# Yr Wyddfa Snowdon Environmental Change Network

## 15 years of work of monitoring on Yr Wyddfa/Snowdon

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# The report

The aim of this report is to highlight some of the results from monitoring and research undertaken over the first 15 years of work at the Welsh long-term Environmental Change Network (ECN) monitoring site on Snowdon. The site was established in 1995 and work continues there to the present day.

The ECN is a UK-wide monitoring network dedicated to investigating how our environment changes over time. The network provides information on the characteristics of ecosystems, how they function and how they change. Monitoring a wide range of parameters in an integrated way gives us an important insight into the impacts of environmental change, including climate change.

After 15 years of recording, results are emerging which suggest a level of change greater than the levels of year-to-year variation typically seen in our environment. Changes have been recorded in temperature, atmospheric pollutants and land management, all with resultant impacts on the environment.

The consequences of environmental change for human well-being are a focus of current environmental policy development. This is evident in proposals to adopt an ecosystem approach to environmental management in Wales. This approach emphasises the inter-connectedness of ecosystems, and how changes in one component may affect the system as a whole, influencing its ability to provide benefits to human society. ECN, rooted in an ecosystem-focused approach to monitoring, is well placed to help us understand the functioning of ecosystems and how this is affected as external pressures change over time.

In addition to furnishing us with invaluable information on the impacts of environmental change, the ECN site on Snowdon also provides a platform for associated research and higher education activities.  Examples of both of these are included in this report.

# Key messages from Wales' long-term ECN site.

## Climate

Modest changes to the climate experienced on Snowdon have been evident since the 1960s and 1970s. Spring air temperatures have risen and winters have become less severe. Soil and grass minimum temperature have also both risen since the earlier period. These changes are accompanied by a rise in annual precipitation totals since 1995. More recent severe winters have, however, reduced the extent of the overall temperature rise since ECN recording started in 1995 because of the year-to-year variations in climate.

## Pollution

Levels of acidification and pollutant concentrations have decreased in response to emission controls. The recovery of Snowdon's ecosystems is taking longer and on-going levels of pollutants (such as nitrate and ozone) are still likely to be having a negative impact on semi-natural habitats. Avoiding such impacts is the key driver behind the UK Air Quality Strategy which set air quality objectives for a number of major pollutants to be achieved by 2020.

## Land-use

Snowdon has experienced a significant reduction in grazing intensity over the recording period, with sheep numbers on the site having fallen by around 50% from the levels recorded in 1997. This fall in sheep numbers has been accompanied by a limited reintroduction of cattle grazing on the site and a small increase in goat numbers.

## Biodiversity

Over the recording period some biological variables have been observed to respond relatively rapidly to shorter-term fluctuations in weather patterns e.g. flowering times and butterfly numbers. Others have changed over a longer period in response to land-use change e.g. increased dwarf-shrub cover in acid grasslands as a result of a decrease in sheep numbers. In contrast, other changes demonstrate the time ecosystems take to respond or recover from impacts. This is exemplified by the responses of plants following the introduction of pollution controls and reductions in deposition. Plant community recovery is continuing today with different components of the vegetation appearing to respond at differing rates. Lower plants appear to be responding directly to reduced atmospheric inputs of acidifying pollutants and are thus changing more rapidly. In contrast, higher plants are responding more significantly to changes in soil conditions and so their response appears to be taking much longer to be fully realized.

## Ecosystem health

With a scientifically robust approach to monitoring, the ECN sites provide a means to differentiate short-term variation from long-term patterns of change in our ecosystems. This ability, and the breadth of ecosystem components studied, mean that ECN sites are well placed to investigate the health of ecosystems. Furthermore, the ability to add other variables to the basic observation platform can make it possible to respond quickly to emerging issues and opportunities.

# Environmental Change Network


The UK Environmental Change Network is a long-term, integrated environmental monitoring and research programme. There are currently 12 terrestrial and 45 freshwater sites in the network[27,28]. Sites range from upland to lowland, moorland to chalk grassland, small ponds and streams to large rivers and lakes. Each of the 14 sponsoring organisations provides one or more sites and is supported through work with a number of research organisations including the Centre for Ecology and Hydrology.

The network also provides educational resources, including online tutorials on weather and climate change together with open days and student project opportunities.

ECN sites provide well-instrumented locations acting as a research focus for many short and long-term environmental research programmes. The co-location of numerous recorded variables enables the analysis of important relationships both between environmental variables and across ecosystem components.

In Wales, CCW works in partnership with the Welsh Government to run Wales' only joint freshwater and terrestrial ECN site. It is located on the eastern slopes of Snowdon and covers an area of 715ha. The monitoring and research on this site helps deliver information on the changing environment of both Wales and the UK as a whole.

## The Value of the Environmental Change Network

An understanding of the health of our ecosystems, and their ability to provide sustainable supplies of such things as clean water, is aided by long-term study of the interactions between components of our ecosystems. Such work also enables trends to be differentiated from the inherent variability observed within all natural systems and those driven by anthropogenic (human) factors.

Change within an ecosystem can take place over different time scales depending on the characteristics of the system under study. Some aspects can change rapidly, as shown by the direct rise in pH following reductions in acidifying pollutants, such as sulphur dioxide. In contrast, some components of an ecosystem can take a considerable time to respond. An example of this is the recovery of soil buffering capacity, which depends on the slow, gradual weathering of underlying rocks. Such long-term weathering processes change soils and subsequently impact the plant communities growing on them, a process of change which can take many decades to become apparent.

The work undertaken across the network is unique in that it enables an overview of all of these differing processes over the varied time periods it takes for change to become apparent and thus improves our understanding of how and why environments change.

A recent review of 15 years data across the network identified climate change, air pollution and land management as the principal drivers of change within our ecosystems[22]. This shows the power of ECN to detect impacts linked to what are seen as the most pressing drivers of environmental change, both in the UK and globally[21].

## The Snowdon ECN Site

Snowdon was chosen as an ECN site partly because it has a history of biological, climatological and land-use research going back to the 1950s: in particular, between 1966 and 1977, it was the focus of research under the International Biological Programme (IBP), a global research programme looking into the flow of nutrients and minerals through ecosystems. The site was also chosen for its conservation status, its range of vegetation types, in particular its arctic-alpine flora, and for its stability of management. Today the availability of this long-term data is helping us understand current changes in the context of the recent past and how such change may be a response to policy interventions.

The terrestrial ECN site on Snowdon started in 1995 and the freshwater site in 2006. Through the accumulated understanding on this site we have been able to undertake additional research in response to emerging demands, including analysis of long-term vegetation change, volcanic ash deposition sampling and investigations into long-term changes in snowfall patterns.

The Snowdon ECN site is jointly funded by the Countryside Council for Wales (CCW) and the Welsh Government. As a long-term, multi-parameter surveillance site it collects a vast range of data (Table 1). Physical measurements include meteorology and surface water discharge. Chemical analysis is undertaken on precipitation, surface water and soil water for pH, conductivity, alkalinity and a range of chemical ions. Biological recording includes seasonal recording of birds, bats, frog spawning, butterflies, ground predators, spittle bugs and vegetation. Finally, land-use activities, specifically sheep grazing intensity, are also recorded.

Supplementary non-ECN measurements are also undertaken: these include snow-lie duration, phenology (the timing of biological events), arctic-alpine plant and fungal monitoring. Samples are also collected in support of partner networks including the UK Eutrophying and Acidifying atmospheric Pollutants (UKEAP) network.

### Snowdon's history

Snowdon is an iconic site in Wales. It is the highest mountain (1085m) south of the Scottish Highlands. Current uses of Snowdonia's upland ecosystems are only a part of a long history of human use of this environment. Post-glacial conditions enabled a forest cover to develop over much of Snowdonia, and by the Mesolithic (about 8,000 years BP) humans started to utilise the local resources provided by woodland, taking deer, aurochs and wild boar for food and timber for fuel and building materials[23]. The exploitation of these resources then evolved into forms of shifting agriculture during the Neolithic, together with the early exploitation of minerals. Agriculture slowly expanded and by the 12th century systematic woodland clearance became more advanced with the shift from woodland exploitation to farming[23].

By the 18th century mixed farming had been replaced by sheep-dominated husbandry, together with an expansion of mining for minerals such as arsenic, copper, lead and slate[23]. Mining peaked during the industrial revolution and had ceased by the end of the First World War.

The history of human use of the area has resulted in a complex tapestry of vegetation overlying a postglacial landscape valued for its cultural, farming and environmental resources. These environmental resources include many rare and important species and habitats.

In conservation terms, it has been designated as a National Nature Reserve and forms a part of the Eryri Site of Special Scientific Interest and the Eryri Special Area of Conservation designated under the EU Habitats Directive. The site is particularly important for its assemblage of relict arctic-alpine species and montane habitats, many of which occur here near the southern limit of their range in the UK. It also has possibly the largest number of visitors of any mountain in the UK.

Table 1: Monitoring carried out at the Snowdon ECN site

| DRIVER OR RESPONSE VARIABLE | MEASUREMENT | METHOD | FREQUENCY |
|---|---|---|---|
| TERRESTRIAL: Physical | | | |
| Meteorology | Temperature, precipitation, wind speed and direction, solar irradiance | Automatic weather station and manual measurements | Hourly and weekly |
| Water discharge | Surface water discharge | Automatic recorder | Every 15 minutes |
| Snow-cover recording | Snowline, snowpatch duration | Manual estimates of altitude and duration | Weekly (autumn–spring) |
| TERRESTRIAL: Chemical | | | |
| Atmospheric chemistry | Oxides of nitrogen | Diffusion tubes | Fortnightly |
| | Sulphur dioxide | Diffusion tubes | Monthly |
| | Ozone & oxides of nitrogen at Marchlyn Mawr for Welsh Air Quality Forum & UKEAP | Automatic analyzer | Hourly |
| | Ammonia for UKEAP | Diffusion tubes and Alpha sampler | Monthly |
| | $NO_2$ diffusion tube for UKEAP | Diffusion tubes | Monthly |
| Rainfall chemistry | pH, conductivity, alkalinity, Na, K, Ca, Mg, Fe, Al, $NO_x$, $SO_4$, Cl, $PO_4$, DOC, Total N, alkalinity | Chemical analysis | Weekly |
| Rainfall chemistry for UKEAP | | Chemical analysis by UKEAP | Fortnightly |
| Water chemistry | | Chemical analysis | Weekly |
| Soil solution chemistry | | Chemical analysis | Fortnightly |
| Soils | Physical structure and chemistry | Physical and chemical analysis | 5- and 20-yearly |
| TERRESTRIAL: Biological | | | |
| Vertebrates | Bats | Counts along two transects | Four times yearly |
| | Birds | Breeding Bird Scheme | Twice yearly |
| | Frog spawning | Timing of lifestage events, chemical analysis | Weekly during season |
| Invertebrates | Butterflies | Butterfly Monitoring Scheme | Weekly (April - September ) |
| | Ground beetles and spiders | Species and individual counts | Fortnightly (March - November) |
| | Spittle bugs | Quadrat counts | Twice yearly |
| Vegetation | Fine-grain sampling | Quadrat counts | 3-yearly/subset annually |
| | Coarse-grain sampling | Quadrat counts | 9-yearly |
| | Arctic-alpines | Quadrat cell counts | 3 yearly/subset annually |
| | Phenology for UK Phenology Network | Flowering species counts | Weekly |
| Pollen for Pollen Monitoring Programme | Rainwater collection | Pollen grain counts | Quarterly |
| Fungi | Fungi | Species counts | Fortnightly |
| Land use | Sheep and goat numbers | Counts within sample areas | Weekly |
| FRESHWATER: Physical & Chemical | | | |
| 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 |
| Conductivity and temperature | Conductivity and temperature | Automatic logger | Every 15 minutes |
| FRESHWATER: Biological | | | |
| Vegetation | Aquatic macrophytes | Species percentage cover | Annually |
| Phytoplankton | Chlorophyll-a | Acetone extract | Monthly |
| Invertebrate fauna | Macro-invertebrates | Species counts from kick sampling | Twice yearly |
| Diatoms | Epilithic diatoms | Slide counts from submerged rocks | Annually |

Core ECN terrestrial and freshwater measurements are fully described in published texts[27,28]. UKEAP = UK Eutrophying and Acidifying Pollutants Network

## Building community capital

ECN undertakes capacity-building work by providing opportunities for students to undertake dissertation projects and also through a research partnership with a number of Welsh universities and the Centre for Ecology and Hydrology.

Under this partnership Stephanie McGovern recently completed her PhD[19] on the long-term processes of change in vegetation (see vegetation results) and soils on the ECN site. The results of this work are beginning to appear as research papers[18].

Training is also periodically available for those not in employment or education.

In addition to more formal research, work with students and volunteers helps to support those interested in developing careers in ecology and in the Welsh environment.

# Climate

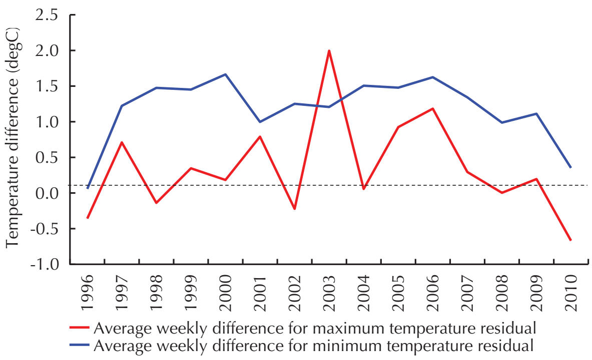
The ECN has observed changes in temperature and rainfall at both the Snowdon site and at the UK network level.

Concern over climate change has prompted much modelling of future climate change scenarios. Based on medium emission scenarios for the UK, it is estimated that, by 2080, average winter temperature will have increased by 2.8°C and average summer temperature by 3.5°C. Over the same timescale, average precipitation is predicted to increase by 19% in winter and decrease by 20% in summer (UKCP09 http://www.ukcip.org.uk/ukcp09).

The differences between the weekly temperatures recorded by ECN in each year of its operation (1995-2010) and the average weekly temperatures recorded during an earlier reference period (1966-1977) – 'temperature residuals' – are used to investigate changes between the two periods. This approach shows that average weekly minimum temperatures were consistently higher throughout 1995-2010 than in the earlier period, and that average weekly maximum temperatures were higher in most years (Fig. 1). Over the ECN recording period, increases were recorded in average weekly measurements of maximum air temperature (0.34°C), minimum air temperature (1.18°C), minimum grass temperature (2.02°C) and soil temperature (0.87°C). This long-term pattern is modified by shorter term weather events, such as the warm summer of 2006 and the cooler winters of 1995/96 and 2009/10.

Increases in average maximum weekly temperature are most pronounced in spring (+1.22°C), while average minimum temperatures have increased in all seasons, though again they are most pronounced in spring (+1.88°C).

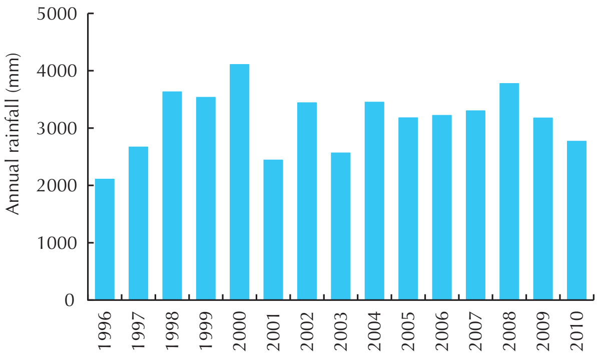
**Figure 1** Average annual maximum and minimum temperature residuals over the period 1995-2010 compared to 1966-77 data.




Across the network as a whole, a significant warming trend of 0.9°C was recorded between 1992 and 2007 (ranging between 0.6°C and 1.1°C for different ECN sites). Upland sites showed a greater increase (1.2°C) than lowland sites (0.7°C)[22]. Since 2007, however, on Snowdon, this trend has been disrupted as a result of the cooler winters experienced over recent years.

Annual rainfall totals on Snowdon show large variation, with 2000 exhibiting a peak value of 4109mm (c. 13.5ft of rain) (Fig. 2). Overall there is a small upward trend in total annual precipitation.

**Figure 2** Annual precipitation 1996-2010.




Comparison of annual rainfall totals across the network has revealed a significant increase in precipitation of over 170mm, though no distinct difference in trend between upland and lowland sites is evident.

**Figure 3** Winter on Snowdon in late 1960s (L) (© Don Perkins) and early 2009 (R).

## Weather extremes

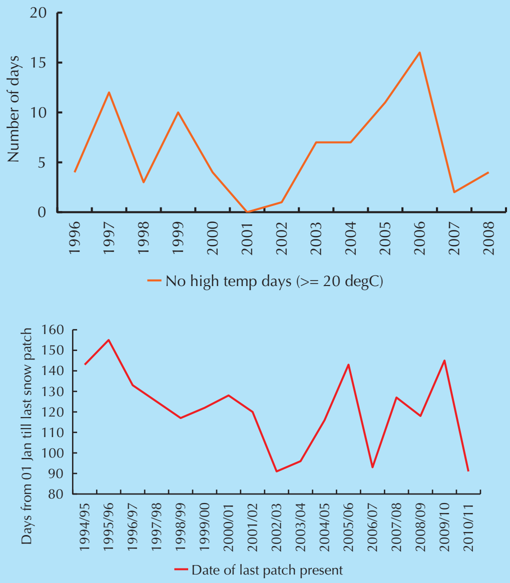
The effects of changes in climate on the Snowdon ecosystem come about not only as a consequence of changes in mean values, but also of changes in the frequency of occurrence of episodic and extreme events. Some of these are driven by varying atmospheric circulation patterns shown by changes in the North Atlantic Oscillation index and the Arctic Oscillation index.

Strong westerly storms can deposit considerable amounts of marine sulphate and chloride from the Irish Sea and Atlantic Ocean into the water bodies of Snowdon, producing acidification events when their acid neutralizing capacity is exceeded. As a result the recovery of these water bodies, following the acidification of the mid and late 20th century caused by industrial airborne pollution, can be slowed down.

A situation where the benefits to ecosystem recovery arising from emission controls could be negated by shifts in storm events potentially arising from climate change patterns has been suggested under UKCP09.

The annual number of high temperature days (defined as those where the temperature exceeds 20°C) show a small increase but with a large amount of year to year variation (Fig. 4a).

**Figure 4** (a) Number of high temperature days (over 20°C) over the period 1996-2008; (b) Date of last snow present on the ECN site 1994/5 - 2010/11.




The warming trend is also impacting snowfall patterns on Snowdon (Fig. 3), with gradually earlier dates for final snow patch melting. The late melting snow of 2009/10 compared with 2010/11 illustrates the variability of the winter climate on Snowdon (Fig. 4b).

# Pollution

The ECN monitors long-term changes in the concentration of a number of air pollutants such as sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$) (the components of 'acid rain') and ammonia ($NH_3$). These pollutants, which originate from a number of sources including power stations, vehicle emissions and shipping, are transported within the atmosphere, so impacting both land and water. At the Snowdon site, in keeping with the wider network, these pollutants are recorded in air, precipitation, soil and stream water.

## Sulphate and sulphur dioxide

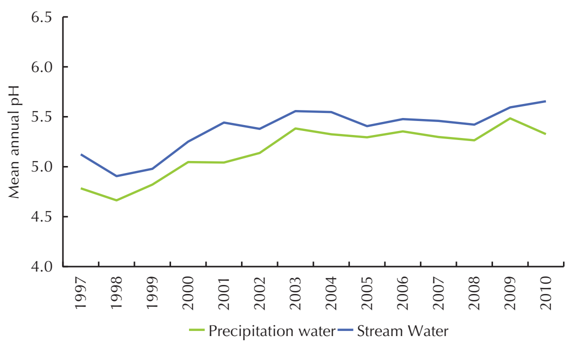
At a national and wider EU level atmospheric chemistry data shows a decrease in dry deposition of $SO_2$ following reductions in emissions since the 1970s as a result of the Gothenberg Protocol[24]. Within the ECN this decline is also evident, with the reduction in sulphate being particularly notable[22].

A decrease in atmospheric pollutants (Fig. 5), in response to emission control policies, can help the gradual recovery of both terrestrial and freshwater ecosystems from historic acidification events, particularly those associated with 'acid rain' and will have continued benefits for our ecosystems.

Analysis of ECN precipitation and stream water samples clearly demonstrates the continued increase in pH (Fig 5a) as sulphate ($SO_4^{2-}$) levels fall (Fig. 5b).

**Figure 5** Changes in (a) pH over the period 1997-2010 and (b) wet-deposited sulphate ($SO_4$) over the period 1997-2010 (left-hand axis) and dry deposited $SO_2$ over the period 2002-2010 (right-hand axis).

(a)

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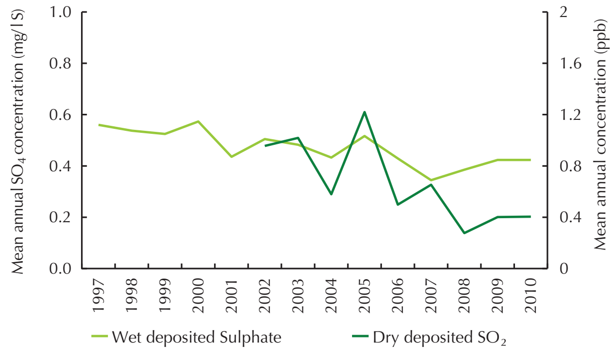
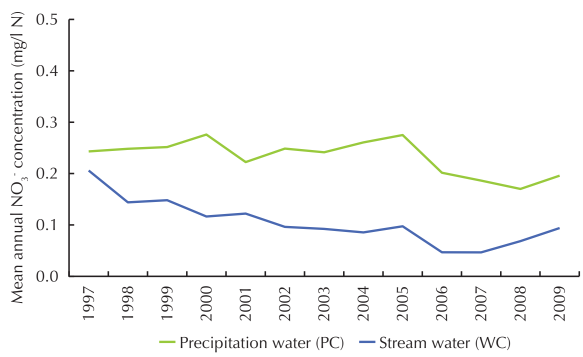



## Nitrate and oxides of nitrogen

Nitrogen deposition can have important consequences for vegetation, particularly in low nutrient habitats such as those found on Snowdon (e.g. causing nitrogen-loving species to increase in abundance). Despite reductions in emissions of c.50% between 1970 and 2007[24], the total UK deposition of $NO_x$ has fallen little.

ECN precipitation and stream water samples are analysed for nitrate ($NO_3$-N) concentrations and show a decrease in concentration (Fig. 6). Deposition of nitrates at these levels can potentially impact the plant communities on Snowdon as suggested in recent vegetation research[18] which found a reduction in species richness coupled with an increase in the grass:forb ratio since 1968.

**Figure 6** Changes in the concentration of Nitrate ($NO_3$-N) over the period 1997-2010 in rainfall (PC) and stream water (WC)




## Ozone

A third pollutant regularly sampled as part of the ECN project is ozone. Whilst ozone ($O_3$) is a natural constituent of our upper atmosphere, industrial activity has raised concentrations in the lower atmosphere where it can have negative impacts on human health (e.g. through increased asthma levels). Low altitude ozone can also have a significant negative impact on plant growth including both crops and natural plant communities.

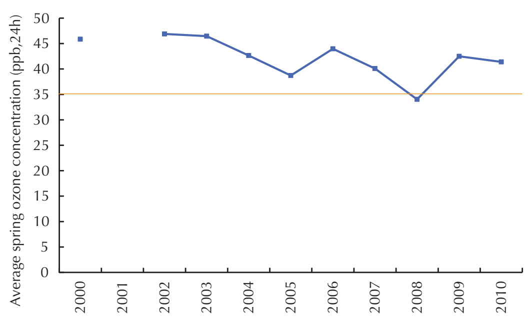
Concentrations of ozone fluctuate considerably from year to year due to variations in meteorological factors. During settled periods with strong sunlight low altitude ozone concentrations can rise considerably. Nationally, emission controls appear to have reduced such peak $O_3$ levels by 30ppb since the 1990s in the UK[24]. In contrast the average UK background concentration has continued to rise with an upward trend in the last 20 years of 0.2ppb per year[24]. More recently, however, observations suggest that the historic trend may now be levelling out[8].

Recent UK studies[24] have demonstrated that plants are susceptible to ozone damage at not only the peak levels but also the recorded background levels. Whilst some estimates have been made of the economic cost of such damage to arable land and horticulture in the UK[13], our knowledge of the potential impact on natural and semi-natural plant communities is limited and further research is required.

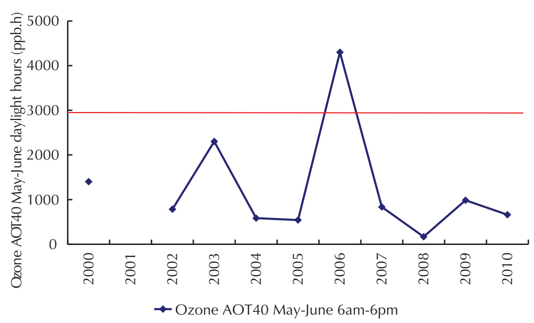
Investigations into ozone levels[24] suggest that northern hemisphere background concentrations have now increased to such a degree (24hr average concentration of 35ppb), that they may well be damaging sensitive species during spring in parts of the UK, including upland Wales. The ECN site has recorded 24 hr average concentrations exceeding 35ppb for more than 50% of the recording period (Fig. 7a).

**Figure 7** Ozone concentrations at Marchlyn Mawr (2000-2010). (a) average spring concentration (b) accumulated dose over 40 ppb

(a)




(b)




AOT40, the accumulated dose over 40ppb during daylight hours in May-July, is a measure of the potential effect of ozone on vegetation. The critical level for semi-natural vegetation, 3000 ppb.h was exceeded in 2006 (Fig. 7b).

The UK level analysis for the UK Air quality indicator suggests that given the recent levelling-off of background ozone levels there is no clear overall UK trend[8]. A similar levelling out of ozone concentration has been observed in Wales[1].

## Land use

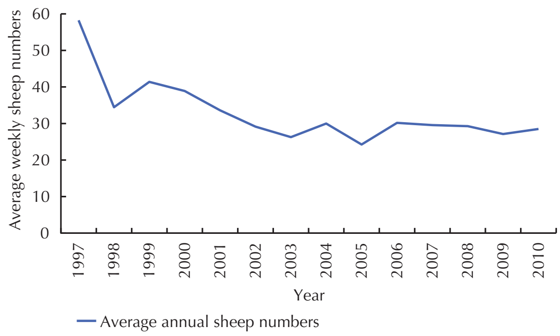
There has been a long history of livestock grazing in Snowdonia. Cattle were once far more common in the uplands than they are now[14] and were grazed together with goats and sheep. Such farming involved transhumance, with small-scale arable and hay production for local use. This system remained until the 18th Century when the shift to sheep-dominated grazing began with parliamentary enclosure acts. There is the remains of an old hafodty (summer shieling) within the ECN site which was still occupied seasonally in the late 1770s.

Sheep numbers rose gradually through the 18th Century until after 1945 when numbers increased more dramatically, particularly in the 1970s as a result of sheep farming support following the UK's entry into the European Community[15].

At high densities, sheep selectively search out the more palatable plant species, reducing the cover of herbs, which are subsequently replaced by less palatable species. This has the effect of producing swards with reduced plant species diversity, both from an ecological and a landscape perspective.

Following reform of the Common Agricultural Policy, headage-based payments were replaced by an area-based payment system in 2005[16]. As a result sheep numbers have fallen generally. On the ECN site (Fig. 8) sheep numbers have declined by approximately 50% since 1997.

**Figure 8** Average numbers of sheep on the Snowdon ECN land-use monitoring plot (13ha, 1997-2010)



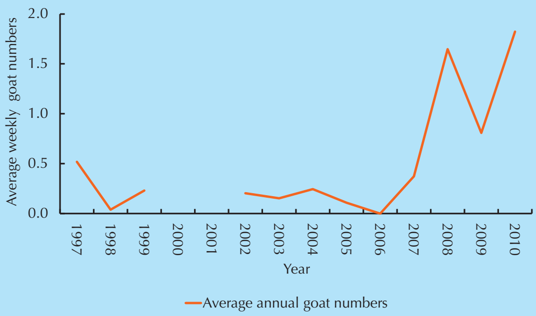
The impact of grazing by livestock has modified the vegetation in the uplands, converting many areas of heathland to acid grassland[16]. Monitoring of livestock numbers on the study site enables the relationship between grazing impacts and vegetation change to be investigated.

### Feral goats

Feral goats are an iconic species in the north Wales mountains, being the largest 'wild' mammal many visitors see. Farmed in the UK since Neolithic times[31], goats now constitute a self-sustaining feral population in Snowdonia. They often graze areas avoided by sheep such as cliff ledges and rocky outcrops. As a result their impact on relict arctic-alpine vegetation can be greater than that of sheep. The full extent of their impact on these ledge communities remains of concern.

Warmer winter and early spring weather during the last 13 years have ensured the survival of larger numbers of new-born kids and the population of goats on the ECN site has increased (Fig.9). In 2010-2011, 59 different individuals were noted on the ECN site.

**Figure 9** Average numbers of feral goats on the Snowdon ECN land-use monitoring plot (13ha,1997-2010)




## Biodiversity

Scientifically robust monitoring of the natural environment is necessary for detecting and attributing the effects of environmental change on biodiversity[22]. The principal direct drivers of biodiversity loss, in general, have been identified as habitat disturbance, pollution (especially nutrient load), invasive species, over-exploitation and, increasingly, climate change[4].

Long-term ECN monitoring and research helps to build our evidence base and improve our understanding of the relationship between drivers and impacts. The long-term nature of the programme helps enhance our understanding of temporal variability in the environment and the time taken for ecosystems to recover from past events. In addition, the link between biodiversity, ecosystem health and the provision of ecosystem services can increasingly be explored in greater depth.

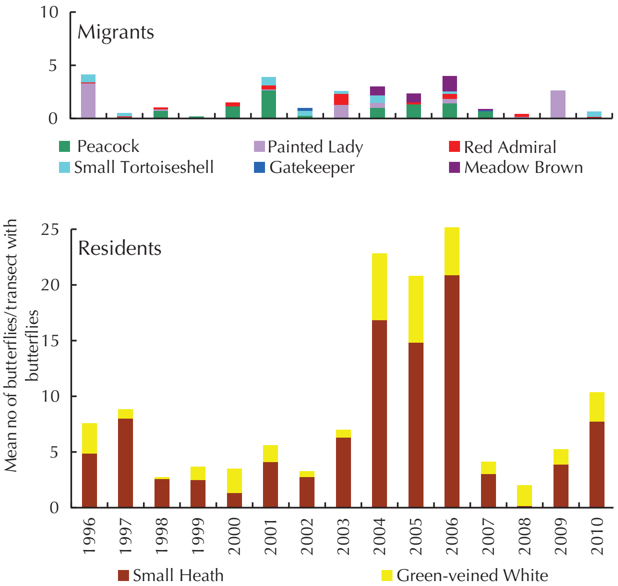
### Invertebrates - Butterflies

Butterfly populations are recognised to be sensitive to environmental change and so are considered to be a useful biological indicator.

UK Network-level analysis shows a significant increase in total butterfly numbers, particularly for upland sites. Single-generation species are increasing at more sites than multi-generation species, and species over-wintering as larvae are increasing at more sites than those over-wintering as eggs[22].

On the Snowdon site 11 species of butterfly have been recorded, the most abundant of which has been the small heath (*Coenonympha pamphilus*). The majority of the recorded species feed on grasses on the sheep-grazed upland pasture or associated wet flushes. Given the upland nature of the habitat, species are sensibly split into resident breeding populations and local or long-distance migrant populations which move into the site from lower levels during the spring and summer (Fig. 10).

**Figure 10** Average numbers of butterfly species per transect (1996-2010) separated into migrant and resident species.




Change over time in these two groups (residents and migrants) is dominated by episodic events. Large increases in the number of individuals from the resident species group were seen between 2004 and 2006, though numbers have since returned to lower levels typical of preceding years (Fig. 10). Conditions during 2004-2006 appear to have favoured both butterfly populations overall and their regional dispersal, as shown by the local influx of a number of other butterfly species to the site e.g. meadow brown (*Maniola jurtina*). The UK Butterfly Monitoring Scheme now considers this species to be increasing in Wales[3].

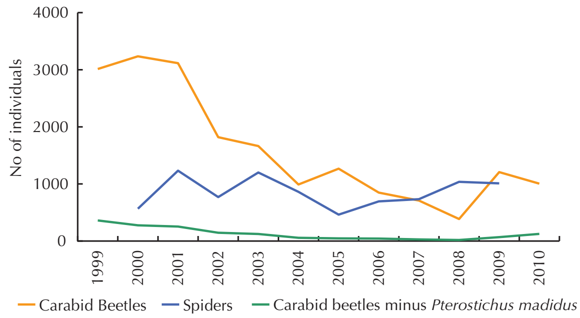
Butterfly numbers can be supplemented by major migratory events such as the influx of long-distance migrants e.g. the painted lady (*Vanessa cardui*). This species arrived in two major pulses during the recording period, in 1996 and 2009 (Fig.10). Butterfly Conservation estimate that up to 100 million painted ladies were in Britain at one stage during 2009[3].

## Invertebrates - Beetles and spiders

Invertebrate predators such as ground beetles and spiders are known to be sensitive to environmental change[11].

Over the recording period (1993-2007) there has been no network-level trend in total beetle numbers or species richness[22]. Monitoring on Snowdon has recorded 32 species of ground beetle on the site, the commonest (over 91% of all beetles caught) being *Pterostichus madidus*, a species of open habitats. Given the overwhelming dominance of this species the observed changes in overall beetle numbers (Fig. 11) are mainly a reflection of changes to *P. madidus* populations. What lies behind the recorded decrease in numbers is unclear, though supplementary work has demonstrated that it is not a result of using pitfall trapping for beetles on the site[29]. There is evidence that the number of species on Snowdon has also decreased over the recording period[22].

**Figure 11** Total numbers of carabid beetles and spiders collected from 30 traps (1999-2010)



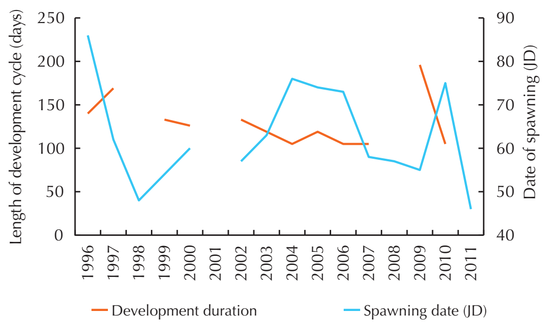

Identifying ecological responses can be complicated by the ecological traits of a given species or community. In the case of spiders, for example, their use of spider silk for ballooning, as a juvenile dispersal mechanism, can mean population and species data for a given site may be heavily influenced by immigration each year. As a consequence of this high dispersal ability, populations recorded on the site may not be demonstrating a response to any site-specific change but a response to more general factors. At present, there is little evidence of any consistent trend in spider numbers on Snowdon (Fig. 11).

## Vertebrates - Frogs

While there is a slight trend towards earlier breeding of frogs on Snowdon (Fig. 12), timing of breeding in amphibians can vary considerably between years e.g. the date of first spawning has spanned a range of 40 days over the recording period. Given such variation, long-term monitoring is essential if we are to separate short-term events from longer term shifts in biological responses to environmental change[6].

Timing of amphibian metamorphosis from spawn through to adult is known to vary in response to environmental cues such as changes in water volume, presumably as an adaptive mechanism to improve survival in response to desiccation risks[20]. However, the trigger for adult emergence prior to spawning is less clear and probably involves a combination of mechanisms, including a period of temperature sensitivity which results in emergence from hibernation when a cumulative temperature has been experienced. Thus variation in springtime temperatures is an important influence on frog emergence.

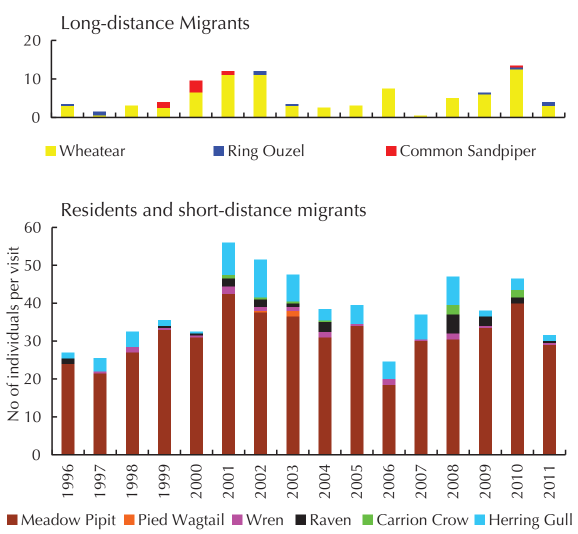
**Figure 12** Trends in the spring spawning date and duration of development of common frog (*Rana temporaria*)

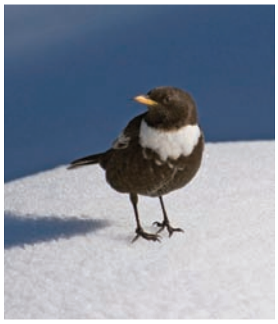



## Vertebrates - Birds

Birds are one of the most familiar parts of the UK's biodiversity, and are the focus of much conservation action and recording effort. Birds are often sensitive biological indicators of many types of environmental change and pollution[9]. They tend to occur near or at the top of food-chains, and by monitoring populations of birds it is possible to infer something about the health of the ecosystems upon which they depend. Eleven species of birds have been recorded on the ECN site during breeding bird surveys, the commonest being wheatear (*Oenanthe oenanthe*) and meadow pipit (*Anthus pratensis*) (Fig. 13).

**Figure 13** Numbers of breeding birds (1996-2010) separated into long-distance migrants or residents and short-distance migrants



Of particular conservation interest on the ECN site is the breeding population of 3-4 pairs of ring ouzel (*Turdus torquatus*) (pictured left), one of the UK's fastest declining upland birds[12], whose numbers in Wales dropped by 69% over the period 1999-2006[14]. This migratory species overwinters mainly in the Atlas Mountains of Morocco and returns each spring to breed in UK uplands. Studies in upland areas in northern Britain indicate the number of breeding territories is strongly related to climate, not only the UK climate but also the climate in their Moroccan wintering grounds[2]. High summer temperatures, intermediate levels of summer rainfall in Britain, and high spring rainfall in Morocco all appear to have a negative impact on territory occupancy in Britain the following year[2]. These impacts may be a consequence of weather-related effects on food availability, e.g. at the point at which adults and juveniles are feeding prior to their migration.

## Vertebrates - Bats

Bats account for a third of UK mammal species and, as top predators of nocturnal insects, they can be useful indicators of the state of our environment[9]. Whilst they occupy a diverse array of habitats their use of uplands is poorly understood. Monitoring on Snowdon has recorded low numbers of just three bat species, common pipistrelle (*Pipistrellus pipistrellus*), Daubenton's bat (*Myotis daubentonii*) and noctule (*Nyctalus noctula*). These low numbers currently prevent the detection of trends specifically for the Snowdon site. Bat monitoring at Snowdon does, however, contribute to the larger monitoring effort across the network, and here ECN has detected a significant increase in the number of pipistrelles[22]. This trend is in line with national population change where bat populations have risen by 20% since 2000 [9].

## Vegetation

Vegetation is sensitive to a variety of pressures, including changes in grazing intensity, nutrient inputs and soil properties. Evidence suggests that nitrogen inputs are responsible for some of the recent changes in vegetation in Britain, including the increase of nitrogen-loving lowland species in upland areas[5]. This change is a result of both historic and current deposition levels.

In a unique new study on Snowdon, it has been possible to investigate the change in plant community composition over a 40-year period, comparing current vegetation with that recorded as part of the International Biological Programme in the 1970s[18]. This study found evidence that the most significant driver of change in vascular plants and bryophytes, as well as in upland soils, is acidification arising from historic deposition of pollutants, particularly sulphur[19]. Analysis suggests the community composition has shifted to one more indicative of acidic habitats, and that species richness has decreased with grasses becoming more dominant over herbs e.g. the grass *Agrostis capillaris* showed a 15.41 ±0.88 increase in % cover[18]. This supports the findings of recent UK-level surveys where competitive species such as grasses were found to have increased and reflected deterioration in upland vegetation condition[5].

Many of the observed changes may result from acidification of soils during the 40-year period between surveys. Although acidification has reduced more recently following emission controls, recovery of vegetation appears to be lagging behind changes to inputs, probably as the innately low-buffering potential of the naturally slightly acidic soils takes time to recover. This in turn has meant that there has been a lag in seeing changes to the plant communities on the site.

The same recently completed research[18] has suggested that different components of plant communities are responding differently to atmospheric inputs. Lower plants respond directly and thus are likely to respond more rapidly to changing pollution levels. In contrast, vascular plants respond more significantly to changes in soil conditions and so their response can take much longer to be fully realized.

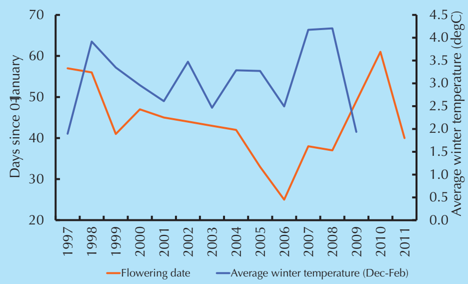
Routine vegetation sampling on the ECN site in 2000 and 2010 has shown a significant increase in frequency of dwarf-shrub species (such as heather) in areas of acid grassland. This is believed to be a result of the reduction in grazing intensity across the site (Fig. 8). Detailed vegetation sampling will continue to investigate the complex relationship between vegetation composition, land use and atmospheric deposition.

### Purple saxifrage

Purple saxifrage is one of the most striking of the arctic-alpine relict species which have survived in the north Wales mountains since the last Ice Age. The plant has a lower altitudinal limit of around 400m-500m on Snowdon and its distribution is limited by the 26°C mean maximum annual temperature isotherm[7] indicating that marginal populations are susceptible to climatic warming.

Monitoring of the species between 1997 and 2011 indicates that, since 1997, first flowering has, on average, taken place 7 days earlier, although in 2010 flowering again occurred around the same date as in 1997 (Fig. 14). The monitoring sites are all at the minimum altitude for the species in the area. Although this earlier flowering follows the general warming trend on Snowdon, the precise mechanism involved is difficult to elucidate with what is still a relatively short run of data.

**Figure 14.** Date of first flowering of purple saxifrage (*Saxifraga oppositifolia)* on slopes above Llyn Llydaw with average winter temperature (1997-2011)




## ECN and Ecosystem services

Through its Natural Environment Framework, the Welsh Government aims to implement an ecosystem approach under which ecological processes will be safeguarded. This is part of a wider response at national[17,30] and international levels that reflects an emerging consensus on the importance of ecosystem processes for society[21]. These processes provide the basic resources - food, water and air - essential for human life. Among many other things, they are also the means by which air and water quality are regulated, and waste materials broken down. These are all examples of what have come to be termed 'ecosystem services' – aspects of ecosystems that in some way, directly or indirectly, underpin human well-being. Commonly, such services are classified into four types:[21]

**Supporting services** - such as nutrient cycling and ecological processes.

**Regulating services** - such as local climate regulation, soil, air and water quality.

**Provisioning services** - such as food production, water and peat.

**Cultural services** - including national icons, recreation and tourism[21].

The supply of these services is underpinned by an array of varyingly complex and interacting ecological processes. The recent national assessment of UK ecosystems[30] and the Countryside Survey[26] have recognised the contribution which ECN can make to enhancing our understanding of ecological processes, and how they change over time in a number of different mediums such as soil, air and water.

The monitoring undertaken at ECN sites has particular value in relation to supporting and regulating services, not least because these services are poorly covered by most other routine monitoring activities.

A much wider range of ecosystem services is, however, provided by ECN sites. In a recent ECN-wide assessment, 73 ecosystem services, either direct or proxy services, were identified[10]. Through an analysis of biogeographical data, ECN sites were placed into one of four groups.

Snowdon was assigned to the upland group together with Cairngorm (Scotland) and Moor House (Northern England). The principal differences in services provided by the three upland sites lay within the cultural services, with Snowdon providing 33 services in contrast to 28 for both the Scottish and English sites (key additional services include climbing, military training and film production at Snowdon).

This ECN study emphasised the iconic status of Snowdon and the importance of this upland area, with its characteristic landscape, biodiversity and geodiversity, as a tourist attraction and place for outdoor recreation. With around 500,000 visitors to the site each year (data from Snowdonia National Park and Snowdon Mountain Railway), Snowdon is one of the most heavily used ECN sites in the UK.

The many services identified for Snowdon illustrate the significance of such ecosystems to society. How we have used our environment in the past, how we use it in the present and how we use it in the future will all influence the resilience of our ecosystems together with the quality and extent of the services they provide to future generations.

## Snowdon ECN – an important part of our evidence base

After 15 years of recording on Snowdon we are able to see the impact of anthropogenic factors in the Snowdonia environment, as described in the preceding pages. But the value of the Snowdon site lies not only in its capacity to tell us about local changes but also, by virtue of it being part of a larger network, in its contribution to a collective exercise that tells us about environmental change more widely. By looking across the network as a whole, we are able to see whether local changes are specific to Snowdon or have been mirrored by changes at other sites.

It is clear that the network, though relatively small, is capable of detecting trends in a range of different variables (Table 2). While it is sensible that some caution be exercised in interpreting data from what is still a relatively short period of data collection, we believe that the data series are now of a length that they will increasingly yield information about how different aspects of the various monitored ecosystems are changing, how and why such changes occur, and the consequences of these changes.

A case in point is recent work[22] that investigated trends in a number of variables across the network over the period 1992-2007. The most noticeable upward trends across the network are for temperature, precipitation and soil pH. Trends specific to upland sites include increases in butterfly species and numbers, and a downward trend in numbers of ground predators seen on Snowdon and Cairngorm. (An earlier analysis of ground beetle numbers[25] indicates a geographical split in the UK, with numbers of individuals decreasing in the north-west upland sites while generally increasing in most of the south-east lowland sites.) Some trends are less consistent across the network, where local conditions may be more important (e.g. for Ammonia $NH_3$), with many sites not showing a distinct change.

The strength of ECN is its ability to monitor causes and consequences of environmental change in the same programme, at the same locations, using highly standardized procedures. The ability to attribute causes to observed changes is essential if we are to understand the effects of our actions on the environment and to support the development of environmental policy and management in the 21st Century.

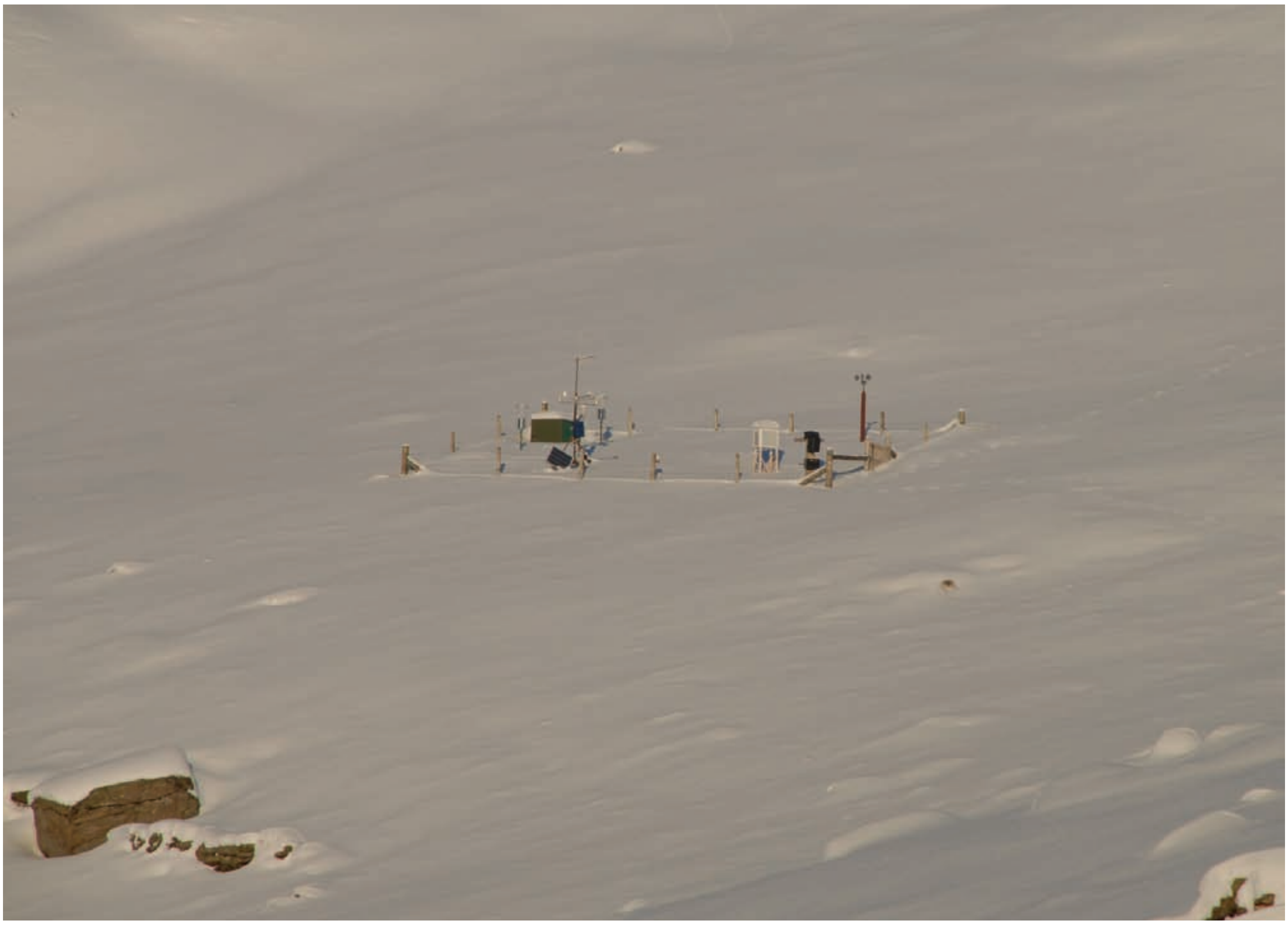


**Table 2:** Summary of major trends in UK ECN sites over the period 1992-2007[from 22]. Red arrows indicate upward trends and blue arrows downward trends.

| Site | UPLAND | | | | | LOWLAND | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Snowdon | Moor House | Sourhope | Glensaugh | Cairngorm | North Wyke | Alice Holt | Rothamsted | Wytham Wood | Drayton | Hillsborough | Porton Down |
| Nitrogen deposition rank across ECN sites | 1 | 4 | 7 | 3 | 11 | 5 | 8 | 9 | 6 | 10 | 2 | - |
| Temperature | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | - |
| Precipitation | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | - |
| Ammonia ($NH_3$) | | ↑ | | ↑ | | | | ↑ | ↓ | ↓ | | - |
| Soil pH | ↑ | ↑ | ↑ | ↑ | ↓ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| Vegetation - species richness | ↓ | ↓ | | | | ↓ | ↑ | | | | | |
| Nutrient - Ellenberg N | ↓ | | | | | | | ↓ | ↓ | | | |
| Butterfly - species richness | ↑ | ↑ | | | | | | | | | | |
| Butterfly - total number | | ↑ | ↑ | | ↓ | | | | | | | |
| Carabid - species richness | ↓ | | | | ↓ | | | | | ↓ | | ↑ |
| Bat - pipistrelles | | | ↑ | | | | ↑ | | | | | ↑ |

# References:


1 Air Quality in Wales (2010) Welsh Air quality forum. http://www.welshairquality.co.uk/trend.php

2 **Beale, C.M. et al.** (2006) Climate change may account for the decline in British Ring Ouzels Turdus torquatus. Journal of Animal Ecology 75:826-835.

3 **Botham, M.S. et al.** (2009). United Kingdom Butterfly Monitoring Scheme report for 2009. Centre for Ecology & Hydrology, Wallingford.

4 **Butchart, S.H.M. et al. (2010)** 'Global Biodiversity: Indicators of Recent Declines', Science, 328: 1164-68.

5 **Carey, P.D. et al.** (2008) Countryside Survey: UK Results from 2007. NERC/Centre for Ecology & Hydrology, 105pp.

6 **Corn, P.S.** (2003) Amphibian Breeding and Climate Change: Importance of Snow in the Mountains. Conservation Biology 17(2):622-625.

7 **Dahl, E.** (1998) The Phytogeography of Northern Europe. Cambridge University Press.

8 **Defra** (2011) Air quality indicator for sustainable development 2010 - Final Results. Available at HYPERLINK "http://uk-air.defra.gov.uk/news" http://uk-air.defra.gov.uk/news

9 **Defra** (2011) UK Biodiversity Indicators in Your Pocket 2011. Department for Environment, Food and Rural Affairs, London.

10 **Dick, J. et al.** (2011) A comparison of ecosystem services delivered by 11 long-term monitoring sites in the UK Environmental Change Network. Environmetrics 2(5): 639-648.

11 **Eyre, M.D. et al.** (1989). Ground beetles and weevils (Carabidae and Curculionidae) as indicators of grassland management practice. Journal of Applied Entomology. 10: 508-517.

12 **Gregory, R.D., Wilkinson, N.I. et al.** (2002) The population status of birds in the United Kingdom, Channel Islands and Isle of Man: an analysis of conservation concern 2002:2007. British Birds, 95:410–448.

13 **Holland, M. et al.** (2006) Development of a framework for probabilistic assessment of the economic losses caused by ozone damage to crops in Europe. Centre for Ecology and Hydrology. (Natural Environment Research Council).

14 **Hughes, R.E. et al.** (1973) Studies in sheep populations and environment in the mountains of north-west Wales. The status of the sheep in the mountains of North Wales since mediaeval times. Journal of Applied Ecology 10:113-132.

15 **Johnstone, I.G., Thorpe, R.I. and Noble, D.G.** (2010) The state of birds in Wales. RSPB Cymru, Cardiff.

16 **Jones, B.** (2007) A framework to set conservation objectives and achieve favourable condition in Welsh upland SSSIs. Countryside Council for Wales.

17 **Lawton, J.H., et al.** (2010) Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.

18 **McGovern, S. et al**. (2011) Identifying drivers of species compositional change in a semi-natural upland grassland over a 40-year period. Journal of Vegetation Science 22: 346-356.

19 **McGovern, S.** (2011). Long-term Impacts of Environmental Change on the Soils and Vegetation of Snowdonia. PhD Thesis, Bangor University.

20 **Merila, J. et al. A.** (2000) Adaptive phenotypic plasticity in timing of metamorphosis in the common frog Rana temporaria. Ecoscience, 7(1):18-24.

21 **Millenium Ecosystem Assessment.** (2005). Ecosystems and Human Well Being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

22 **Morecroft, M.D. et al.** (2009) The UK Environmental Change Network: Emerging trends in the composition of plant and animal communities and the physical environment. Biological Conservation 142: 2814-2832.

23 **Rhind, P. and Jones, B.** (2003) The vegetation history of Snowdonia since the late glacial period. Field Studies 10:539-552.

24 **RoTAP** (2010) Review of Transboundary Air Pollution. Centre for Ecology and Hydrology. Available at HYPERLINK "http://www.rotap.ceh.ac.uk/documents" www.rotap.ceh.ac.uk/documents

25 **Sier, A.R.J. and Scott, W.A. (eds)** (2008) North-South divide – climate impacts on UK ground beetles, pp5-6 in Climate change impacts: evidence from ECN sites. 26pp. Lancaster, UK.

26 **Smart, S., et al.** (2010). An Integrated Assessment of Countryside Survey Data to Investigate Ecosystem Services in Great Britain. Technical Report No. 10/07 NERC/Centre for Ecology & Hydrology 230pp. (CEH Project Number: C03259).

27 **Sykes, M.A. and Lane, A.M.J.** (1996) The UK Environmental Change Network: Protocols for Standard Measurements at Terrestrial Sites. The Stationery Office, London.

28 **Sykes, M.A., Lane, A.M.J. and George, D.G.** (1999) The UK Environmental Change Network: Protocols for Standard Measurements at Freshwater Sites. The Stationary Office, London.

29 **Turner, A.J., Bowmaker, V. and Lloyd, D.S.,** (2010). Environmental Change Network Yr Wyddfa/Snowdon ECN Site. Progress report to the Welsh Assembly Government for financial year 2009/2010. CCW Staff Science Report Number 10/2/1.

30 **UK Ecosystem Assessment** (2011) The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge..

31 **Yalden, D.** (1999) The history of British mammals. Poyser, London.

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