roseroot) shows a significant increasing

Figure 64: Changes in cell occupancy of sampling quadrats observed for the arctic-alpines Roseroot (*Sedum rosea*) and Purple saxifrage (*Saxifraga oppositifolia*) recorded in quadrats on Diffwys (n=6) from 2001-2015.

Fungi – number of fruiting bodies



Fungi:

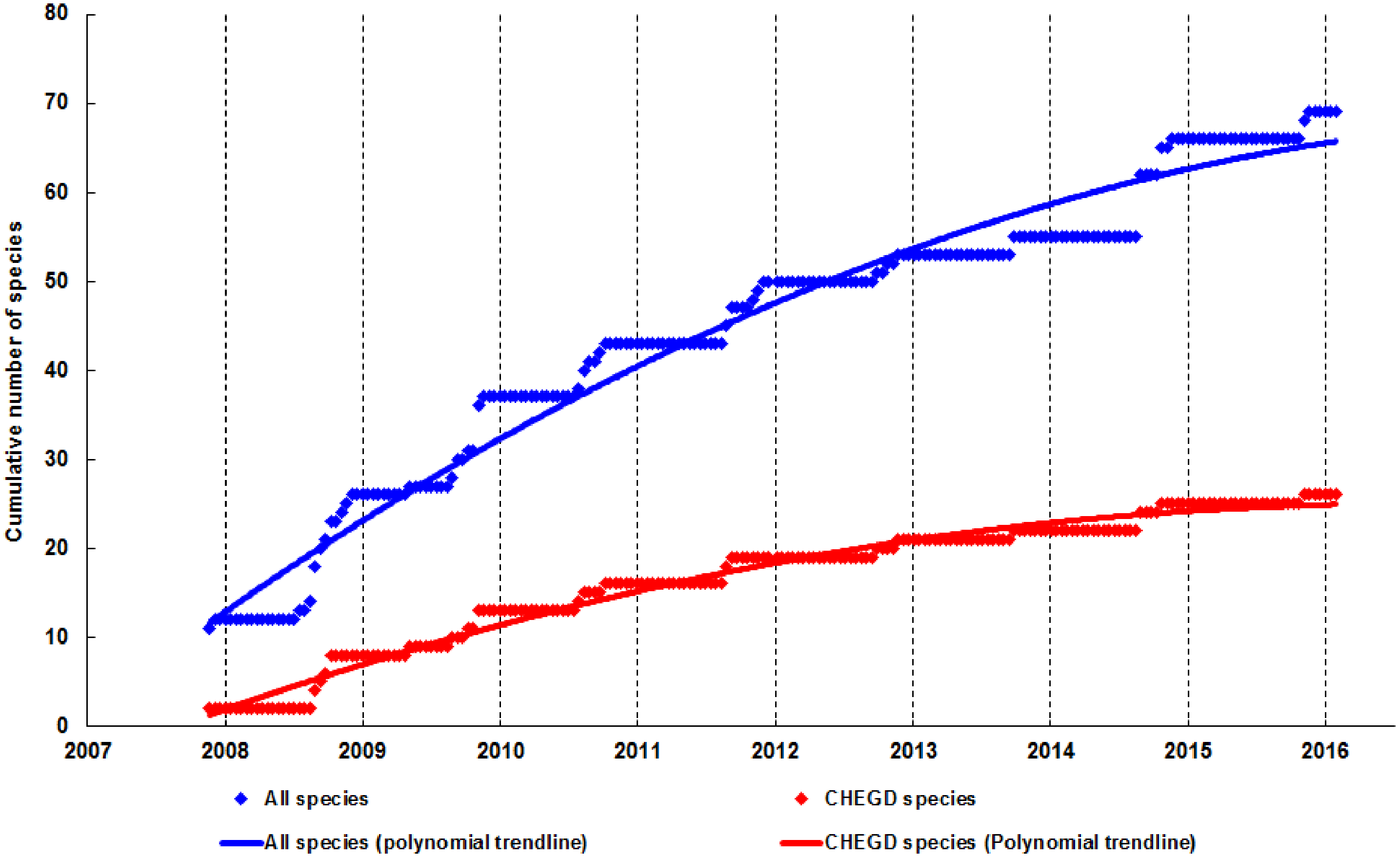
Fungi monitoring is a non-ECN protocol and recording is carried out fortnightly throughout the year, with identification of difficult species carried out by a local mycological expert.

Fruiting varies quite considerably from year-to-year, both in intensity and timing. 2013 was the most productive year since recording started, following after the least productive year in 2012. There is no significant trend in cumulative numbers.

The intensity of continuous recording on the ECN site is unique in the UK. The count data provides an insight into the triggers for fruiting in the mycoflora

Figure 65: Number of individual fungal fruiting bodies recorded at fortnightly intervals within the ECN fungus sampling area over the period 2007 - 2015.

Fungi – cumulative species numbers



Fungi:

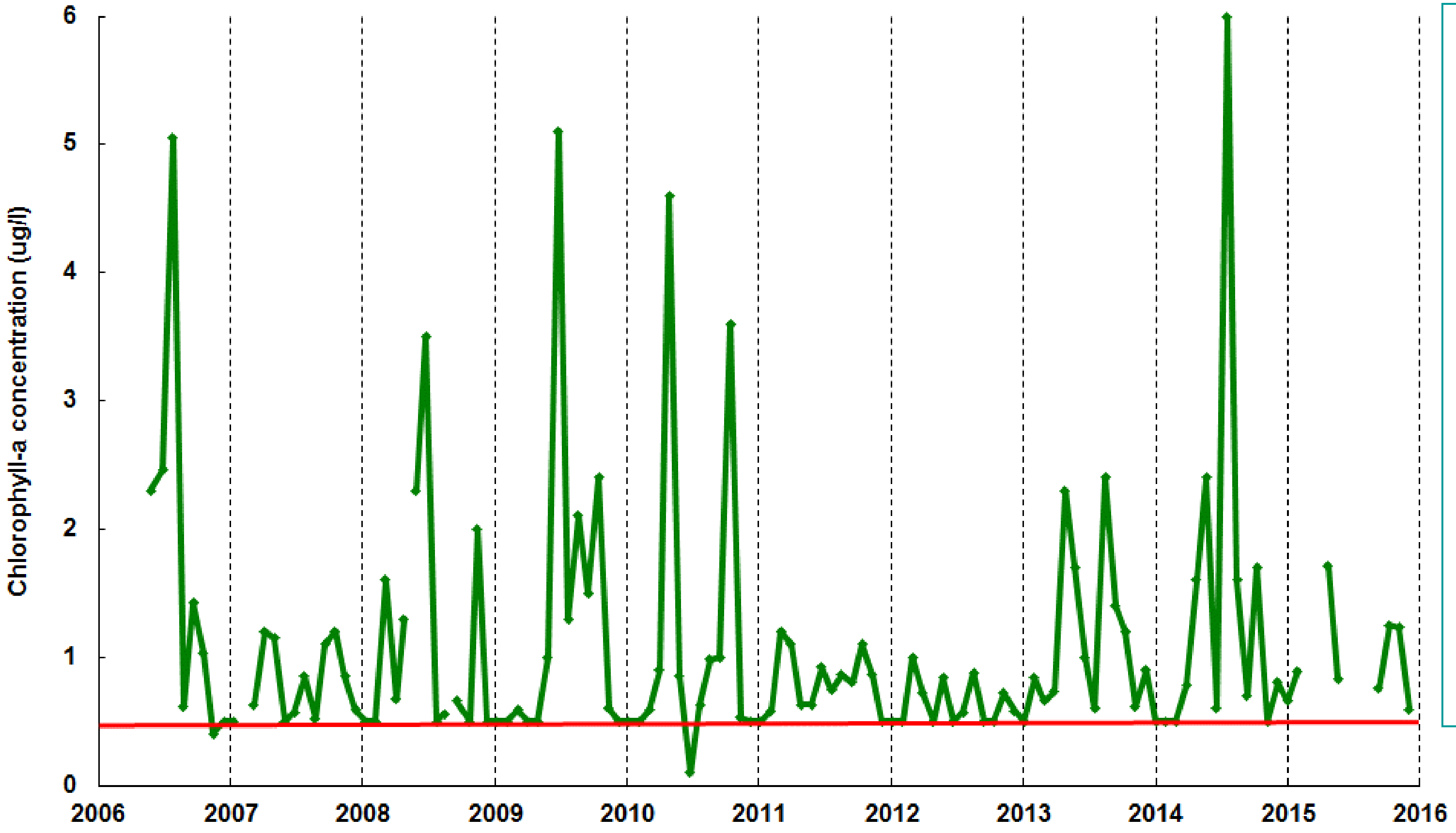
The number of species recorded has continued to increase each year since recording began in late 2007, and the rate of increase showslittle sign of slowing.

CHEGD species, comprise the **C**lavariaceae, ***H***_ygrocybe_ species, ***E***_ntoloma species_, **G**eoglossaceae and ***D***_ermoloma_ species which are indicators of unimproved acid grassland (Griffiths *et al.* 2006).

30 soil cores were taken by Gareth Griffiths, University of Aberystwyth, in 2014 with a view to using the species counts to help with barcoding the mycoflora present on the site.

Figure 66: Cumulative numbers of species and CHEGD species recorded at fortnightly intervals within the ECN fungus sampling plot over the period 2007 - 2015.

Phytoplankton – Chlorophyll-a



Chlorophyll-a:

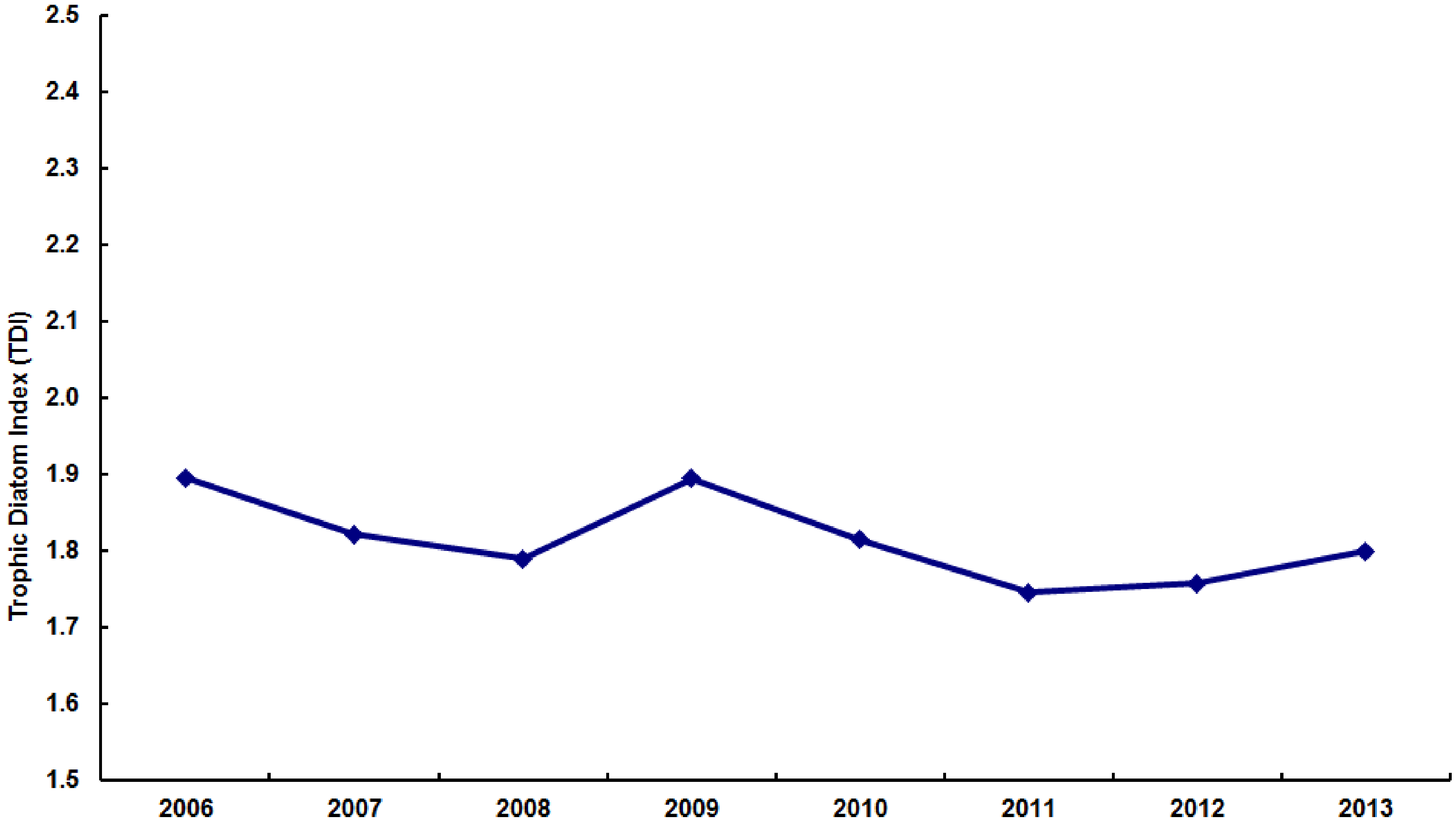
Nant Teyrn is the outlet stream for Llyn Teyrn which means the chlorophyll-*a* results mainly reflect changes in chlorophyll-a in Llyn Teyrn.

Low Chlorophyll-a values are evident all through 2007, 2011 and 2012, with the latter year being particularly low. 2011 and 2012 were also years with poor summers and persistent cloudy conditions. By contrast, the warmer and sunnier summer of 2013 is reflected in higher values. There is no significant trend.

Gaps in the record for 2015 are the result of laboratory changeover.

Figure 67: Chlorophyll-*a* concentration from Nant Teyrn, 2006 - 2015, horizontal line shows the detectable limit at 0.50 µg.l^{-1}.

Epilithic Diatoms - Trophic Diatom Index



Epilithic diatoms:

The Trophic Diatom Index (TDI) was developed to assess the level of eutrophication in running water using benthic diatoms (Kelly *et al.* 2001, 2007).

There is no significant trend over the recording period (8 years), and the average TDI of for Nant Teyrn is 1.81, typical of a low-nutrient watercourse.

Samples from 2014 and 2015 are awaiting identification.

Figure 68: Trophic Diatom Index averaged from 3 locations in Nant Teyrn, 2006 – 2013.

Aquatic Macrophytes - frequency

Species	Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Marsupella emarginata		IV	IV	IV	IV	IV	V	IV	II	V	IV
Nardia compressa		V	IV	IV	V	V	V	V	V	V	IV
Unidentified Green algae		V	V	IV	V	IV	IV	IV	IV	IV	IV
Pellia epiphylla		IV	IV	IV	III	III	IV	IV	V	IV	V
Lobelia dortmanna		II	II	II	II	I	I	I	I	I	
Racomitrium aciculare		III	III	III	II	III	III	III	II	IV	IV
Carex rostrata		II	II	I	II	I	II	I	II	I	II
Potamogeton polygonifolius		II	I	II	II	II	II	II	III	III	III
Batrachospermom turfosum			IV	V	V	IV	V	V	IV	IV	IV
Sphagnum compactum		V									
Sphagnum tenellum		II									
Molinia caerulea		V	III	I	I	I	I	IV	I	V	IV
Narthecium ossifragum		IV	II	III	II	III	IV	IV	IV	IV	V
Juncus bulbosus		IV	II	III	II	II	II	I	III	III	II
Viola palustris		IV	II	II	III	IV	V	V	V	V	V
Sphagnum denticulatum			III	III	II	IV	IV	IV	V	III	IV
Cladopodiella fluitans			IV	III	I	III	II	III	II	III	II
Ephebe lanata			I	III	IV	IV	IV	IV	IV	IV	IV
Sphagnum palustre			II	II	IV	II	III	II	II	II	II
Unidentified Brown algae				II	IV	V	V	V	V	V	V
Scapania undulata			II		II		I	II			I
Juncus acutiflorus			I	I	I	I	I	I	I	I	I
Cephalozia bicuspidata			I								
Calypogeia fissa			I								
Sphagnum inundatum			I	I				I	I	II	I
Carex nigra			I	I				I			
Campylopus atrovirens					I						I
Juncus effusus					I						
Cephaloziella sp.					I		I				
Bryum alpinum						I		I			
Bryum pseudotriquetrum										I	
Blindia acuta							I				
Calypogeia sp.							I				
Unidentified Red Algae							I				
Hyocomium armoricum							I	I	I	II	I
Andreaea rothii falcata							I	I			I
Unidentified Yellow Algae								II	I	II	I
Carex echinata								I			
Andreaea rupestris								I	III	II	
Carex demissa							I	I	II		I
Carex panicea							I	I	II	II	II
Agrostis canina									I	I	II
Eriophorum angustifolium									I		
Trichophorum cespitosum									I	I	I
Globular green alga										IV	I
Bare rock		V	V	V	V	V	V	V	V	V	V

Macrophytes:

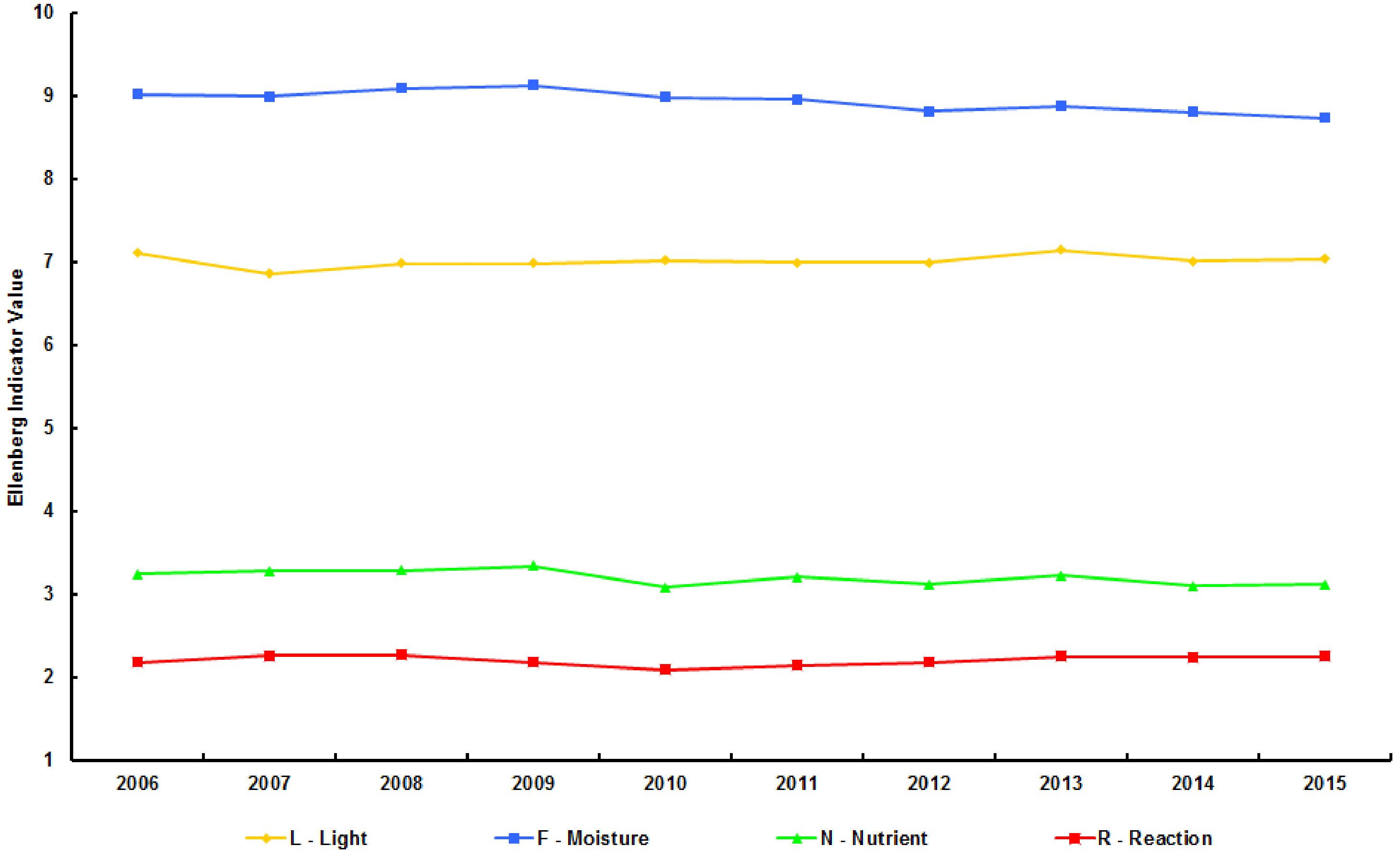
The bulk of the species observed are typical of upland streams flowing through peat or over mildly acidic igneous rocks. The upper and lower sections of the sampled length are different in character, the upper being a deep slower-flowing channel cut through deep peat, while the lower is faster flowing, with very thin peaty soils and abundant large boulders.

Little change is visible over such a short span of time. There has been a slow reduction in frequency and eventual disappearance of *Lobelia dortmanna* (Water Lobelia) and an increase in *Potamogeton polygonifolus* (Bog Pondweed) in the higher peaty section of the stream.

The difference between 2006 and later years is due to different recorders. A number of species in 2006 e.g. *Sphagnum compactum* and *S. tenellum* are probably misidentifications.

Table 11: Results from macrophyte surveys in Nant Teyrn 2006-2015. Abbreviations: I 1-20% frequency, II 21-40%, III 41-60%, IV 61-80%, V 81-100%.

Aquatic Macrophytes – Ellenberg Indicator Values



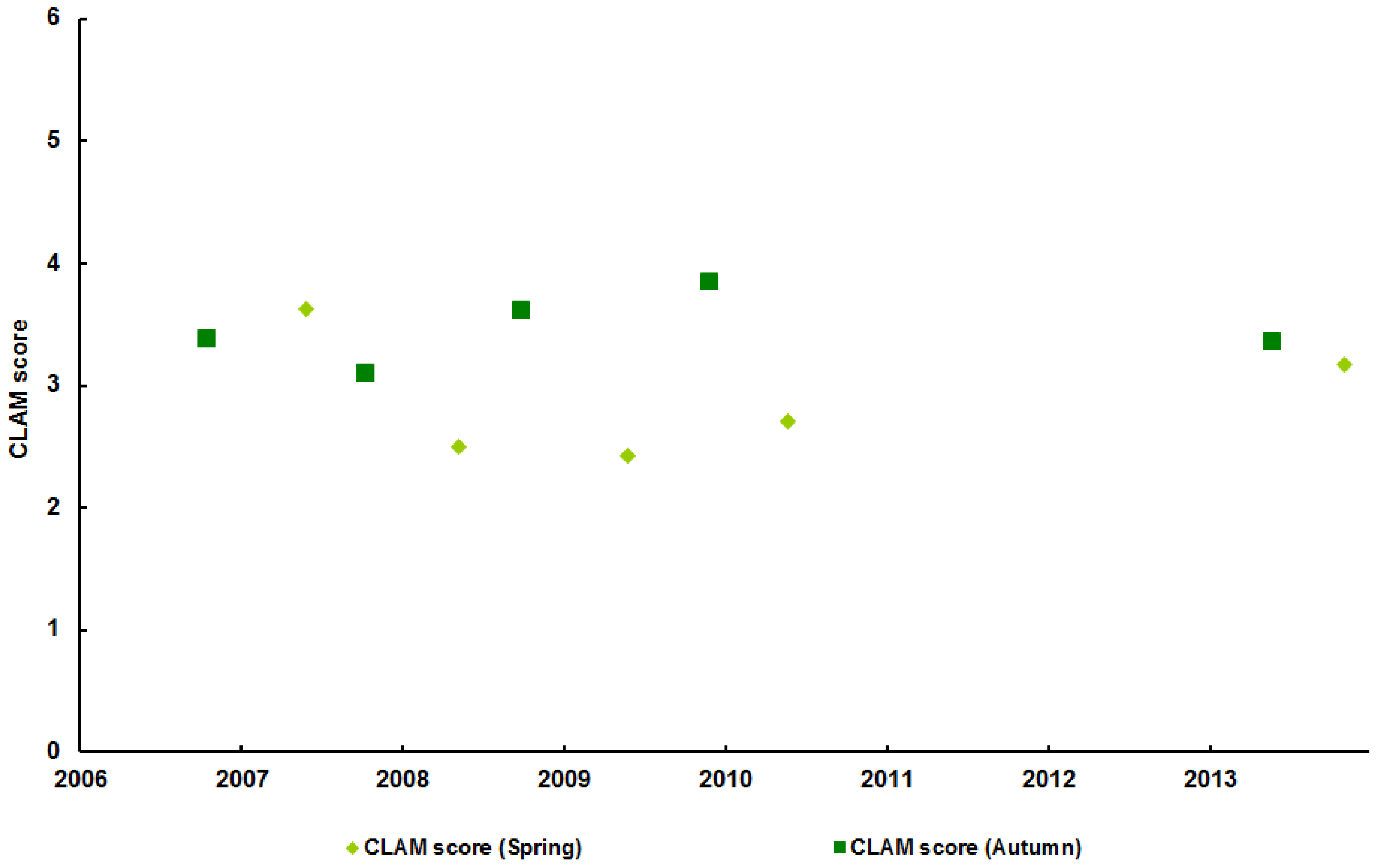
Macrophytes - Ellenberg Indicator Values:

Hill's modified Ellenberg indicator values can be calculated from the frequency data. Those for nutrient (EbN), reaction or acidity (EbR) and light (EbL) show no change over the short period of recording. Ellenberg's moisture indicator, EbF, however, shows a significant decline over the period of recording, the explanation for which is difficult to provide as annual and seasonal rainfall has not changed appreciably.

The low level of the R indicator shows how acidic the stream vegetation in Nant Teyrn is, R=2 being ascribed to species occurring typically in conditions between acid and extremely acid (Hill et. al. 1999).

Figure 69: Weighted average Hill's Ellenberg Indicator Values for N - Nutrient and R - Reaction for Nant Teyrn, 2006 – 2015.

Aquatic macroinvertebrates



Macroinvertebrates

The data for macroinvertebrates is incomplete as some samples are archived but not identified yet. Also not every year had two samples taken.

The data is summarised using the Clear Lake Acidification Metric (McFarland, 2008) separated for the two seasons. The provisional average value for Llyn Teyrn is 3.17, which puts it below the Moderate Poor & Below Boundary.

Figure 70: Clear Lake Acidification Metric score for Llyn Teyrn calculated from macroinvertebrate abundances.

3.4 Summary of trends for land use and cultural services

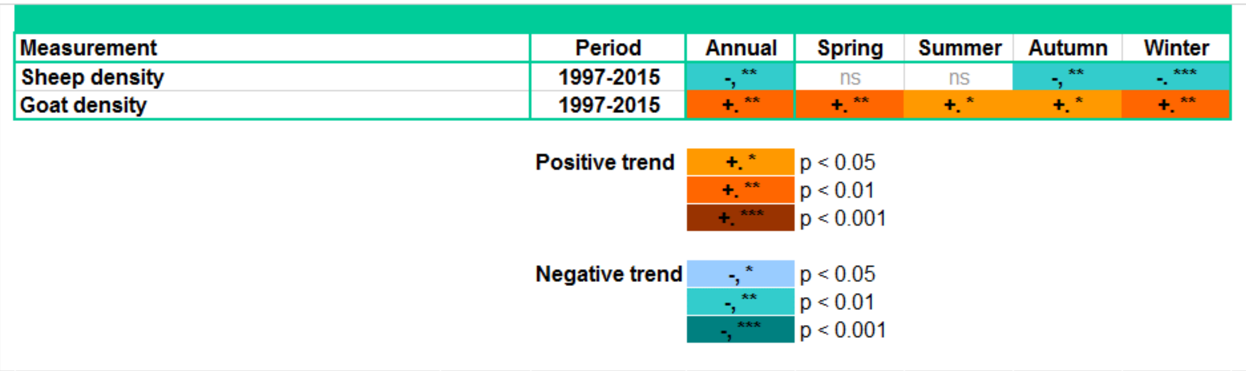
The primary land-uses within the site may be divided into agricultural, recreational and power generating.

The main agricultural use of the site is for sheep grazing, and the area of the ECN site within Cwm Dyli forms part of Gwastadannas farm, which is owned by the Bulkeley family of Baron Hill Estates and which is run by a tenant farmer. There are approximately 1000 breeding ewes which are on the mountain between April and November, reaching a maximum in August and September. In addition to the sheep, a small number of Welsh Black cattle were pastured on the lower part of the site during the summers of 2009-2012. Three other landowners have small areas of the ECN site in Cwm Glas and in Cwm Llan, which are also run as part of larger sheep farms.

Monitoring of sheep numbers has been taking place on the site since the late 1950s, and was started as part of investigations into the impact of sheep grazing on upland vegetation (e.g. Dale & Hughes 1978) across the mountains of Eryri. Recording was undertaken using a number of irregular marked out areas easily visible from a distance, and four of these areas are utilised for the weekly counts undertaken on the site for ECN.

Recording for ECN started in 1997 and since that time there has been approximately a 50% reduction in numbers. The reduction occurred early in the recording period and numbers stabilised around 2002-03. The reduction in numbers is most significant in autumn and winter ($p < 0.01$ and $p < 0.001$ resp.). Sheep are significant modifiers of vegetation structure and composition, and the distribution of some of the more uncommon vegetation types across the site is a reflection of the ease of access by sheep, or lack of it. A study by McGovern et al (2014) on the site highlighted the differences, not only in vegetation but also in soil solution chemistry between the long-term grazing exclosures and the surrounding grazed land.

Table 12: Summary of trends for land use variables – sheep and goat numbers



Measurement	Period	Annual	Spring	Summer	Autumn	Winter
Sheep density	1997-2015	-, **	ns	ns	-, **	-. ***
Goat density	1997-2015	+. **	+. **	+. *	+. *	+. **

Positive trend	+. *	p < 0.05
	+. **	p < 0.01
	+. ***	p < 0.001
Negative trend	-, *	p < 0.05
	-, **	p < 0.01
	-, ***	p < 0.001

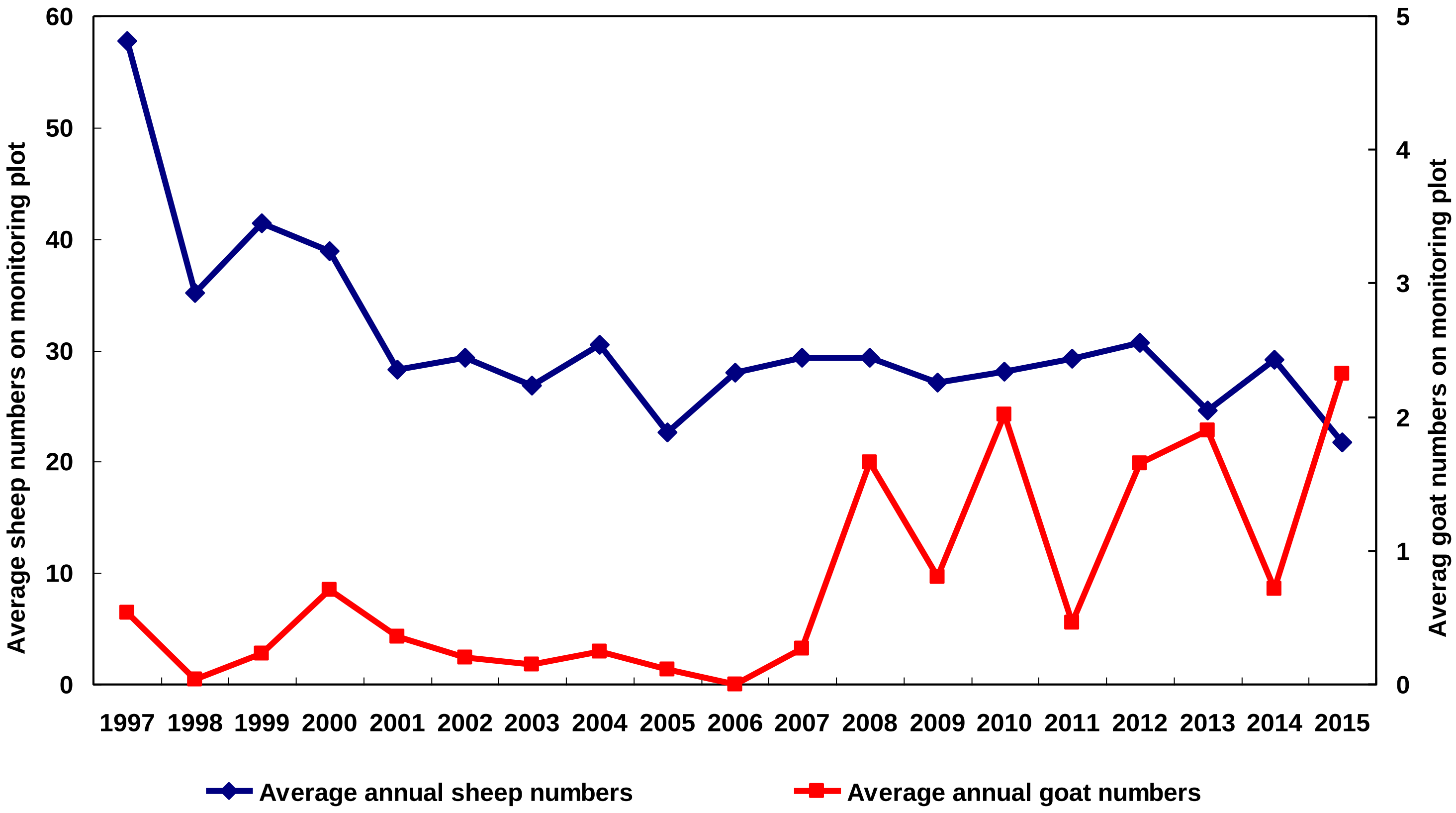
Feral goats are included under land-use, although there are no controls on numbers on the ECN site itself. These goats originate from the descendants of domestic goats, which formed a significant part of the local farming economy before the time of the enclosures in the early 19th century and the rise of sheep farming. Although still at a relatively low level in comparison with sheep, goat numbers have increased significantly ($p < 0.01$) on an annual scale (Figure 71) although with year-to-year variation. Anecdotal reports from the 1960s and 1970s (Don Perkins, pers. comm.) indicate that goats were not present on the site at that time. Numbers have risen significantly in all seasons particularly in winter and spring and breeding success may be linked to recent less severe winters. Goats are browsers and spend a large proportion of their time on steep ground, and there is some concern about their impact on some of the rarer Annex 1 habitats which occupy some of the cliffs on Snowdon.

Snowdon, being the highest mountain in England and Wales, attracts a disproportionate number of visitors for a variety of recreational activities, but is primarily a destination for walkers. Approximately 500,000 people reach the summit of Snowdon annually of whom around 30% arrive by train from Llanberis (Snowdonia National Park and Snowdon Mountain Railway figures). As part of a study into the ecosystem services provided by the Snowdon ECN site (Dick et al. 2010), it became apparent that this aspect of the mountain ecosystem had been neglected by the traditional suite of ECN measurements which focussed on physical, chemical and biological drivers and response variables. In order to collect some data on recreational and other users of the site, a simple relatively time-efficient methodology was developed to capture some of this information and was started in spring 2014. Two timed counts are made during weekly visits to the site and all activities are recorded during these periods. In addition any other significant activities observed while on the site outside of the timed count period are also noted. The activities recorded range from walkers, climbers, cyclists, runners, campers, photographers, etc., to educational users (size and type or party noted) to use by the military, mountain rescue, film crews, helicopter training etc. to use by National Power, Snowdonia National Park, NRW and the farmer. For walkers, an assessment of degree of preparedness for the mountain environment is also noted. Some of the preliminary results can be seen in Figure 73. There is clearly a great diversity of activities taking place with some only just starting e.g. drone operators. There is no clear pattern yet apart from a minimum in winter, and it will be interesting to see how different activities are affected by changes in the weather on the site. In terms of educational use, Snowdon is used frequently and a seasonal pattern is clear in Figure 74 with a maximum use in spring and minimum in winter. Apart from school groups, there are parties of adults throughout the year undertaking various forms of mountain training e.g. Mountain Leader Certificate, Hill Skills etc. under the supervision of local mountain centres and providers.

Dick et al (2016, in press) provide an analysis of change in the delivery of ecosystem services comparison over a 20 year period across the ECN. For Snowdon the main changes have been an increase in the number of walkers and sport-based activities and a decrease in the wilderness element.

Finally, power generation is by hydropower which uses Llyn Llydaw as a head reservoir with a large pipe crossing lower Cwm Dyli and dropping down to a generating station in Nant Gwynant. It is the oldest large scale hydroelectric scheme running in the UK. No recent figures for power generated are available, but in the 2000s, the annual amount was of the order of 10^4 MWh (J. Baxendale, National Power, pers. comm.)

Land use and site management – sheep and goat numbers



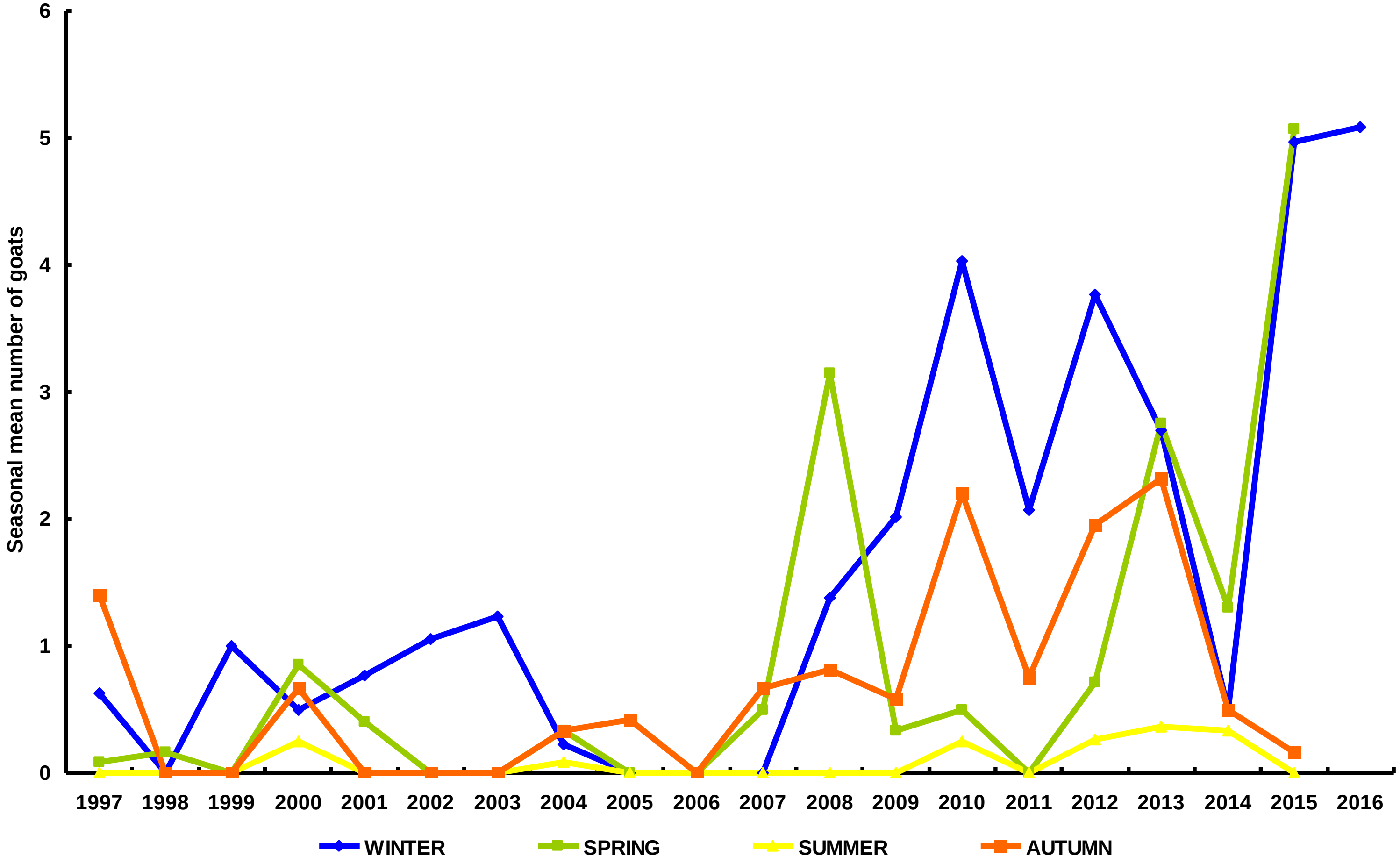
Sheep and goat numbers:

Sheep grazing intensity fell sharply in the late-1990s and has continued at around 50% with the numbers in 2015 being the lowest recorded since yet. Numbers have fallen most significantly in the autumn and winter seasons.

The increasing trend in average annual goat numbers is significant ($p < 0.01$). There is much year-to-year variation in the numbers counted on the sampling site reflecting the localized grazing preferences of different groups of goats.

Figure 71: Average annual sheep and goat numbers on the ECN sheep monitoring plot. Note the left- and right-hand scales are different

Land use and site management (LU) – seasonal goat numbers



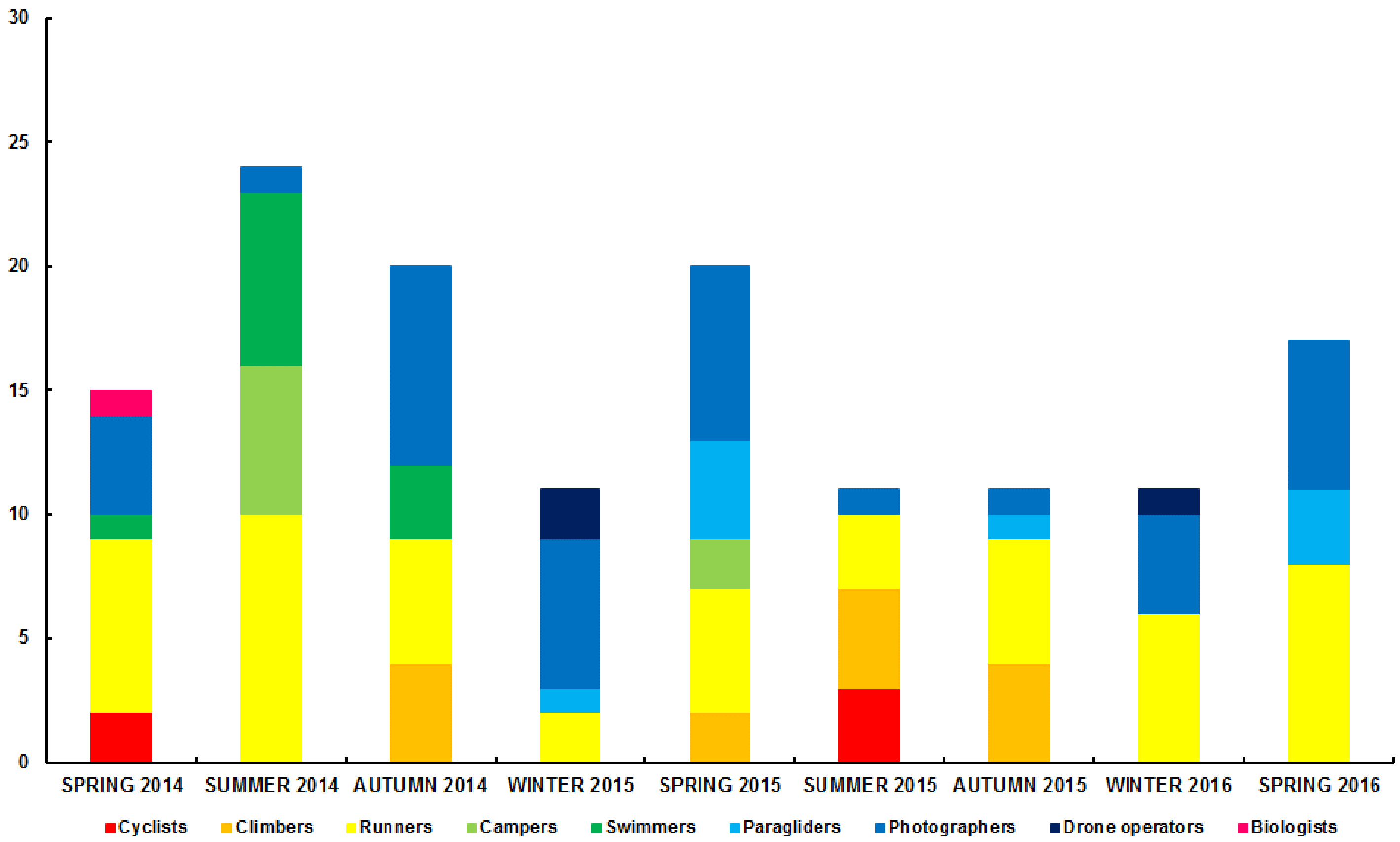
Goats:

Goat numbers have risen over the lifetime of the ECN project on Snowdon, but particularly since 2006. The increase is significant in all seasons, but the summer levels are the lowest which may be due to hefts of goats using higher level grazing beyond the area used for sampling.

There is anecdotal evidence (Don Perkins pers comm.) that the rise in numbers is relatively recent, with goats not having been seen during the IBP project on the site from 1966-77.

Figure 72: Seasonal goat numbers on monitoring plot area, 1997-2014.

Cultural Services – sport/leisure activities



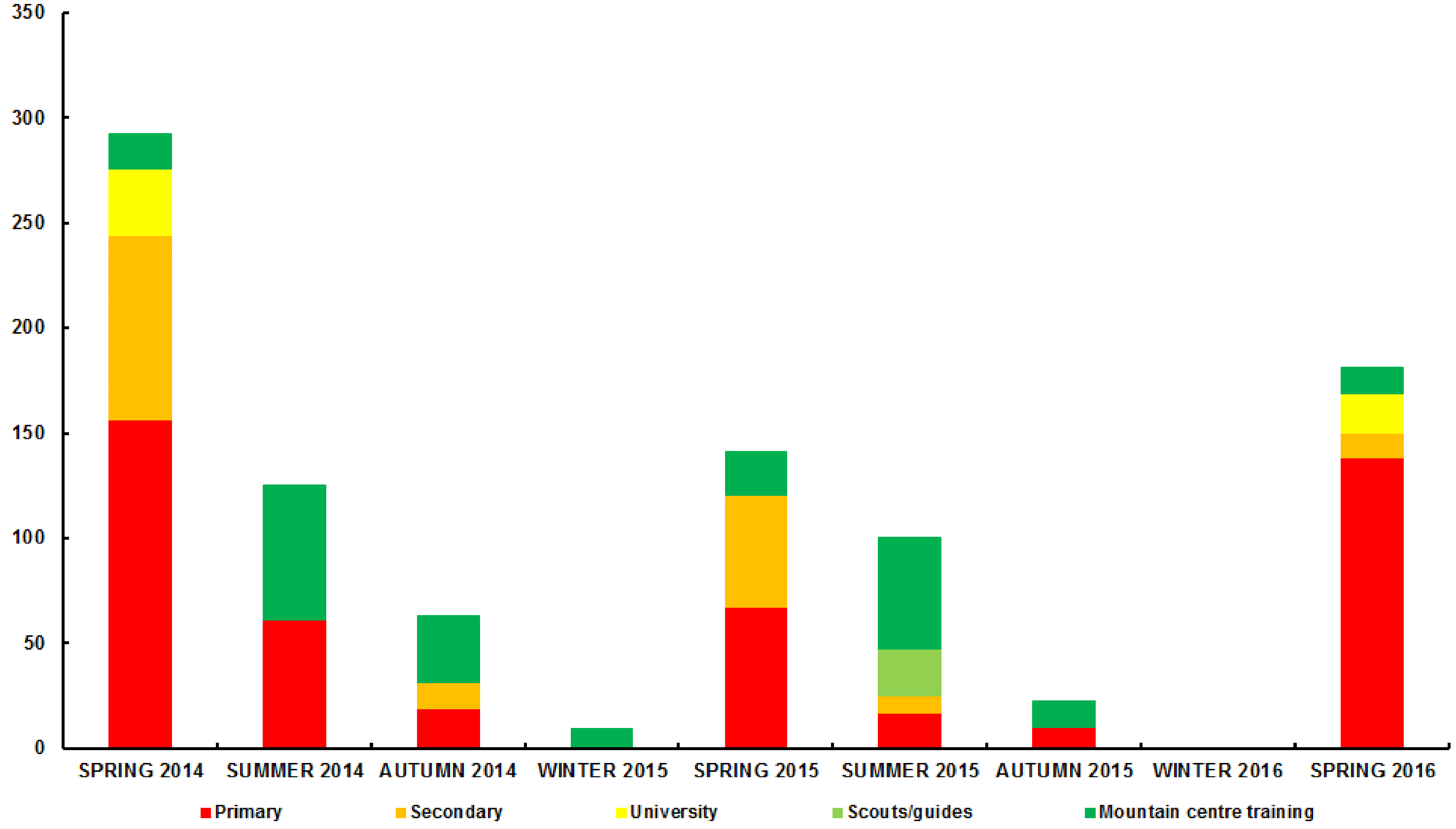
Sport/Leisure activities

Cultural services have not traditionally been considered by ECN protocols. A simple recording scheme was instituted in early 2014 on Snowdon, and activity counts are made weekly for all activities including sport/leisure, educational, agriculture, hydroelectric, military, entertainment (e.g. film-making) and statutory.

Figure 73 shows sport/leisure activities excluding hillwalkers, and it is clear there is a great diversity. There is no clear seasonal pattern yet with such a short run of data except for a minimum in winter. Activities such as drone operation new on the site and will probably become more common in the future.

Figure 73: Outdoor activities (excluding hill walkers) – number of participants summed over all sampling days (n=13) per season over the period Spring 2014-Spring 2016.

Cultural Services – educational use



Educational use

Snowdon is extensively used by educational providers from primary schools through to university parties on field trips. There is also occasional use by groups such as the Scouts.

There is a clear pattern emerging even with only a short data run. The optimum period for primary school groups appears to be spring and summer. Secondary school groups only appear in numbers in spring, perhaps due to exam commitments in summer.

Mountain centre groups form a significant proportion of educational visits and appear almost all year round reflecting the need for training in all weather conditions.

Figure 74: Educational activities - number of participants (including staff) summed over all sampling days (n=13) per season over the period Spring 2014-Spring 2016.

Figure 75: The two major ‘land users’ of the upland environment on Snowdon – sheep and people.

4. Abbreviations

ANC	Acid Neutralizing Capacity
AOI	Arctic Oscillation Index
AOT40	Accumulated dose over threshold concentration of 40ppb
AWS	Automatic Weather Station
CCU	Central Coordinating Unit
CCW	Countryside Council for Wales
CEH	Centre for Ecology ad Hydrology
DOC	Dissolved Organic Carbon
ECN	Environmental Change Network
IBP	International Biological Programme
NAOI	North Atlantic Oscillation Index
NRW	Natural Resources Wales
NVC	National Vegetation Classification
RoTAP	Review of Transboundary Air Pollution
TDI	Trophic Diatom Index
UKEAP	UK Eutrophying and Acidifying atmospheric Pollution network
WG	Welsh Government
xSO_4	Non-marine sulphate

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Appendix 1 Trend statistics

The significance of the trends shown in this report have been tested using the non-parametric Mann-Kendall Trend Test in the package Kendall of the open-source statistical software R (R Development Core Team 2014).

Table 13 Physical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed signific.
MA	Average temperature	1996-2015	7.14		0.099	19	n.s.
MA	Average Spring temperature	1996-2015	5.87		-0.076	19	n.s.
MA	Average Summer temperature	1995-2015	11.86		-0.158	20	n.s.
MA	Average Autumn temperature	1995-2015	8.04		0.211	20	n.s.
MA	Average Winter temperature	1996-2016	2.79		0.076	21	n.s.
MA	Average January Temp	1996-2016	2.63		0.048	21	n.s.
MA	Average February Temp	1996-2016	2.54		-0.200	21	n.s.
MA	Average March Temp	1996-2015	3.67		-0.085	18	n.s.
MA	Average April Temp	1996-2015	5.54		0.099	19	n.s.
MA	Average May Temp	1995-2015	8.16		-0.137	20	n.s.
MA	Average June Temp	1995-2015	10.69		0.200	21	n.s.
MA	Average July Temp	1995-2015	12.39		-0.105	21	n.s.
MA	Average August Temp	1995-2015	12.45	-VE	-0.358	20	*
MA	Average September Temp	1995-2015	10.87		0.076	21	n.s.
MA	Average October Temp	1995-2015	8.24		0.021	20	n.s.
MA	Average November Temp	1995-2015	5.37		0.032	20	n.s.
MA	Average December Temp	1995-2015	3.20		0.219	21	n.s.
MA	Maximum temperature	1996-2015	22.70		0.126	20	n.s.
MA	Minimum temperature	1996-2015	-5.30		-0.041	19	n.s.
MA	Average soil temperature (10cm)	1996-2015	8.01		0.085	18	n.s.
MA	Maximum soil temperature (10cm)	1996-2015	19.16		-0.064	19	n.s.
MA	Minimum soil temperature (10cm)	1996-2015	0.72		0.085	18	n.s.
MA	Average Spring soil temperature (10cm)	1996-2015	6.45		-0.099	19	n.s.
MA	Average Summer soil temperature (10cm)	1995-2015	12.67		-0.228	19	n.s.
MA	Average Autumn soil temperature (10cm)	1995-2015	9.21		0.076	19	n.s.
MA	Average Winter soil temperature (10cm)	1995-2016	3.62		0.126	20	n.s.
MA	Average soil temperature (10cm) January	1996-2016	3.45		0.132	20	n.s.
MA	Average soil temperature (10cm) February	1996-2016	3.13		-0.124	21	n.s.
MA	Average soil temperature (10cm) March	1996-2015	4.23		-0.0643	19	n.s.
MA	Average soil temperature (10cm) April	1996-2015	6.22		0.0877	19	n.s.
MA	Average soil temperature (10cm) May	1996-2015	8.89		-0.158	20	n.s.
MA	Average soil temperature (10cm) June	1995-2015	11.51		0.004777	21	n.s.
MA	Average soil temperature (10cm) July	1995-2015	13.22		-0.0811	21	n.s.
MA	Average soil temperature (10cm) August	1995-2015	13.37	-VE	-0.564	19	***
MA	Average soil temperature (10cm) September	1995-2015	11.77		-0.222	20	n.s.
MA	Average soil temperature (10cm) October	1995-2015	9.35		0.0414	19	n.s.
MA	Average soil temperature (10cm) November	1995-2015	6.52		0.17	19	n.s.
MA	Average soil temperature (10cm) December	1995-2015	4.36		0.222	20	n.s.
MA	Average soil temperature (30cm)	1996-2015	8.19		0.203	18	n.s.
MA	Average Spring soil temperature (30cm)	1996-2015	6.36		-0.123	19	n.s.
MA	Average Summer soil temperature (30cm)	1995-2015	12.17		-0.193	19	n.s.
MA	Average Autumn soil temperature (30cm)	1995-2015	9.76		0.076	19	n.s.
MA	Average Winter soil temperature (30cm)	1995-2016	4.39		0.063	20	n.s.
MA	Average soil temperature (30cm) January	1996-2016	4.20		0.174	20	n.s.
MA	Average soil temperature (30cm) February	1996-2016	3.76		-0.186	21	n.s.
MA	Average soil temperature (30cm) March	1996-2015	4.42		-0.124	19	n.s.
MA	Average soil temperature (30cm) April	1996-2015	6.12		0.0526	19	n.s.

Table 13 (continued): Physical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
MA	Average soil temperature (30cm) May	1996-2015	8.52		-0.116	20	n.s.
MA	Average soil temperature (30cm) June	1995-2015	10.89		0.0334	21	n.s.
MA	Average soil temperature (30cm) July	1995-2015	12.53		0.019	21	n.s.
MA	Average soil temperature (30cm) August	1995-2015	13.16	-VE	-0.457	19	**
MA	Average soil temperature (30cm) September	1995-2015	11.99		-0.248	20	n.s.
MA	Average soil temperature (30cm) October	1995-2015	9.98		0.0469	19	n.s.
MA	Average soil temperature (30cm) November	1995-2015	7.34		0.135	19	n.s.
MA	Average soil temperature (30cm) December	1995-2015	5.25		0.0897	20	n.s.
MA	Maximum soil temperature (30cm)	1996-2015	14.38		-0.129	19	n.s.
MA	Minimum soil temperature (30cm)	1996-2015	0.72		0.085	18	n.s.
MA	High Temperature days	1996-2015	6.55		0.059	20	n.s.
MA	High Temperature days, Spring	1996-2015	0.74		-0.126	19	n.s.
MA	High Temperature days, Summer	1996-2015	5.65		-0.153	20	n.s.
MA	High Temperature days, Autumn	1996-2015	1.25		0.161	20	n.s.
MA	High Temperature days, April	1996-2015	0.11		0.000	19	n.s.
MA	High Temperature days, May	1995-2015	0.63		-0.108	19	n.s.
MA	High Temperature days, June	1995-2015	1.00		-0.090	20	n.s.
MA	High Temperature days, July	1995-2015	3.05		-0.087	20	n.s.
MA	High Temperature days, August	1995-2015	2.11	-VE	-0.464	18	**
MA	High Temperature days, September	1995-2015	0.52		0.000	21	n.s.
MA	High Temperature days, October	1995-2015	0.05		0.180	19	n.s.
MA	High Temperature days, November	1995-2015	0.65		0.216	20	n.s.
MA	Frost days	1995/96-2014/15	41.50		0.048	20	n.s.
MA	Frost days, Autumn	1995-2015	2.10		0.191	20	n.s.
MA	Frost days, Winter	1996-2016	28.81		-0.014	21	n.s.
MA	Frost days, Spring	1996-2015	10.74		0.047	19	n.s.
MA	Frost days, September	1995-2015	0.00		0.000	21	n.s.
MA	Frost days, October	1995-2015	0.32		0.229	19	n.s.
MA	Frost days, November	1995-2015	1.80		0.066	20	n.s.
MA	Frost days, December	1995-2015	8.57	-VE	-0.383	21	**
MA	Frost days, January	1996-2016	10.29		-0.025	21	n.s.
MA	Frost days, February	1996-2016	9.95		0.217	21	n.s.
MA	Frost days, March	1996-2015	7.89		0.158	18	n.s.
MA	Frost days, April	1996-2015	2.84		-0.201	19	n.s.
MA	Frost days, May	1995-2015	0.42		-0.142	19	n.s.
MA	Frost sum	1995/96-2014/15	-75.92		-0.032	20	n.s.
MA	Frost sum, Autumn	1995-2015	-2.84		-0.229	20	n.s.
MA	Frost sum, Winter	1996-2016	-56.47		0.038	21	n.s.
MA	Frost sum, Spring	1996-2015	-15.28		0.024	19	n.s.
MA	Frost sum, September	1995-2015	0.00		0.000	21	n.s.
MA	Frost sum, October	1995-2015	-0.36		-0.226	19	n.s.
MA	Frost sum, November	1995-2015	-2.51		-0.094	20	n.s.
MA	Frost sum, December	1995-2015	-17.97		0.253	21	n.s.
MA	Frost sum, January	1996-2016	-22.05		0.057	21	n.s.
MA	Frost sum, February	1996-2016	-16.46		-0.124	21	n.s.
MA	Frost sum, March	1996-2015	-12.70		-0.059	18	n.s.
MA	Frost sum, April	1996-2015	-3.04		0.189	19	n.s.
MA	Frost sum, May	1995-2015	-0.21		0.113	19	n.s.
MA	Day-degrees > 0degC, Annual	1996-2015	2599.5		0.229	18	n.s.
MA	Day-degrees > 0degC, Spring	1996-2015	518.5		0.099	19	n.s.
MA	Day-degrees > 0degC, Summer	1995-2015	1007.8		-0.088	19	n.s.
MA	Day-degrees > 0degC, Autumn	1995-2015	709.7		0.205	19	n.s.
MA	Day-degrees > 0degC, Winter	1996-2016	276.1		0.086	21	n.s.
MA	Day-degrees > 0degC, January	1996-2016	92.4		-0.019	21	n.s.
MA	Day-degrees > 0degC, February	1996-2016	75.9		-0.152	21	n.s.
MA	Day-degrees > 0degC, March	1996-2015	116.8		-0.072	18	n.s.
MA	Day-degrees > 0degC, April	1996-2015	166.7		0.088	19	n.s.
MA	Day-degrees > 0degC, May	1996-2015	252.7		-0.216	19	n.s.
MA	Day-degrees > 0degC, June	1995-2015	314.0		0.221	20	n.s.
MA	Day-degrees > 0degC, July	1995-2015	360.4		-0.053	20	n.s.
MA	Day-degrees > 0degC, August	1995-2015	386.4	-VE	-0.359	18	*
MA	Day-degrees > 0degC, September	1995-2015	322.0		0.095	21	n.s.
MA	Day-degrees > 0degC, October	1995-2015	250.8		0.041	19	n.s.
MA	Day-degrees > 0degC, November	1995-2015	159.3		0.011	20	n.s.
MA	Day-degrees > 0degC, December	1995-2015	107.8		0.210	21	n.s.

Table 13 (continued): Physical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
MA	Day-degrees > 5.6degC, Annual	1996-2015	977.1		0.190	18	n.s.
MA	Day-degrees > 5.6degC, Spring	1996-2015	128.4		0.076	19	n.s.
MA	Day-degrees > 5.6degC, Summer	1995-2015	534.8		-0.105	20	n.s.
MA	Day-degrees > 5.6degC, Autumn	1995-2015	262.1		0.200	20	n.s.
MA	Day-degrees > 5.6degC, Winter	1996-2016	19.5		0.067	21	n.s.
MA	Day-degrees > 5.6degC, January	1996-2016	5.5		0.005	21	n.s.
MA	Day-degrees > 5.6degC, February	1996-2016	3.9		-0.088	21	n.s.
MA	Day-degrees > 5.6degC, March	1996-2015	13.4		-0.111	18	n.s.
MA	Day-degrees > 5.6degC, April	1996-2015	32.6		0.164	19	n.s.
MA	Day-degrees > 5.6degC, May	1996-2015	89.4	-VE	-0.287	19	*
MA	Day-degrees > 5.6degC, June	1995-2015	149.7		0.211	20	n.s.
MA	Day-degrees > 5.6degC, July	1995-2015	198.6		-0.063	20	n.s.
MA	Day-degrees > 5.6degC, August	1995-2015	214.0	-VE	-0.359	18	*
MA	Day-degrees > 5.6degC, September	1995-2015	156.4		0.095	21	n.s.
MA	Day-degrees > 5.6degC, October	1995-2015	85.7		0.099	19	n.s.
MA	Day-degrees > 5.6degC, November	1995-2015	26.1		-0.063	20	n.s.
MA	Day-degrees > 5.6degC, December	1995-2015	10.1		0.148	21	n.s.
MA	T-SUM, Annual	1996-2015	2656.4		0.255	18	n.s.
MA	T-SUM, Spring	1996-2015	538.4		0.099	19	n.s.
MA	T-SUM, Summer	1995-2015	1026.7		-0.105	20	n.s.
MA	T-SUM, Autumn	1995-2015	722.7		0.189	20	n.s.
MA	T-SUM, Winter	1996-2016	280.5		0.067	21	n.s.
MA	T-SUM, January	1996-2016	93.8		-0.029	21	n.s.
MA	T-SUM, February	1996-2016	77.4		-0.162	21	n.s.
MA	T-SUM, March	1996-2015	122.2	-VE	-0.327	18	*
MA	T-SUM, April	1996-2015	173.8		0.088	19	n.s.
MA	T-SUM, May	1996-2015	260.7		-0.158	19	n.s.
MA	T-SUM, June	1995-2015	320.5		0.242	20	n.s.
MA	T-SUM, July	1995-2015	367.3		-0.053	20	n.s.
MA	T-SUM, August	1995-2015	392.1	-VE	-0.359	18	*
MA	T-SUM, September	1995-2015	328.9		0.086	21	n.s.
MA	T-SUM, October	1995-2015	254.6		0.041	19	n.s.
MA	T-SUM, November	1995-2015	161.8		0.042	20	n.s.
MA	T-SUM, December	1995-2015	109.4		0.219	21	n.s.
MA	Growing Season Days, Average Temp >= 5	1996-2015	240.0		0.210	18	n.s.
MA	Growing Season Days, Average Temp >= 5, Spring	1996-2015	52.5		0.018	19	n.s.
MA	Growing Season Days, Average Temp >= 5, Summer	1995-2015	89.4		0.268	19	n.s.
MA	Growing Season Days, Average Temp >= 5, Autumn	1995-2015	72.0		0.264	20	n.s.
MA	Growing Season Days, Average Temp >= 5, Winter	1996-2016	21.1		-0.010	21	n.s.
MA	Growing Season Days, Average Temp >= 5, January	1996-2016	6.9		-0.124	21	n.s.
MA	Growing Season Days, Average Temp >= 5, February	1996-2016	5.1		-0.167	21	n.s.
MA	Growing Season Days, Average Temp >= 5, March	1996-2015	9.6		-0.180	18	n.s.
MA	Growing Season Days, Average Temp >= 5, April	1996-2015	17.1		-0.024	19	n.s.
MA	Growing Season Days, Average Temp >= 5, May	1996-2015	26.3		0.134	19	n.s.
MA	Growing Season Days, Average Temp >= 5, June	1995-2015	29.4		0.169	20	n.s.
MA	Growing Season Days, Average Temp >= 5, July	1995-2015	29.0		0.138	20	n.s.
MA	Growing Season Days, Average Temp >= 5, August	1995-2015	31.0		0.000	18	n.s.
MA	Growing Season Days, Average Temp >= 5, September	1995-2015	29.5		0.040	21	n.s.
MA	Growing Season Days, Average Temp >= 5, October	1995-2015	27.9		0.013	19	n.s.
MA	Growing Season Days, Average Temp >= 5, November	1995-2015	17.3		0.124	20	n.s.
MA	Growing Season Days, Average Temp >= 5, December	1995-2015	9.1		-0.005	21	n.s.
MA	Annual rainfall	1996-2015	3705.65		0.032	20	n.s.
MA	Spring Rainfall	1996-2015	697.92		-0.074	20	n.s.
MA	Summer Rainfall	1995-2015	761.65		0.248	21	n.s.
MA	Autumn Rainfall	1995-2015	1094.20		-0.076	21	n.s.
MA	Winter Rainfall	1996-2016	1133.94		0.190	21	n.s.
MA	January Rainfall	1996-2016	401.15		0.221	20	n.s.
MA	Februaryruary Rainfall	1996-2016	290.17		-0.029	21	n.s.
MA	March Rainfall	1996-2015	241.57		-0.111	19	n.s.
MA	April Rainfall	1996-2015	230.34		-0.053	19	n.s.
MA	May Rainfall	1995-2015	232.59		0.116	20	n.s.
MA	June Rainfall	1995-2015	217.65		-0.124	21	n.s.
MA	July Rainfall	1995-2015	262.97	+VE	0.333	21	*
MA	August Rainfall	1995-2015	270.19	+VE	0.310	19	*
MA	September Rainfall	1995-2015	286.36		-0.105	20	n.s.

Table 13 (continued): Physical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
MA	October Rainfall	1995-2015	401.05		0.032	20	n.s.
MA	November Rainfall	1995-2015	388.16		-0.228	19	n.s.
MA	December Rainfall	1995-2015	459.78	+VE	0.347	20	*
MA	Raindays (>=0.2mm/day)	1996-2015	249.0		0.105	18	n.s.
MA	Spring Raindays, (>= 0.2 mm/day), (>= 0.2 mm/day)	1996-2015	58.9		0.177	19	n.s.
MA	Summer Raindays, (>= 0.2 mm/day)	1995-2015	60.0		0.204	18	n.s.
MA	Autumn Raindays, (>= 0.2 mm/day)	1995-2015	67.3		-0.126	18	n.s.
MA	Winter Raindays, (>= 0.2 mm/day)	1996-2016	64.8		0.208	20	n.s.
MA	Raindays, January	1996-2016	22.6		0.222	20	n.s.
MA	Raindays, February	1996-2016	19.6		-0.0586	21	n.s.
MA	Raindays, March	1996-2015	20.2		0.0904	19	n.s.
MA	Raindays, April	1996-2015	19.2		-0.0893	19	n.s.
MA	Raindays, May	1995-2015	19.4	+VE	0.303	20	*
MA	Raindays, June	1995-2015	18.1		-0.185	21	n.s.
MA	Raindays, July	1995-2015	20.0		0.176	21	n.s.
MA	Raindays, August	1995-2015	20.7	+VE	0.415	18	**
MA	Raindays, September	1995-2015	18.7		0.0164	20	n.s.
MA	Raindays, October	1995-2015	24.3		0.0484	19	n.s.
MA	Raindays, November	1995-2015	23.9		-0.176	19	n.s.
MA	Raindays, December	1995-2015	22.8	+VE	0.342	20	*
MA	Wet days (>=1.0mm/day)	1996-2015	214.5		0.124	18	n.s.
MA	Spring Wetdays (>=1.0mm/day)	1996-2015	49.2		0.047	19	n.s.
MA	Summer Wetdays (>=1.0mm/day)	1996-2015	50.4		0.232	18	n.s.
MA	Autumn Wetdays (>=1.0mm/day)	1996-2015	59.7		-0.153	18	n.s.
MA	Winter Wetdays (>=1.0mm/day)	1996-2015	56.1		0.260	20	n.s.
MA	Wet days, January	1996-2016	19.1	+VE	0.283	20	*
MA	Wet days, February	1996-2016	16.6		-0.0976	21	n.s.
MA	Wet days, March	1996-2015	15.7		-0.0245	19	n.s.
MA	Wet days, April	1996-2015	17.1		-0.13	19	n.s.
MA	Wet days, May	1995-2015	16.2		0.215	20	n.s.
MA	Wet days, June	1995-2015	15.4		-0.193	21	n.s.
MA	Wet days, July	1995-2015	16.7		0.215	21	n.s.
MA	Wet days, August	1995-2015	17.4	+VE	0.313	18	*
MA	Wet days, September	1995-2015	15.9		-0.0593	20	n.s.
MA	Wet days, October	1995-2015	21.5		0.0605	19	n.s.
MA	Wet days, November	1995-2015	21.7		-0.268	19	n.s.
MA	Wet days, December	1995-2015	20.7	+VE	0.359	20	*
MA	Very wet days (>=50mm/day)	1996-2015	12.7		0.193	18	n.s.
MA	Spring Very wet days (>=50mm/day)	1996-2015	1.8		0.147	19	n.s.
MA	Summer Very wet days (>=50mm/day)	1996-2015	2.1		0.277	19	n.s.
MA	Autumn Very wet days (>=50mm/day)	1996-2015	3.6		-0.261	20	n.s.
MA	Winter Very wet days (>=50mm/day)	1996-2016	4.8		0.189	21	n.s.
MA	Very wet days, January	1996-2016	1.6		0.171	21	n.s.
MA	Very wet days, February	1996-2016	1.2		-0.227	21	n.s.
MA	Very wet days, March	1996-2015	0.6		-0.176	18	n.s.
MA	Very wet days, April	1996-2015	0.5		0.275	19	n.s.
MA	Very wet days, May	1995-2015	0.7		0.262	19	n.s.
MA	Very wet days, June	1995-2015	0.6		0.127	20	n.s.
MA	Very wet days, July	1995-2015	0.7		0.198	20	n.s.
MA	Very wet days, August	1995-2015	0.8		0.236	18	n.s.
MA	Very wet days, September	1995-2015	1.0	-VE	-0.345	21	*
MA	Very wet days, October	1995-2015	1.5	-VE	-0.306	20	*
MA	Very wet days, November	1995-2015	1.1		-0.055	20	n.s.
MA	Very wet days, December	1995-2015	1.9	+VE	0.324	21	*
MA	Extremely wet days (>=100mm/day)	1996-2015	1.2	+VE	0.304	18	*
MA	Spring Extremely wet days	1996-2015	0.2		0.083	19	n.s.
MA	Summer Extremely wet days	1996-2015	0.1		0.216	19	n.s.
MA	Autumn Extremely wet days	1996-2015	0.2		0.163	20	n.s.
MA	Winter Extremely wet days	1996-2016	0.8		0.042	21	n.s.
MA	Extremely wet days, January	1996-2016	0.2		0.123	21	n.s.
MA	Extremely wet days, February	1996-2016	0.0		-0.062	21	n.s.
MA	Extremely wet days, March	1996-2015	0.1		-0.114	18	n.s.
MA	Extremely wet days, April	1996-2015	0.1		0.252	19	n.s.
MA	Extremely wet days, May	1995-2015	0.0		0.000	19	n.s.
MA	Extremely wet days, June	1995-2015	0.1		0.216	20	n.s.

Table 13 (continued): Physical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
MA	Extremely wet days, July	1995-2015	0.0		0.000	20	n.s.
MA	Extremely wet days, August	1995-2015	0.0		0.000	18	n.s.
MA	Extremely wet days, September	1995-2015	0.0		0.185	21	n.s.
MA	Extremely wet days, October	1995-2015	0.1		0.024	20	n.s.
MA	Extremely wet days, November	1995-2015	0.1		0.017	20	n.s.
MA	Extremely wet days, December	1995-2015	0.5		0.073	21	n.s.
MM	Maximum temp. residual (deg C)	1996-2015	0.37		0.042	20	n.s.
MM	Minimum temp. residual (deg C)	1996-2015	1.08	-VE	-0.295	20	*
MM	Temperature range residual (deg C)	1996-2015	-0.79		0.116	20	n.s.
MM	Mid-range temp. residual (deg C)	1996-2015	1.37		-0.053	20	n.s.
MM	Grass minimum temp. residual (deg C)	1996-2015	2.00		0.105	20	n.s.
MM	Soil temperature residual (deg C)	1996-2015	0.90		0.084	20	n.s.
MM	Manual rainfall residual (mm)	1996-2015	5.53		0.074	20	n.s.
RG	Annual rainfall (Crib Goch)	1996-2015	5065.89		0.165	14	n.s.
RG	Spring Rainfall (Crib Goch)	1996-2015	850.55		-0.033	18	n.s.
RG	Summer Rainfall (Crib Goch)	1995-2015	1088.87		0.279	17	n.s.
RG	Autumn Rainfall (Crib Goch)	1995-2015	1507.32		-0.190	18	n.s.
RG	Winter Rainfall (Crib Goch)	1996-2016	1602.08		0.228	19	n.s.
RG	Spring Rainfall (Llydaw Delta)	1996-2015	832.97		0.150	16	n.s.
RG	Summer Rainfall (Llydaw Delta)	1995-2015	1031.16		0.216	18	n.s.
RG	Autumn Rainfall (Llydaw Delta)	1995-2015	1436.82		-0.203	18	n.s.
RG	Winter Rainfall (Llydaw Delta)	1996-2016	1374.99		0.242	18	n.s.
CL	Cloudiness	1996-2015	0.83	+VE	0.328	20	*
CL	Cloudiness, Spring	1996-2015	0.79		0.154	19	n.s.
CL	Cloudiness, Summer	1996-2015	0.83		-0.146	20	n.s.
CL	Cloudiness, Autumn	1996-2015	0.85		0.102	20	n.s.
CL	Cloudiness, Winter	1997-2015	0.84		0.000	19	n.s.
SN	Date of last snowlie	1995-2015	123.86		-0.091	21	n.s.
AOI	Average Winter AO	1996-2016	-0.24		0.0525	21	n.s.
AOI	Average Spring AO	1996-2015	0.13		0.232	20	n.s.
AOI	Average Summer AO	1995-2015	-0.14	-VE	-0.291	21	*
AOI	Average Autumn AO	1995-2015	-0.03	+VE	0.267	21	*
NAOI	Average Winter NAO	1996-2016	0.29	+VE	0.276	21	*
NAOI	Average Spring NAO	1996-2015	0.05		0.148	20	n.s.
NAOI	Average Summer NAO	1995-2015	-0.41	-VE	-0.415	21	**
NAOI	Average Autumn NAO	1995-2015	-0.21		0.229	21	n.s.
AOI	Arctic Oscillation January	1996-2016	-0.32		-0.00952	21	n.s.
AOI	Arctic Oscillation February	1996-2016	-0.12		-0.124	21	n.s.
AOI	Arctic Oscillation March	1996-2015	-0.06		0.263	20	n.s.
AOI	Arctic Oscillation April	1996-2015	0.27	+VE	0.307	20	*
AOI	Arctic Oscillation May	1996-2015	0.17		0.137	20	n.s.
AOI	Arctic Oscillation June	1995-2015	-0.10		-0.105	21	n.s.
AOI	Arctic Oscillation July	1995-2015	-0.20		-0.158	21	n.s.
AOI	Arctic Oscillation August	1995-2015	-0.11	-VE	-0.329	21	*
AOI	Arctic Oscillation September	1995-2015	0.03		0.2	21	n.s.
AOI	Arctic Oscillation October	1995-2015	-0.22		-0.0762	21	n.s.
AOI	Arctic Oscillation November	1995-2015	0.11	+VE	0.267	21	*
AOI	Arctic Oscillation December	1995-2015	-0.28		0.171	21	n.s.
NAOI	North Atlantic Oscillation January	1996-2016	0.35		0.0476	21	n.s.
NAOI	North Atlantic Oscillation February	1996-2016	0.39		0.043	21	n.s.
NAOI	North Atlantic Oscillation March	1996-2015	0.22		0.0316	20	n.s.
NAOI	North Atlantic Oscillation April	1996-2015	0.15	+VE	0.295	20	*
NAOI	North Atlantic Oscillation May	1996-2015	-0.23		0.0211	20	n.s.
NAOI	North Atlantic Oscillation June	1995-2015	-0.54		-0.177	21	n.s.
NAOI	North Atlantic Oscillation July	1995-2015	-0.44		-0.263	21	n.s.
NAOI	North Atlantic Oscillation August	1995-2015	-0.26	-VE	-0.511	21	***
NAOI	North Atlantic Oscillation September	1995-2015	-0.01		0.215	21	n.s.
NAOI	North Atlantic Oscillation October	1995-2015	-0.69		-0.0571	21	n.s.
NAOI	North Atlantic Oscillation November	1995-2015	0.07	+VE	0.324	21	*
NAOI	North Atlantic Oscillation December	1995-2015	0.14	+VE	0.343	21	*

Table 14: Chemical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed signific.
PC	pH Precipitation	1997-2015	5.20	+VE	0.427	19	**
PC	Conductivity Precipitation	1997-2015	21.35		0.111	19	n.s.
PC	Alkalinity Precipitation	1997-2015	-0.14	+VE	0.314	19	*
PC	SO4 Precipitation	1997-2015	0.44	-VE	-0.692	19	***
PC	NO3 Precipitation	1997-2015	0.20	-VE	-0.610	19	***
PC	NH4-N Precipitation	1997-2015	0.30	-VE	-0.305	19	*
PC	PO4 Precipitation	1997-2015	0.00		-0.141	19	n.s.
PC	Cl Precipitation	1997-2015	3.31		-0.059	19	n.s.
PC	DOC Precipitation	1997-2015	1.18	-VE	-0.446	19	**
PC	Tot-N Precipitation	1997-2015	0.59	-VE	-0.479	19	**
PC	Tot-NOx Precipitation	1997-2015	0.22	-VE	-0.461	19	**
PC	Na Stream Water	1997-2015	1.78		0.000	19	n.s.
PC	K Stream Water	1997-2015	0.10		0.195	19	n.s.
PC	Ca Stream Water	1997-2015	0.18		0.096	19	n.s.
PC	Mg Stream Water	1997-2015	0.22		-0.068	19	n.s.
PC	Fe Precipitation	1997-2015	0.01		0.169	19	n.s.
PC	Al Precipitation	1997-2015	0.01		-0.111	19	n.s.
PC	xSO4, Non-marine sulphate (kg/ha)	1997-2015	7.24	-VE	-0.765	17	***
PC	NO3-N + NH4-N (kg/ha)	1997-2015	10.49	-VE	-0.632	17	***
PC	xSO4 + NO3-N + NH4-N (kg/ha)	1997-2015	17.73	-VE	-0.721	17	***
PC	Average Winter ANC for PC	1998-2015	-21.64	+VE	0.32	18	*
PC	Average Spring ANC for PC	1998-2015	-31.38		0.216	18	n.s.
PC	Average Summer ANC for PC	1998-2015	-29.31	+VE	0.399	18	*
PC	Average Autumn ANC for PC	1998-2015	-22.74	+VE	0.359	18	*
PC	Average Winter pH for PC	1998-2015	5.22		0.229	18	n.s.
PC	Average Spring pH for PC	1998-2015	5.27	+VE	0.399	18	*
PC	Average Summer pH for PC	1998-2015	5.23		0.268	18	n.s.
PC	Average Autumn pH for PC	1998-2015	5.17	+VE	0.346	18	*
PC	Average Winter COND for PC	1998-2015	23.59	+VE	0.464	18	**
PC	Average Spring COND for PC	1998-2015	20.64		0.124	18	n.s.
PC	Average Summer COND for PC	1998-2015	14.13		0.0719	18	n.s.
PC	Average Autumn COND for PC	1998-2015	21.26		0.19	18	n.s.
PC	Average Winter ALKAL mg/l CaCO3 for PC	1998-2015	-0.03		0.098	18	n.s.
PC	Average Spring ALKAL mg/l CaCO3 for PC	1998-2015	-0.15	+VE	0.49	18	**
PC	Average Summer ALKAL mg/l CaCO3 for PC	1998-2015	0.34		0.124	18	n.s.
PC	Average Autumn ALKAL mg/l CaCO3 for PC	1998-2015	-0.08	+VE	0.294	18	*
PC	Average Winter Na mg/l for PC	1998-2015	2.60		0.0458	18	n.s.
PC	Average Spring Na mg/l for PC	1998-2015	1.67		-0.124	18	n.s.
PC	Average Summer Na mg/l for PC	1998-2015	0.84		0.203	18	n.s.
PC	Average Autumn Na mg/l for PC	1998-2015	1.82		-0.085	18	n.s.
PC	Average Winter K mg/l for PC	1998-2015	0.11	+VE	0.425	18	**
PC	Average Spring K mg/l for PC	1998-2015	0.07		0.0987	18	n.s.
PC	Average Summer K mg/l for PC	1998-2015	0.13		-0.0327	18	n.s.
PC	Average Autumn K mg/l for PC	1998-2015	0.08		0.257	18	n.s.
PC	Average Winter Ca mg/l for PC	1998-2015	0.17		0.268	18	n.s.
PC	Average Spring Ca mg/l for PC	1998-2015	0.20		-0.15	18	n.s.
PC	Average Summer Ca mg/l for PC	1998-2015	0.14		0.137	18	n.s.
PC	Average Autumn Ca mg/l for PC	1998-2015	0.17		0.0393	18	n.s.
PC	Average Winter Mg mg/l for PC	1998-2015	0.32		0.0327	18	n.s.
PC	Average Spring Mg mg/l for PC	1998-2015	0.21		-0.0525	18	n.s.
PC	Average Summer Mg mg/l for PC	1998-2015	0.11		0.178	18	n.s.
PC	Average Autumn Mg mg/l for PC	1998-2015	0.22		-0.118	18	n.s.
PC	Average Winter Fe mg/l for PC	1998-2015	0.00	+VE	0.493	18	**
PC	Average Spring Fe mg/l for PC	1998-2015	0.01		0.104	18	n.s.
PC	Average Summer Fe mg/l for PC	1998-2015	0.04	+VE	0.582	18	***
PC	Average Autumn Fe mg/l for PC	1998-2015	0.01		0.12	18	n.s.
PC	Average Winter Al mg/l for PC	1998-2015	0.01		0.273	18	n.s.
PC	Average Spring Al mg/l for PC	1998-2015	0.01	+VE	0.419	18	**
PC	Average Summer Al mg/l for PC	1998-2015	0.01		0.283	18	n.s.
PC	Average Autumn Al mg/l for PC	1998-2015	0.01		-0.0407	18	n.s.
PC	Average Winter PO4 mg/l P for PC	1998-2015	0.01		0.0279	18	n.s.
PC	Average Spring PO4 mg/l P for PC	1998-2015	0.00	-VE	-0.299	18	*
PC	Average Summer PO4 mg/l P for PC	1998-2015	0.05		-0.25	18	n.s.
PC	Average Autumn PO4 mg/l P for PC	1998-2015	0.00		-0.101	18	n.s.
PC	Average Winter NO3-N mg/l N for PC	1998-2015	0.16		0.157	18	n.s.

Table 14 (continued): Chemical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
PC	Average Spring NO3-N mg/l N for PC	1998-2015	0.28		0.0262	18	n.s.
PC	Average Summer NO3-N mg/l N for PC	1998-2015	0.22	-VE	-0.341	18	*
PC	Average Autumn NO3-N mg/l N for PC	1998-2015	0.18		-0.17	18	n.s.
PC	Average Winter NH4-N mg/l N for PC	1998-2015	0.16		-0.124	18	n.s.
PC	Average Spring NH4-N mg/l N for PC	1998-2015	0.37		0.229	18	n.s.
PC	Average Summer NH4-N mg/l N for PC	1998-2015	0.43	-VE	-0.294	18	*
PC	Average Autumn NH4-N mg/l N for PC	1998-2015	0.18		0.0787	18	n.s.
PC	Average Winter Cl mg/l for PC	1998-2015	4.83		0.111	18	n.s.
PC	Average Spring Cl mg/l for PC	1998-2015	2.91		-0.085	18	n.s.
PC	Average Summer Cl mg/l for PC	1998-2015	1.56		0.105	18	n.s.
PC	Average Autumn Cl mg/l for PC	1998-2015	3.32		-0.0327	18	n.s.
PC	Average Winter SO4 mg/l for PC	1998-2015	0.41		0.0327	18	n.s.
PC	Average Spring SO4 mg/l for PC	1998-2015	0.47	-VE	-0.464	18	**
PC	Average Summer SO4 mg/l for PC	1998-2015	0.41	-VE	-0.529	18	***
PC	Average Autumn SO4 mg/l for PC	1998-2015	0.41	-VE	-0.425	18	**
PC	Average Winter DOC mg/l C for PC	1998-2015	1.00	+VE	0.412	18	**
PC	Average Spring DOC mg/l C for PC	1998-2015	1.14	-VE	-0.412	18	**
PC	Average Summer DOC mg/l C for PC	1998-2015	1.41	-VE	-0.373	18	*
PC	Average Autumn DOC mg/l C for PC	1998-2015	0.95	-VE	-0.529	18	***
PC	Average Winter TOT-N mg/l N for PC	1998-2015	0.35	-VE	-0.399	18	*
PC	Average Spring TOT-N mg/l N for PC	1998-2015	0.64		0.0196	18	n.s.
PC	Average Summer TOT-N mg/l N for PC	1998-2015	0.88	-VE	-0.333	18	*
PC	Average Autumn TOT-N mg/l N for PC	1998-2015	0.44		-0.281	18	n.s.
PC	Average Winter TOT-NOx mg/l for PC	1998-2015	0.16		0.119	18	n.s.
PC	Average Spring TOT-NOx mg/l for PC	1998-2015	0.28		0.0719	18	n.s.
PC	Average Summer TOT-NOx mg/l for PC	1998-2015	0.22	-VE	-0.336	18	*
PC	Average Autumn TOT-NOx mg/l for PC	1998-2015	0.19		-0.236	18	n.s.
PC	xSO4, Non-marine sulphate (kg/ha), Spring	1998-2015	1.98	-VE	-0.618	17	***
PC	xSO4, Non-marine sulphate (kg/ha), Summer	1998-2015	1.91		-0.255	18	n.s.
PC	xSO4, Non-marine sulphate (kg/ha), Autumn	1998-2015	2.07	-VE	-0.582	18	***
PC	xSO4, Non-marine sulphate (kg/ha), WInter	1998-2015	1.49	-VE	-0.516	18	**
PC	NO3-N + NH4-N (kg/ha), Spring	1998-2015	3.06	-VE	-0.382	17	*
PC	NO3-N + NH4-N (kg/ha), Summer	1998-2015	3.02	-VE	-0.399	18	*
PC	NO3-N + NH4-N (kg/ha), Autumn	1998-2015	2.44	-VE	-0.699	18	***
PC	NO3-N + NH4-N (kg/ha), WInter	1998-2015	2.25	-VE	-0.529	18	***
WC	pH Stream Water	1997-2015	5.39	+VE	0.333	19	*
WC	Conductivity Stream Water	1997-2015	23.99		0.193	19	n.s.
WC	Alkalinity Stream Water	1997-2015	0.33		0.270	18	n.s.
WC	SO4 Stream Water	1997-2015	0.65	-VE	-0.743	19	***
WC	NO3 Stream Water	1997-2015	0.08	-VE	-0.759	19	***
WC	NH4-N Stream Water	1997-2015	0.02	-VE	-0.415	19	**
WC	PO4 Stream Water	1997-2015	0.01		0.145	19	n.s.
WC	Cl Stream Water	1997-2015	4.74		-0.216	19	n.s.
WC	DOC Stream Water	1997-2015	1.95	-VE	-0.415	19	**
WC	Tot-N Stream Water	1997-2015	0.26	-VE	-0.482	19	**
WC	Tot-NOx Stream Water	1997-2015	0.10	-VE	-0.563	19	***
WC	Na Stream Water	1997-2015	2.81		-0.035	19	n.s.
WC	K Stream Water	1997-2015	0.19		-0.086	19	n.s.
WC	Ca Stream Water	1997-2015	0.58		-0.202	19	n.s.
WC	Mg Stream Water	1997-2015	0.36		-0.119	19	n.s.
WC	Fe Stream Water	1997-2015	0.02		-0.162	19	n.s.
WC	Al Stream Water	1997-2015	0.05	-VE	-0.370	17	*
WC	ANC Stream Water	1997-2015	2.88	+VE	0.392	19	**
WC	Average Winter ANC for WC	1998-2015	-6.18		0.163	18	n.s.
WC	Average Spring ANC for WC	1998-2015	-0.97	+VE	0.32	18	*
WC	Average Summer ANC for WC	1998-2015	9.75	+VE	0.556	18	***
WC	Average Autumn ANC for WC	1998-2015	9.89	+VE	0.307	18	*
WC	Average Winter pH for WC	1998-2015	5.21	+VE	0.294	18	*
WC	Average Spring pH for WC	1998-2015	5.38		0.289	18	n.s.
WC	Average Summer pH for WC	1998-2015	5.48		0.223	18	n.s.
WC	Average Autumn pH for WC	1998-2015	5.47	+VE	0.294	18	*
WC	Average Winter COND for WC	1998-2015	28.47		0.216	18	n.s.
WC	Average Spring COND for WC	1998-2015	26.04		0.255	18	n.s.
WC	Average Summer COND for WC	1998-2015	20.37		0.176	18	n.s.
WC	Average Autumn COND for WC	1998-2015	21.05		0.111	18	n.s.

Table 14 (continued): Chemical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
WC	Average Winter ALKAL mg/l CaCO3 for WC	1998-2015	0.66		0.203	18	n.s.
WC	Average Spring ALKAL mg/l CaCO3 for WC	1998-2015	0.12	+VE	0.386	18	*
WC	Average Summer ALKAL mg/l CaCO3 for WC	1998-2015	0.52	+VE	0.307	18	*
WC	Average Autumn ALKAL mg/l CaCO3 for WC	1998-2015	0.43		0.242	18	n.s.
WC	Average Winter Na mg/l for WC	1998-2015	3.32		-0.184	18	n.s.
WC	Average Spring Na mg/l for WC	1998-2015	3.08		0.0588	18	n.s.
WC	Average Summer Na mg/l for WC	1998-2015	2.31		-0.163	18	n.s.
WC	Average Autumn Na mg/l for WC	1998-2015	2.43		-0.163	18	n.s.
WC	Average Winter K mg/l for WC	1998-2015	0.25		-0.112	18	n.s.
WC	Average Spring K mg/l for WC	1998-2015	0.20		0.249	18	n.s.
WC	Average Summer K mg/l for WC	1998-2015	0.12		-0.12	18	n.s.
WC	Average Autumn K mg/l for WC	1998-2015	0.19		-0.00658	18	n.s.
WC	Average Winter Ca mg/l for WC	1998-2015	0.62		-0.144	18	n.s.
WC	Average Spring Ca mg/l for WC	1998-2015	0.61		0.00654	18	n.s.
WC	Average Summer Ca mg/l for WC	1998-2015	0.54		-0.124	18	n.s.
WC	Average Autumn Ca mg/l for WC	1998-2015	0.54		-0.0719	18	n.s.
WC	Average Winter Mg mg/l for WC	1998-2015	0.44		-0.098	18	n.s.
WC	Average Spring Mg mg/l for WC	1998-2015	0.40		0.0656	18	n.s.
WC	Average Summer Mg mg/l for WC	1998-2015	0.30		-0.0719	18	n.s.
WC	Average Autumn Mg mg/l for WC	1998-2015	0.33		-0.111	18	n.s.
WC	Average Winter Fe mg/l for WC	1998-2015	0.22		-0.06	18	n.s.
WC	Average Spring Fe mg/l for WC	1998-2015	0.02		-0.0204	18	n.s.
WC	Average Summer Fe mg/l for WC	1998-2015	0.04	-VE	-0.33	18	*
WC	Average Autumn Fe mg/l for WC	1998-2015	0.04		0.0464	18	n.s.
WC	Average Winter Al mg/l for WC	1998-2015	0.06	-VE	-0.564	18	***
WC	Average Spring Al mg/l for WC	1998-2015	0.05		-0.258	18	n.s.
WC	Average Summer Al mg/l for WC	1998-2015	0.04		-0.0861	18	n.s.
WC	Average Autumn Al mg/l for WC	1998-2015	0.04		-0.272	18	n.s.
WC	Average Winter PO4 mg/l P for WC	1998-2015	0.01		0.115	18	n.s.
WC	Average Spring PO4 mg/l P for WC	1998-2015	0.00		0.208	18	n.s.
WC	Average Summer PO4 mg/l P for WC	1998-2015	0.01		0.269	18	n.s.
WC	Average Autumn PO4 mg/l P for WC	1998-2015	0.01		0.104	18	n.s.
WC	Average Winter NO3-N mg/l N for WC	1998-2015	0.14	-VE	-0.446	18	**
WC	Average Spring NO3-N mg/l N for WC	1998-2015	0.11		-0.223	18	n.s.
WC	Average Summer NO3-N mg/l N for WC	1998-2015	0.04	-VE	-0.354	18	*
WC	Average Autumn NO3-N mg/l N for WC	1998-2015	0.08	-VE	-0.643	18	***
WC	Average Winter NH4-N mg/l N for WC	1998-2015	0.02	-VE	-0.472	18	**
WC	Average Spring NH4-N mg/l N for WC	1998-2015	0.02		-0.176	18	n.s.
WC	Average Summer NH4-N mg/l N for WC	1998-2015	0.02		-0.257	18	n.s.
WC	Average Autumn NH4-N mg/l N for WC	1998-2015	0.02	-VE	-0.356	18	*
WC	Average Winter Cl mg/l for WC	1998-2015	6.17		-0.19	18	n.s.
WC	Average Spring Cl mg/l for WC	1998-2015	5.45		-0.00654	18	n.s.
WC	Average Summer Cl mg/l for WC	1998-2015	3.60		-0.229	18	n.s.
WC	Average Autumn Cl mg/l for WC	1998-2015	3.98		-0.216	18	n.s.
WC	Average Winter SO4 mg/l for WC	1998-2015	0.66	-VE	-0.503	18	**
WC	Average Spring SO4 mg/l for WC	1998-2015	0.69	-VE	-0.42	18	**
WC	Average Summer SO4 mg/l for WC	1998-2015	0.65	-VE	-0.669	18	***
WC	Average Autumn SO4 mg/l for WC	1998-2015	0.59	-VE	-0.564	18	***
WC	Average Winter DOC mg/l C for WC	1998-2015	1.63	-VE	-0.438	18	**
WC	Average Spring DOC mg/l C for WC	1998-2015	1.71	-VE	-0.451	18	**
WC	Average Summer DOC mg/l C for WC	1998-2015	2.43	-VE	-0.438	18	**
WC	Average Autumn DOC mg/l C for WC	1998-2015	1.95	-VE	-0.32	18	*
WC	Average Winter TOT-N mg/l for WC	1998-2015	0.24	-VE	-0.38	18	*
WC	Average Spring TOT-N mg/l for WC	1998-2015	0.22		-0.229	18	n.s.
WC	Average Summer TOT-N mg/l for WC	1998-2015	0.24	-VE	-0.354	18	*
WC	Average Autumn TOT-N mg/l for WC	1998-2015	0.28	-VE	-0.556	18	***
WC	Average Winter TOT-NOx mg/l for WC	1998-2015	0.15	-VE	-0.412	18	**
WC	Average Spring TOT-NOx mg/l for WC	1998-2015	0.11		-0.283	18	n.s.
WC	Average Summer TOT-NOx mg/l for WC	1998-2015	0.05	-VE	-0.302	18	*
WC	Average Autumn TOT-NOx mg/l for WC	1998-2015	0.08	-VE	-0.669	18	***
SSS	pH Soil Solution (Shallow)	1997-2015	6.23	+VE	0.544	19	***
SSS	Conductivity Soil Solution (Shallow)	1997-2015	26.92		-0.088	19	n.s.
SSS	Alkalinity Soil Solution (Shallow)	1997-2015	2.99		0.086	15	n.s.
SSS	SO4 Soil Solution (Shallow)	1997-2015	0.53	-VE	-0.322	19	*
SSS	NO3-N Soil Solution (Shallow)	1997-2015	0.06		-0.265	19	n.s.

Table 14 (continued): Chemical trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
SSS	NH4-N Soil Solution (Shallow)	1997-2015	0.03	-VE	-0.546	19	***
SSS	PO4 Soil Solution (Shallow)	1997-2015	0.01	+VE	0.316	19	*
SSS	Cl Soil Solution (Shallow)	1997-2015	5.19		-0.275	19	n.s.
SSS	DOC Soil Solution (Shallow)	1997-2015	3.03	-VE	-0.485	19	**
SSS	Tot-N Soil Solution (Shallow)	1997-2015	0.37		-0.219	19	n.s.
SSS	Tot-NOx Soil Solution (Shallow)	1997-2015	0.08		-0.078	19	n.s.
SSS	Na Soil Solution (Shallow)	1997-2015	2.84		-0.024	19	n.s.
SSS	K Soil Solution (Shallow)	1997-2015	0.31		0.100	19	n.s.
SSS	Ca Soil Solution (Shallow)	1997-2015	1.31		-0.251	19	n.s.
SSS	Mg Soil Solution (Shallow)	1997-2015	0.61		-0.053	19	n.s.
SSS	Fe Soil Solution (Shallow)	1997-2015	0.01	-VE	-0.394	19	**
SSS	Al Soil Solution (Shallow)	1997-2015	0.06		0.075	17	n.s.
SSD	pH Soil Solution (Deep)	1999-2015	5.95	+VE	0.500	17	**
SSD	Conductivity Soil Solution (Deep)	1999-2015	30.19		0.118	17	n.s.
SSD	Alkalinity Soil Solution (Deep)	1999-2015	4.27		0.050	16	n.s.
SSD	SO4 Soil Solution (Deep)	1999-2015	0.62	-VE	-0.406	17	*
SSD	NO3-N Soil Solution (Deep)	1999-2015	0.11	-VE	-0.627	17	***
SSD	NH4-N Soil Solution (Deep)	1999-2015	0.01	-VE	-0.388	17	*
SSD	PO4 Soil Solution (Deep)	1999-2015	0.00		-0.212	17	n.s.
SSD	Cl Soil Solution (Deep)	1999-2015	4.61		-0.235	17	n.s.
SSD	DOC Soil Solution (Deep)	1999-2015	1.23	-VE	-0.471	17	**
SSD	Tot-N Soil Solution (Shallow)	1999-2015	0.25	-VE	-0.667	17	***
SSD	Tot-NOx Soil Solution (Shallow)	1999-2015	0.14	-VE	-0.354	17	*
SSD	Na Soil Solution (Deep)	1999-2015	2.91		-0.206	17	n.s.
SSD	K Soil Solution (Deep)	1999-2015	0.26	+VE	0.439	17	**
SSD	Ca Soil Solution (Deep)	1999-2015	1.67		0.066	17	n.s.
SSD	Mg Soil Solution (Deep)	1999-2015	0.59		-0.216	17	n.s.
SSD	Fe Soil Solution (Deep)	1999-2015	0.00		0.285	17	n.s.
SSD	Al Soil Solution (Deep)	1999-2015	0.03	-VE	-0.322	17	*
AN	NO2, dry deposition	2002-2015	1.77		-0.067	16	n.s.
AS	SO2, dry deposition	2002-2015	0.59	-VE	-0.385	14	*
OZ	Average annual ozone concentration	2000-2015	35.80	-VE	-0.527	16	**
OZ	Ozone AOT40 May-July	2000-2014	1103.07		-0.121	14	n.s.
OZ	Ozone AOT40 mid Apr-midOct	2000-2014	5985.86		-0.297	14	n.s.
OZ	Average annual NOx concentration	2000-2014	3.04		-0.211	15	n.s.
OZ	Average ozone concentration Winter	2000-2016	35.08		-0.249	15	n.s.
OZ	Average ozone concentration Spring	2000-2014	41.75	-VE	-0.451	14	*
OZ	Average ozone concentration Summer	2000-2015	32.29		-0.260	15	n.s.
OZ	Average ozone concentration Autumn	1999-2015	33.06	-VE	-0.486	15	**
NH3	NH3, ECN	2008-2015	0.32		0.286	8	n.s.
NH3	NH3, ECN, Spring	2009-2015	0.58		-0.238	7	n.s.
NH3	NH3, ECN, Summer	2008-2015	0.40	+VE	0.571	8	*
NH3	NH3, ECN, Autumn	2008-2015	0.22	+VE	0.571	8	*
NH3	NH3, ECN, Winter	2009-2015	0.13		0.238	7	n.s.
FWC	BOD Stream Water	2007-2015	1.27		-0.444	9	n.s.
FWC	Cu Dissolved Stream Water	2007-2015	0.71	-VE	-0.500	9	*
FWC	Cu Total Stream Water	2007-2015	0.72		-0.444	9	n.s.
FWC	Mn Dissolved Stream Water	2007-2015	16.89		-0.056	9	n.s.
FWC	Mn Total Stream Water	2007-2015	17.66		0.056	9	n.s.
FWC	Ni Total Stream Water	2007-2015	1.07	-VE	-0.648	9	*
FWC	Pb Total Stream Water	2007-2015	0.87	+VE	0.618	9	*
FWC	SiO2 Stream Water	2007-2015	0.65		0.222	9	n.s.
FWC	Zn Dissolved Stream Water	2007-2015	4.11		-0.389	9	n.s.
FWC	Zn Total Stream Water	2007-2015	4.35		-0.389	9	n.s.

Table 15 Biological trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
BB	Bird numbers	1996-2015	83.65		0.048	20	n.s.
BB	Birds, Shannon diversity	1997-2015	0.80		0.116	20	n.s.
BB	Bird numbers, Pied Wagtail	1996-2015	0.10		-0.131	20	n.s.
BB	Bird numbers, Carrion Crow	1996-2015	0.35		-0.044	20	n.s.
BB	Bird numbers, Common Sandpiper	1996-2015	0.50		0.238	20	n.s.
BB	Bird numbers, Herring Gull	1996-2015	3.90		-0.097	20	n.s.
BB	Bird numbers, Meadow Pipit	1996-2015	29.88		-0.085	20	n.s.
BB	Bird numbers, Raven	1996-2015	1.08		0.040	20	n.s.
BB	Bird numbers, Ring Ouzel	1996-2015	0.28		-0.048	20	n.s.
BB	Bird numbers, Wheatear	1996-2015	4.93		0.208	20	n.s.
BB	Bird numbers, Wren	1996-2015	0.90		0.060	20	n.s.
BB	Bird numbers, Chough	1996-2015	0.03		0.150	20	n.s.
BB	Phenology - Bird return - Comm Sandpiper	1998-2015	122.13		0.043	16	n.s.
BB	Phenology - Bird return - Meadow Pipit	1998-2015	77.13		0.029	15	n.s.
BB	Phenology - Bird return - Ring Ouzel	1998-2015	96.13		-0.057	15	n.s.
BB	Phenology - Bird return - Wheatear	1998-2015	89.41		0.214	17	n.s.
BA	Bat numbers	1996-2015	3.52		-0.140	20	n.s.
BF	Frog spawning date	1996-2016	62.30		-0.101	20	n.s.
BF	Frog spawning, pool 1, duration	1996-2015	124.47	-VE	-0.450	17	**
IB	Butterflies, Average numbers per transect	1996-2015	9.25		0.158	20	n.s.
IB	Butterflies, Shannon diversity	1996-2015	0.94	-VE	-0.316	20	*
IG	No of Ground beetles (Wks 19-43)	1999-2015	1373.29	-VE	-0.647	17	***
IG	No of Ground beetles,Transect A (Wks 19-43)	1999-2015	939.65	-VE	-0.622	17	***
IG	No of Ground beetles,Transect B (Wks 19-43)	1999-2015	321.82	-VE	-0.426	17	**
IG	No of Ground beetles,Transect B (Wks 19-43)	2004-2015	190.17		-0.061	12	n.s.
IG	No of Ground beetles,Transect C (Wks 19-43)	1999-2015	111.82	-VE	-0.309	17	*
IG	No of Ground beetles,Transect C (Wks 19-43)	2004-2015	40.33		0.303	12	n.s.
IG	No of Ground beetles (excl Perostichus madidus)	1999-2015	118.47	-VE	-0.406	17	*
IG	No of Pterostichus madidus (Wks 19-43)	1999-2015	1254.82	-VE	-0.657	17	***
IG	Log no of Ground beetles+1, All Transects (Wks 19-43)	1999-2015	3.06	-VE	-0.647	17	***
IG	Log no of Ground beetles+1, Transect A (Wks 19-43)	1999-2015	2.90	-VE	-0.662	17	***
IG	Log no of Ground beetles+1, Transect B (Wks 19-43)	1999-2015	2.39	-VE	-0.426	17	**
IG	Log no of Ground beetles+1, Transect C (Wks 19-43)	1999-2015	1.78	-VE	-0.309	17	*
IA	No of spiders (wks 19-43)	2000-2015	730.88		0.176	16	n.s.
IA	No of spiders, Transect A (wks 19-43)	2000-2015	257.19		0.167	16	n.s.
IA	No of spiders, Transect B (wks 19-43)	2000-2015	279.38	+VE	0.444	16	**
IA	No of spiders, Transect C (wks 19-43)	2000-2015	194.31		0.059	16	n.s.
IA	Log no of spiders+1, All Transects (wks 19-43)	2000-2015	2.85		0.176	16	n.s.
IA	Log no of spiders+1, Transect A (wks 19-43)	2000-2015	2.39		0.167	16	n.s.
IA	Log no of spiders+1, Transect B (wks 19-43)	2000-2015	2.43	+VE	0.444	16	**
IA	Log no of spiders+1, Transect C (wks 19-43)	2000-2015	2.27		0.059	16	n.s.
IS	Proportion of spittle bug colour morphs	1998-2015	57.65		0.206	17	n.s.
VF	Vegetation, Species number, All Vegetation, Species, Cal	1999-2015	15.70		0.231	13	n.s.
VF	Vegetation, Species number, All Vegetation, Species, Aci	1999-2015	13.38	+VE	0.458	13	*
VF	Vegetation, Species number, All Vegetation, Species, Vac	1999-2014	10.90		-0.109	8	n.s.
VF	Vegetation, Species number, All Vegetation, Species, Call	1999-2014	11.29		0.000	7	n.s.
VF	Vegetation, Species number, All Vegetation, Species, Juni	1999-2014	13.01		0.327	8	n.s.
VF	Vegetation, Species number, All Vegetation, Species, Aci	1999-2015	10.63	+VE	0.649	13	***
VF	Vegetation, Species number, All Vegetation, Species, Wet	1999-2014	10.36		0.214	8	n.s.
VF	Vegetation, Species number, All Vegetation, Species, Bla	1999-2014	10.91		0.255	8	n.s.
VF	Vegetation, Species number, All Vegetation, Species, Gra	1999-2015	14.29	+VE	0.462	13	*
VF	Vegetation, Species number, All Vegetation, Species, Hea	1999-2014	11.68		0.400	8	n.s.
VF	Vegetation, Species number, All Vegetation, Species, Wet	1999-2014	10.90	+VE	0.632	13	**
VF	Vegetation, Species number, Vascular plants + mosses, C	1999-2015	15.60		0.231	13	n.s.
VF	Vegetation, Species number, Vascular plants + mosses, A	1999-2015	11.18	+VE	0.520	13	**
VF	Vegetation, Species number, Vascular plants + mosses, V	1999-2014	10.14		0.255	8	n.s.
VF	Vegetation, Species number, Vascular plants + mosses, C	1999-2014	9.95		-0.098	7	n.s.
VF	Vegetation, Species number, Vascular plants + mosses, Ju	1999-2014	11.90		0.429	8	n.s.
VF	Vegetation, Species number, Vascular plants + mosses, A	1999-2015	12.56		0.275	13	n.s.
VF	Vegetation, Species number, Vascular plants + mosses, W	1999-2014	8.88		0.111	9	n.s.
VF	Vegetation, Species number, Vascular plants + mosses, B	1999-2014	9.16		0.111	9	n.s.
VF	Vegetation, Species number, Vascular plants + mosses, G	1999-2015	12.92	+VE	0.555	13	**
VF	Vegetation, Species number, Vascular plants + mosses, H	1999-2014	10.64		0.445	8	n.s.
VF	Vegetation, Species number, Vascular plants + mosses, W	1999-2014	10.91		0.357	8	n.s.
VF	Vegetation, Species number, Vascular plants only, Calcare	1999-2015	11.60	+VE	0.400	13	*

Table 15 (continued): Biological trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
VF	Vegetation, Species number, Vascular plants only, Acid gr	1999-2015	7.10	+VE	0.675	13	***
VF	Vegetation, Species number, Vascular plants only, Vaccini	1999-2014	5.03		-0.255	8	n.s.
VF	Vegetation, Species number, Vascular plants only, Calluna	1999-2014	5.66		-0.250	7	n.s.
VF	Vegetation, Species number, Vascular plants only, Juniper	1999-2014	6.88		0.293	8	n.s.
VF	Vegetation, Species number, Vascular plants only, Acid flu	1999-2015	7.75	+VE	0.753	13	***
VF	Vegetation, Species number, Vascular plants only, Wet hea	1999-2014	7.26		0.255	8	n.s.
VF	Vegetation, Species number, Vascular plants only, Blanket	1999-2014	7.23		0.327	8	n.s.
VF	Vegetation, Species number, Vascular plants only, Grassla	1999-2015	8.88	+VE	0.546	13	**
VF	Vegetation, Species number, Vascular plants only, Heath	1999-2014	5.85		0.296	8	n.s.
VF	Vegetation, Species number, Vascular plants only, Wetland	1999-2014	7.78	+VE	0.632	13	**
VF	Vegetation, Ellenberg F, CG10	1999-2015	3.79		-0.051	13	n.s.
VF	Vegetation, Ellenberg N, CG10	1999-2015	3.80		-0.090	13	n.s.
VF	Vegetation, Ellenberg R, CG10	1999-2015	5.06		0.231	13	n.s.
VF	Vegetation, Ellenberg F, Vascular plants, Calc grassland	1999-2015	5.41		-0.323	13	n.s.
VF	Vegetation, Ellenberg F, Vascular plants, Acid grassland	1999-2015	5.76	+VE	0.462	13	*
VF	Vegetation, Ellenberg F, Vascular plants, Vaccinium heath	1999-2015	5.52		0.429	8	n.s.
VF	Vegetation, Ellenberg F, Vascular plants, Calluna heath	1999-2015	6.19		0.293	7	n.s.
VF	Vegetation, Ellenberg F, Vascular plants, Juniper heath	1999-2015	5.68	+VE	0.714	8	**
VF	Vegetation, Ellenberg F, Vascular plants, Acid flush	1999-2015	8.00	+VE	0.359	13	*
VF	Vegetation, Ellenberg F, Vascular plants, Wet heath	1999-2015	8.19		-0.500	8	n.s.
VF	Vegetation, Ellenberg F, Vascular plants, Blanket bog	1999-2015	8.11	-VE	-0.643	8	*
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Calc g	1999-2015	5.41		-0.260	13	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Acid g	1999-2015	5.79		0.154	13	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Vacci	1999-2015	5.74		0.429	8	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Callun	1999-2015	6.08		-0.429	7	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Junipe	1999-2015	5.54		0.286	8	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Acid fl	1999-2015	7.93		0.231	13	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Wet h	1999-2015	7.89		-0.071	8	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Blank	1999-2015	7.88	-VE	-0.571	8	*
VF	Vegetation, Ellenberg F, Vascular plants, Grassland	1999-2015	5.61		0.179	13	n.s.
VF	Vegetation, Ellenberg F, Vascular plants, Heathland	1999-2015	5.78		0.327	8	n.s.
VF	Vegetation, Ellenberg F, Vascular plants, Wetland	1999-2015	8.10		-0.077	13	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Grass	1999-2015	5.63		-0.256	13	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Heathl	1999-2015	5.77		0.255	8	n.s.
VF	Vegetation, Ellenberg F, Vascular plants & mosses, Wetla	1999-2015	7.93		-0.128	13	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Calc grassland	1999-2015	3.79		-0.065	13	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Acid grassland	1999-2015	2.65		-0.333	13	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Vaccinium heath	1999-2015	2.68		-0.071	8	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Calluna heath	1999-2015	2.24		0.238	7	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Juniper heath	1999-2015	2.22		-0.214	8	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Acid flush	1999-2015	1.70		-0.231	13	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Wet heath	1999-2015	1.37	+VE	0.571	8	*
VF	Vegetation, Ellenberg N, Vascular plants, Blanket bog	1999-2015	1.38	+VE	0.571	8	*
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Calc g	1999-2015	3.58		0.179	13	n.s.
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Acid g	1999-2015	2.55	-VE	-0.385	13	*
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Vacci	1999-2015	2.42		0.071	8	n.s.
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Callun	1999-2015	2.10	-VE	-0.714	7	*
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Junipe	1999-2015	2.13		0.143	8	n.s.
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Acid fl	1999-2015	1.76		-0.103	13	n.s.
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Wet h	1999-2015	1.48		0.429	8	n.s.
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Blank	1999-2015	1.50		0.286	8	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Grassland	1999-2015	3.12		0.103	13	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Heathland	1999-2015	2.39		-0.143	8	n.s.
VF	Vegetation, Ellenberg N, Vascular plants, Wetland	1999-2015	1.54	+VE	0.538	13	**
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Grass	1999-2015	2.97	+VE	0.400	13	*
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Heath	1999-2015	2.22		-0.214	8	n.s.
VF	Vegetation, Ellenberg N, Vascular plants & mosses, Wetla	1999-2015	1.63	+VE	0.615	13	**
VF	Vegetation, Ellenberg R, Vascular plants, Calc grassland	1999-2015	5.06		0.231	13	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Acid grassland	1999-2015	3.36		-0.065	13	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Vaccinium heath	1999-2015	2.92		0.214	8	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Calluna heath	1999-2015	2.44		0.143	7	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Juniper heath	1999-2015	2.91		-0.429	8	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Acid flush	1999-2015	2.90		-0.282	13	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Wet heath	1999-2015	2.53		-0.071	8	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Blanket bog	1999-2015	2.47		-0.143	8	n.s.

Table 15 (continued): Biological trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Calc g	1999-2015	4.82	+VE	0.503	13	*
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Acid g	1999-2015	3.23		0.219	13	n.s.
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Vacci	1999-2015	2.77	+VE	0.571	8	*
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Callun	1999-2015	2.42		-0.429	7	n.s.
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Junipe	1999-2015	2.75		0.286	8	n.s.
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Acid fl	1999-2015	2.70		0.179	13	n.s.
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Wet h	1999-2015	2.39		0.357	8	n.s.
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Blank	1999-2015	2.29		0.429	8	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Grassland	1999-2015	4.05	+VE	0.564	13	**
VF	Vegetation, Ellenberg R, Vascular plants, Heathland	1999-2015	2.79		0.143	8	n.s.
VF	Vegetation, Ellenberg R, Vascular plants, Wetland	1999-2015	2.72		0.297	13	n.s.
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Grass	1999-2015	3.87	+VE	0.487	13	*
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Heath	1999-2015	2.66		0.327	8	n.s.
VF	Vegetation, Ellenberg R, Vascular plants & mosses, Wetla	1999-2015	2.56	+VE	0.385	13	*
PH	Phenology, First flowering, Anemone nemorosa	1999-2015	111.62	-VE	-0.374	13	*
PH	Phenology, First flowering, Chrysosplenium oppositifolium	2007-2015	109.78	-VE	-0.500	9	*
PH	Phenology, First flowering, Erica tetralix	2008-2015	183.50	+VE	0.571	8	*
PH	Phenology, First flowering, Euphrasia sp.	2007-2015	185.22	-VE	-0.500	9	*
PH	Phenology, First flowering, Hyacinthoides non-scripta	1999-2015	132.63		-0.075	16	n.s.
PH	Phenology, First flowering, Oxalis acetosella	2008-2015	119.63	+VE	0.786	8	**
PH	Phenology, First flowering, Pilosella officinarum	2007-2015	158.00	+VE	0.535	9	*
PH	Phenology, First flowering, Primula vulgaris	1999-2015	95.56	-VE	-0.377	16	*
PH	Phenology, First flowering, Ranunculus ficaria	1999-2015	79.81		-0.050	16	n.s.
PH	Phenology, First flowering, Saxifraga oppositifolia	1997-2016	42.30	-VE	-0.349	20	*
PH	Phenology, First flowering, Teucrium scorodonia	2007-2015	203.89	-VE	-0.500	9	*
AA	Arctic-alpine, Sedum rosea, cell counts	2001-2015	3.28	+VE	0.477	10	*
AA	Arctic-alpine, Saxifraga oppositifolia, cell counts	2001-2015	19.37		-0.315	10	n.s.
FUN	Fungi, cumulative no of fruitbodies	2008-2015	699.63		0.071	8	n.s.
FMA	Freshwater macrophytes, Ellenberg L	2006-2015	7.01		0.386	10	n.s.
FMA	Freshwater macrophytes, Ellenberg F	2006-2015	8.94	-VE	-0.733	10	**
FMA	Freshwater macrophytes, Ellenberg N	2006-2015	3.20		-0.378	10	n.s.
FMA	Freshwater macrophytes, Ellenberg R	2006-2015	2.20		0.023	10	n.s.
FDT	Trophic Diatom Index	2006-2013	1.81		-0.500	8	n.s.

Table 16: Land-use trends

Protocol	Measurement	Dates	Average	Trend	Mann-Kendall trend test		
					tau	n	1-tailed
LU	Sheep numbers, Annual	1997-2015	30.95	-VE	-0.427	19	**
LU	Sheep Average numbers, Spring	1997-2015	19.67		-0.251	19	n.s.
LU	Sheep Average numbers, Summer	1997-2015	58.21		-0.193	19	n.s.
LU	Sheep Average numbers, Autumn	1997-2015	34.51	-VE	-0.497	19	**
LU	Sheep Average numbers, Winter	1997-2016	10.74	-VE	-0.505	20	***
LU	Goat numbers, Annual	1997-2015	0.76	+VE	0.427	19	**
LU	Goat Average numbers, Spring	1997-2015	0.85	+VE	0.407	19	**
LU	Goat Average numbers, Summer	1997-2015	0.08	+VE	0.351	19	*
LU	Goat Average numbers, Autumn	1997-2015	0.72	+VE	0.387	19	*
LU	Goat Average numbers, Winter	1997-2016	1.53	+VE	0.477	20	**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Protocols

AA	Arctic-alpine (non-ECN)
AN, AS	Atmospheric chemistry - NO_2, SO_2
BA	Bats
BB	Breeding Birds
BF	Frogs spawning
CL	Climate (non-ECN)
FDT	Freshwater diatoms
FMA	Freshwater macrophytes
FUN	Fungi
FWC	Freshwater chemistry
IA	Ground predators - Spiders
IB	Butterflies
IG	Ground predators - Carabid beetles
IS	Spittle Bugs
MA	Meteorology, automatic
MM	Meteorology, manual
NH3	Ammonia (UKAEAP)
OZ	Ozone
PC	Precipitation chemistry
PH	Phenology (non-ECN)
RG	Rain gauges, monthly (non-ECN)
SN	Snow lie and duration (non-ECN)
SSS,SSD	Soil solution, shallow, deep
VF	Vegetation, fine-grain
WC	Surface water chemistry

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