Climate change impacts
evidence from ECN sites

Edited by

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Environmental Change Network

ECN partners

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- Biotechnology and Biological Sciences Research Council, through:
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  - *Institute of Grassland and Environmental Research, North Wyke*
  - *Rothamsted Research*
- Cyngor Cefn Gwlad Cymru - Countryside Council for Wales
- Cynulliad Cenedlaethol Cymru - The National Assembly for Wales
- Defence Science and Technology Laboratory
- Department for Environment Food and Rural Affairs, through:
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On the cover: *(i) Part of an automatic weather station (AWS) at the Moor House-Upper Teesdale ECN site; (ii) red admiral*

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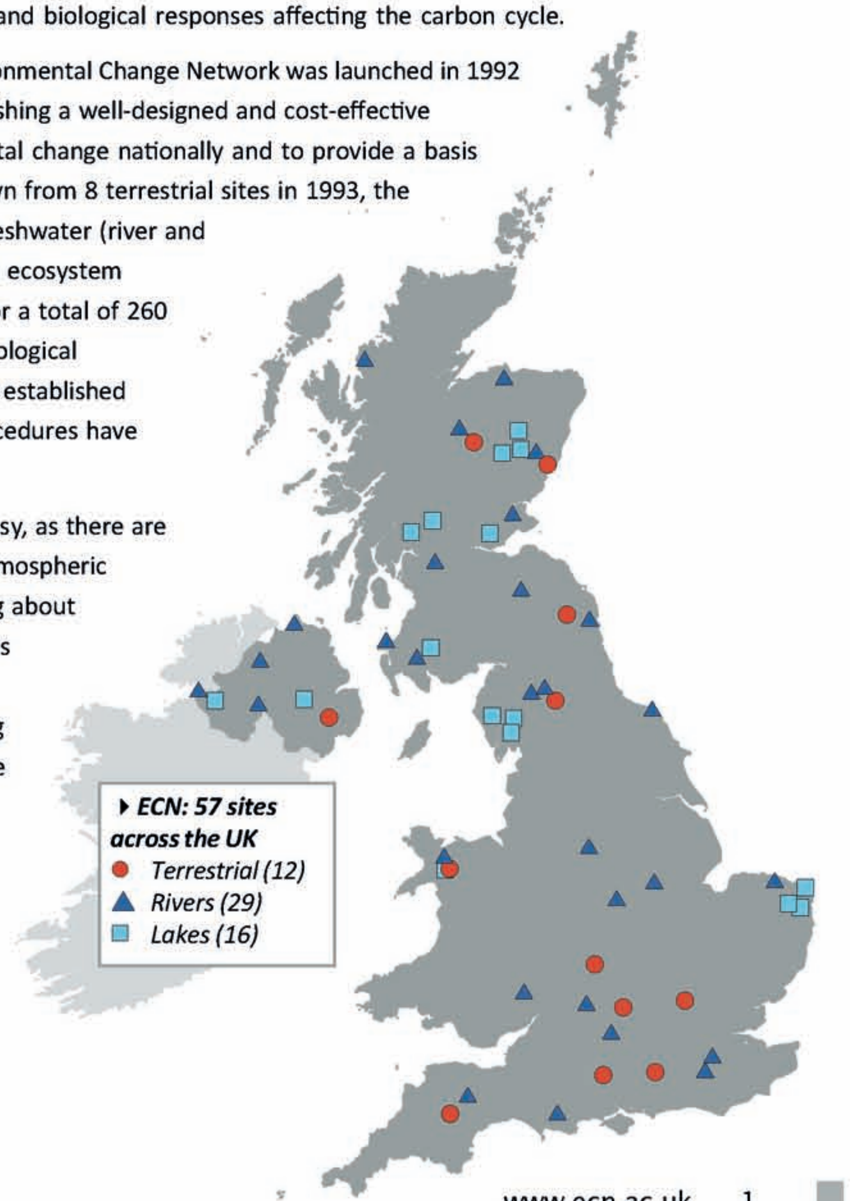
Climate change impacts: Evidence from monitoring

We are living through a period of unprecedented global warming. In the UK, this may be having various impacts, as a result of a changing climate, on animal and plant species and the ecosystems they inhabit. Some of these changes may be beneficial, but others may represent a serious threat to 'ecosystem services', i.e. the processes by which environments produce resources of benefit to people.

The Environmental Change Network (ECN) provides detailed, regular and high quality measurements at a range of sites across the UK to identify and quantify ecological responses to changes in climate and other pressures. This publication highlights some of the findings from ECN monitoring and research which provide evidence of the sensitivity of natural ecosystems in the UK to variability and change in climate. These include assessments of population dynamics, responses to extreme events (drought), changes to the timing of lifecycle events (phenological changes) and biological responses affecting the carbon cycle.

The UK Environmental Change Network was launched in 1992 as a multi-agency programme with the aim of establishing a well-designed and cost-effective network to identify, assess and research environmental change nationally and to provide a basis for international collaboration. The network has grown from 8 terrestrial sites in 1993, the first full year of operation, to 12 terrestrial and 45 freshwater (river and lake) sites in 2008[1]. The network has adopted a whole ecosystem approach; standard protocols have been published for a total of 260 measurements[2,3], covering physical, chemical and biological aspects of the environment. A central database[4] was established from the start and quality control and assurance procedures have been developed and implemented.

Attribution of climatic effects on ecosystems is not easy, as there are many other pressures to consider. Drivers such as atmospheric pollution and land use change, for example, can bring about profound changes in ecosystems. Furthermore, drivers may act in combination. Further monitoring and research are required to gain a greater understanding of the cause of observed trends, and ECN is a valuable resource to support this work.



The climate change challenge

UK climate trends and impacts

Climate change is with us. The three warmest years on record have occurred since 1998, 19 of the warmest 20 since 1980. Long-term monitoring by ECN and others is detecting impacts on ecosystems

Frequent and destructive storms, melting polar ice-caps, sea level rise. These are some of the predicted global-scale effects of climate change, but what does climate change mean for the UK, and what is ECN's role in helping societies to face this challenge?

Present day realities

Many of the predicted effects of changing climate can already be detected in the 350 year UK climatic record. The UK Climate Impacts Programme (UKCIP)[1] reports that:

- The 1990s was the warmest decade in central England since records began
- Warming over land has been accompanied by warming of UK coastal waters
- Summer heatwaves have become more frequent, while there are now fewer frosts and winter cold spells
- Over the last 200 years, winters have become wetter compared with summers and a larger proportion of winter rain and snow now falls as heavy rainfall events than was the case 50 years ago
- Since the start of the 20th century, the average sea level around the UK has risen by about 10 cm.

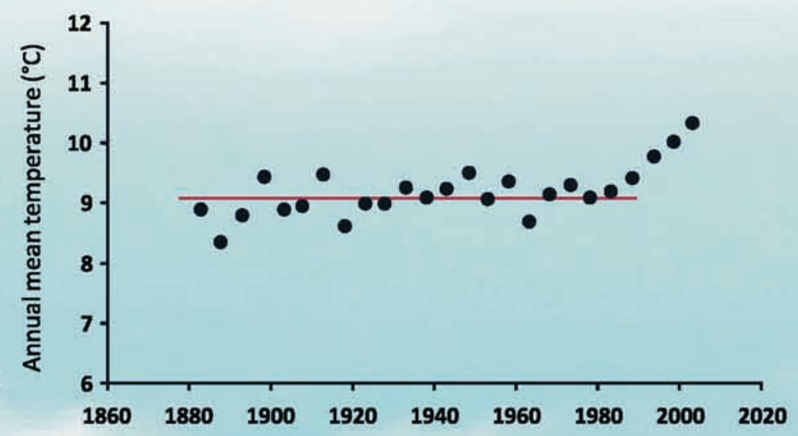
Climate predictions

Climate change scenarios have been developed by the UKCIP to show possible changes in climate over the 21st century[1]. The UK's climate is predicted to become warmer during all seasons, with drier summers and wetter winters. The models predict:

- A rise in mean annual temperature of between 2 and 3.5°C by the 2080s (up to 5°C in some areas)
- More frequent occurrences of extreme high summer temperature
- Fewer very cold winters
- Increased temperature of coastal waters
- Increased intensity of heavy winter rainfall events, but less snowfall
- Sea level rise in all areas, up to 86 cm in southern England by the 2080s.

The climate change challenge

Climate change impacts the natural environment. Some species inhabit limited climatic 'spaces'. As the climate changes so these spaces shift northward (and up mountains), and more mobile species are expected to migrate with them. In contrast, less mobile species could become increasingly restricted because of habitat fragmentation and shrinking climatic space. Climate-driven migration also leads to changes in competition among species. The timing of many natural events (phenology) is also changing, causing problems when tightly-coupled events (e.g. rearing of young timed to coincide with an abundance of a key food source) become desynchronised.



▲ ***The Rothamsted "hockey stick".*** *Data from the ECN Rothamsted site showing 5-yearly averages of annual mean temperatures from 1878-2005. Temperatures were relatively stable over the period up to the late 1980s. Since then temperatures have generally exceeded the long-term mean (red line; mean for 1878-1990) and indicate progressive warming. (Data courtesy of Rothamsted Research Ltd.)*

Societies and governments must address climate change and its many impacts. The UK government is committed, under the Convention on Biological Diversity (CBD)[2], to protect species and habitats. One of the key drivers of sustainable management of natural resources is the need to maintain functioning ecosystems, which provide 'goods and services' essential for human health and well-being. These services include clean air and water and healthy, productive soils[3].

Certain types of organism are known to play essential roles in maintaining ecosystem health, but the extent to which they are vulnerable to change is not fully understood. How far can an ecosystem be altered before the goods and services upon which we rely become threatened, and what actions might be necessary to safeguard them? The human response to climate change needs to be based on sound evidence. Whole ecosystem studies and long-term monitoring like that undertaken by ECN are critical in helping society meet the challenges.

Long term monitoring and associated research at ECN sites is detecting changes in the abundance of species, range-shifts and phenological changes. At a time when the natural environment is under pressure from multiple factors including air pollution and changes in land use, ECN's integrated monitoring of the physical, chemical and biological environment enables us to disentangle these various effects and determine more confidently the role of climate in driving these changes.

- The growing season for plants in central England has lengthened by about one month since 1900
- Long-term monitoring of beetle populations at ECN sites indicates that southern species generally appear to be increasing in number, whilst northern and western species are declining
- Between 1973 and 1998 more than a quarter of Essex saltmarshes, critical to biodiversity and functioning as important fish nursery grounds and as feeding grounds for birds were lost to rising sea levels
- As spring becomes warmer and longer, swallows are arriving earlier, and there is a trend towards the early leaf emergence of oak trees. At ECN sites, frogs are beginning their breeding cycle earlier
- With only a 1°C increase, egg-laying dates of 20 bird species are 4–17 days earlier than 25 years ago
- Monitoring at the River Bush ECN site indicates that survival rates of North Atlantic salmon, an economically important species, have declined markedly, possibly due in part to climate change

Some impacts of climate change in the UK

Exploring further

The IPCC Fourth Assessment report (published in 2007) is available from the IPCC website: www.ipcc.ch. It presents data that, in the view of the IPCC scientists, indicate the extent of climate change, its impacts, its likely cause and likely scenarios of future climate change.

Climate change scenarios for the UK are prepared by the UK Climate Impacts Programme (UKCIP). For more information see www.ukcip.org.uk.

The Millennium Ecosystem Assessment was a global assessment of the consequences of global change for human well-being, providing a snap-shot of the current state of the world's major ecosystems and the goods and services they provide. For more information see: www.millenniumassessment.org.

The big picture

Long-term monitoring programmes like ECN help us to piece together the bigger picture about climate change, and they play a key role in informing policymakers, decision-makers and society about its impacts. They can also help us to shape appropriate responses. ECN's own contribution to three key aspects of climate change are shown here, with links to relevant articles in this publication and on our website

Key climate change issues and questions		*What can ECN offer?*	*Read more ...*
Understanding impacts	How will biodiversity be affected? Will we lose or gain protected and/or valuable species?	Long-term, species level biological datasets	Butterflies p8 • Atlantic salmon p16
	Might the effects of pressures such as land use change or pollution be exacerbated by climate change?	Co-located physical, chemical and biological measurements	Lakes: climate change and water quality p18
	What is the impact on species and habitats of extreme events, such as drought or flash floods?	Frequent, long-term monitoring picks up extreme events	Drought impacts on invertebrates p10
	What are the consequences for ecosystem services, i.e. the benefits we derive from the natural environment?	Range of terrestrial and freshwater measurements, coupled with opportunities for site-based research	Water quality in lakes p18 and reservoirs p19
	What are the consequences for UK semi-natural habitats?	Detailed soil and vegetation survey data collected	Resistance of vegetation to climate change p14
	Which species make suitable indicators of climate change impacts?	ECN monitors plant and animal communities at sites spanning a range of climatic conditions	Beetles as indicators p6 • Frog phenological responses p12
Capacity building & knowledge transfer	How can indicators be used to support policy- and decision-making?	Data relevant to some existing indicators collected. Additional indicators being developed	See 'indicators' on website (www.ecn.ac.uk)
	How do we develop networks to provide early warnings of change at regional and global scales?	Prominent participation in and development of European and global monitoring systems	European and global monitoring networks p21 • Monitoring UK protected areas p23
	How can we best provide data and information to support ecosystem managers and policymakers?	Easy access to raw, summarised and interpreted data	Salmon fisheries p16 • Upland management p19 • Accessing ECN data p22 • Biodiversity in protected areas p23
	How can awareness be raised and individual behaviour be influenced?	Active public engagement programme; Lead science partner in the *Climate Change Explorer* (CCE) project	CCE project: www.climatechangeexplorer.org.uk
Mitigation & adaptation	What are the carbon dynamics of peats, other soils & forests? Can more carbon be stored in these systems?	Long-term soil measurements. Carbon dynamics studied in peatland and forest systems	Carbon in peatlands p19
	Can the resistance of habitats and species to climate change be influenced?	Sites and facilities for experimental research into ecosystem responses	Resistance of vegetation to change p14
	How can we manage the recovery of degraded ecosystems in a changing climate?	ECN can tell us about interactions between climate change and other pressures on ecosystems	Restoration of lake water quality p18 • Recovery of peatlands from acid deposition p19

North-South divide

climate impacts on UK ground beetles

Insect populations in the UK face considerable pressures from both a decline in the availability of suitable habitats and from the effects of climate change, a possibility recently confirmed for British butterflies and moths[1]. ECN monitoring includes butterflies, moths[2], spittle bugs and ground beetles (Carabidae), a group of predatory invertebrate species. They are a useful group to study because, as well as responding directly to environmental factors, changes in their populations may reflect changes in prey populations.

To date, 135 species of carabid have been found at terrestrial ECN sites[3]. Lowland sites have a greater abundance and diversity of carabids than upland sites. Most carabid species have very specific environmental requirements and this is reflected in their distribution, and in the differences observed between sites. Over half of all species recorded are found at only one or two sites, 25% at only one site. At all sites a few species (<5) dominate the species mix, with other species generally found in much lower numbers.

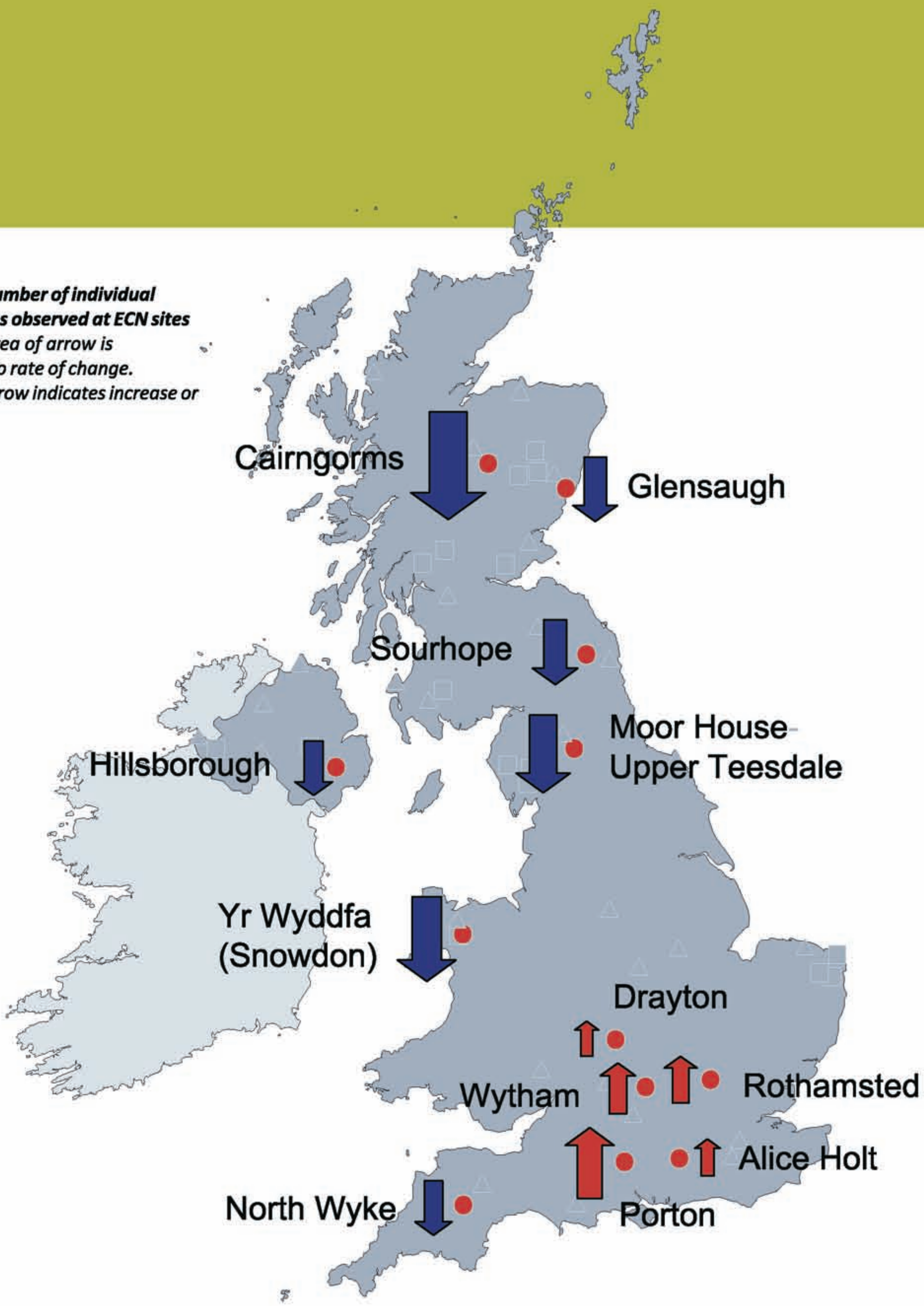
North-south divide

Significant temporal trends in carabid numbers are seen at most ECN sites and they show a very striking geographical pattern: numbers are increasing at sites in the south-east but are decreasing elsewhere (see map).

Carabid numbers at ECN sites appear to be increasing in the south-east and decreasing in the north-west. Temperature change is a possible cause

The reason for the pattern of response observed is still uncertain. Many environmental factors, such as temperature, rainfall, pollution and altitude, vary along the same south-east to north-west gradient and hence it is difficult to separate out their relative importance. Our analysis suggests that these trends are best explained by the effect of rising air temperature on beetle populations in different parts of the country. The upland ECN sites show a more pronounced rise in temperature over the study period and the more northerly populations may be more vulnerable to the impacts of such warming. Whatever the cause, the ECN signal is clear, and it raises a number of questions. For example, do trends in carabids' prey species also show north-south differences?

Trends in number of individual ground beetles observed at ECN sites 1993-2005. *Area of arrow is proportional to rate of change. Direction of arrow indicates increase or decrease.*



ECN monitoring of beetles involves pitfall trapping, an extensively used and well-tested method. Pitfall traps consist of sunken polypropylene cups, with wire mesh to prevent inadvertently catching small mammals and amphibians. Three transects (lines), each comprising ten pitfall traps are set out at each site in early May and are emptied and replaced fortnightly until the end of October. Most ECN terrestrial sites started carabid trapping in 1993 or 1994; Snowdon and the Cairngorms joined the network later and have data only from 1999. More details on the approaches used are available[3].

Monitoring beetles

On frail wings

climate impacts on UK butterflies

The number of species of butterfly is declining at southern ECN sites but increasing at northern or upland sites. Patterns are similar for numbers of individuals, in contrast to ground beetles

Butterflies are valuable indicators of environmental change in the UK. Seventy percent of the 59 species currently resident have range boundaries within the UK and many are highly specialised in terms of habitat and/or food plant requirements. The combination of these two factors means that many species are very sensitive to a wide range of environmental perturbations. Most butterfly species are also relatively easy to distinguish in the adult phase, and are active during the day, making them easy to monitor.

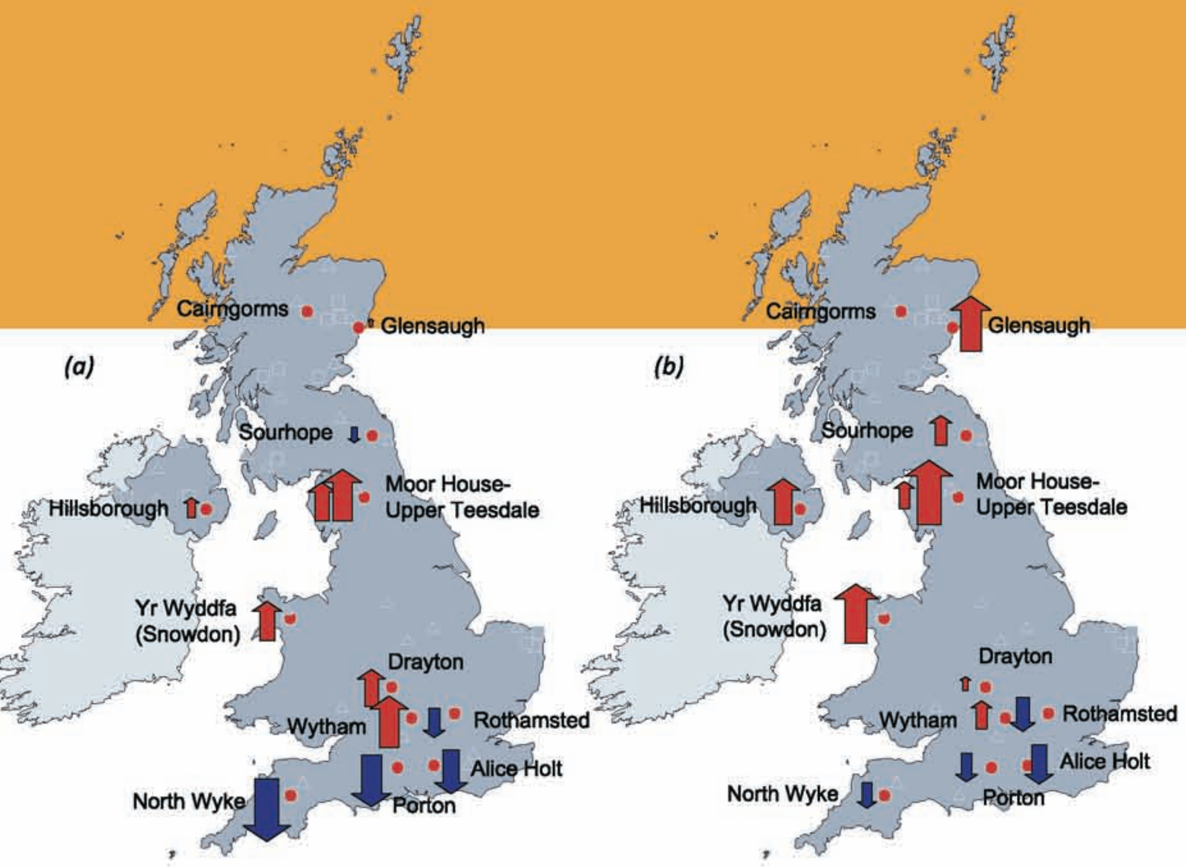
Declines have been observed both in the number and distribution of UK butterflies since at least the start of the twentieth century, particularly from the 1950s onwards. The most likely cause appears to be habitat loss, primarily conversion to agriculture. Species that are rare or restricted in range and/or habitat requirements have shown the greatest declines while generalist or widespread species have declined less or even expanded in range or numbers.

In contrast to the negative effect of habitat loss and land use change, the effects of climate change may benefit butterflies, at least in the long-term. Increases in temperature (particularly milder winters) and the northern movement of food plants may allow for range expansion by the majority of species. This could result in an increase in the diversity of butterflies at some sites. In the short term, however, effects of climate change could be disruptive to ecosystems and phenology. Evidence of range changes likely to have resulted from climate change are already accumulating both globally and in the UK. In addition, increased migration of butterflies and moths into the UK has been detected, including the arrival of species new to the country.

Spatial differences

There are few statistically significant trends in butterfly abundance at individual ECN sites. However, there is a strong geographical pattern in the direction of change, shown in map (a). Of the five sites where a decline in numbers is suggested, all but one are in the south of England. The geographical divide is emphasised when considering the proportion of species which are declining at each site (not illustrated). At all but one of the southern English sites, the majority of species is declining; at all but one of the remaining sites, the reverse is true. For the whole network, slightly more than half the observed species are declining.

▸ Spatial differences in the changes in (a) total numbers of butterflies per site and (b) number of species per site. *Not all changes are statistically significant. Data for 11 ECN sites (see box below). There are two datasets available for Moor House-Upper Teesdale.*



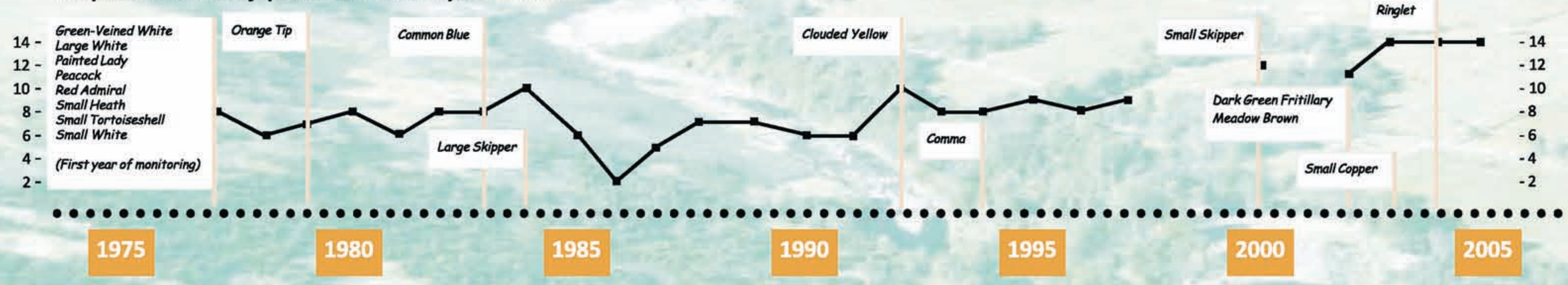
Further evidence of spatially different trends comes from data on number of species observed per site. The direction of change is mixed (map b); four sites show significant recent increases in species and three significant recent losses. A spatial divide can again be seen, with sites in the south of England losing species and more northerly sites gaining species.

The changes in species composition at sites are the result of losses from or gains to a site's existing species set, rather than of a more wholesale replacement of one set of species with another. This is well-illustrated in longer-term data from Upper Teesdale, where observations of butterflies have been made since the 1970s by Ian Findlay (see figure below). The species recorded in 1977 are all still observed at the site, but are joined by recent arrivals; five species new to the site since 2000.

Multiple drivers of change

It is tempting to interpret these trends as being due to continued habitat decline in the more agricultural south, with increases in the north and uplands being due to beneficial climate change. This would, however, be premature; multiple drivers of change are involved and further investigations with many more sites are needed to disentangle the possible causes of the observed trends. Such studies would be possible with the establishment of the Environmental Change Biodiversity Network (see page 23).

▾ Timeline showing the years when species of butterfly were first observed on a transect in Upper Teesdale. Arrivals since 1977 are highlighted. Most have persisted since first being detected. The black line plots the number of species recorded each year at the site



Data courtesy of Ian Findlay

ECN sites are ideal places to monitor butterflies; they have relatively stable management compared to the wider UK countryside and many of the other ECN measurements can aid interpretation of the results. To ensure comparability with the wealth of existing data, ECN uses the widely adopted Butterfly Monitoring Scheme (BMS) monitoring protocol[1]. Data are available for most sites from 1993 or 1994, exceptions being Snowdon and the Cairngorms, which joined the network later.

Monitoring butterflies

The '95 drought

extreme climate events have contrasting effects on species

Extreme events such as intense summer droughts - predicted to increase due to climate change - can benefit some species more than others

The summer of 1995 was one of the warmest and driest in the United Kingdom since records began (see box below). The ecological effects of such an extreme event are of interest in their own right, but in the context of climate change they acquire extra significance. Current climate change scenarios predict that the incidence and intensity of summer droughts in the United Kingdom will increase. It is likely that these will be major drivers of ecological changes. A series of dry, hot summers, for instance, could lead to rapid changes in the populations of some species, which in turn may lead to complex changes to ecosystems.

Long-term records are required to test whether ecological changes are underway, and to ascertain the mechanisms involved. ECN data for vegetation, butterflies, moths and ground beetles have been used to examine the effects of the 1995-6 drought[1]. These contrasting organisms enable us to build a very good picture of drought impacts.

- June–August rainfall was the lowest in the 229-year combined series for England and Wales
- Temperature in August 1995 was the second highest for any month in the 336-year Central England Temperature Record
- Rainfall was below average throughout most of 1996
- Dry soil conditions and low river flows, persisted until 1997, despite some wet periods in autumn 1995 and winter 1995–96

Features of the 1995-96 drought

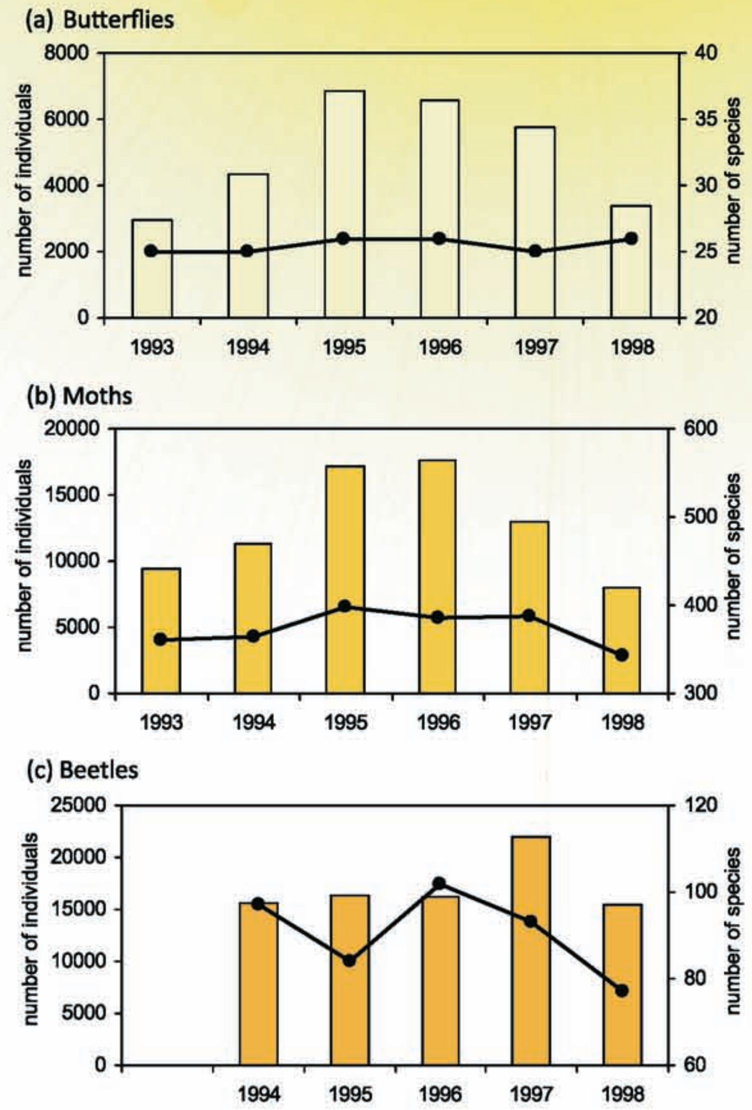
Winners and losers

The ECN study showed contrasting responses to drought conditions over the range of plants and animals monitored. Overall there was an increase in most butterfly and moth species, and in plant species, particularly 'weedy' annual species in some grasslands. However in all the groups studied, some species showed no response or declined. The main findings are shown in the box (right).

Implications

Plants, beetles, butterflies and moths represent different levels in food chains. They also contrast in other ways. For example, mobility of individuals typically increases from plants through beetles to butterflies and moths. The animal groups encounter very different microclimates; moths are mainly night-flying, butterflies day-flying, and ground beetles are typically found in the shady, damp litter layer. Within each of the groups there are many different species, with different distributions, life histories and ecological requirements.

The ECN results suggest that many species are acutely sensitive to climatic fluctuations but individually they have limitations as indicators. The longevity and slow dispersal rates of plants restrict their short-term responses, while invertebrate populations appear to respond very quickly. Shifts in climate therefore could lead to important impacts on patterns of herbivory and pollination as new species assemblages form. Climate induced changes in species interactions may be extremely difficult to predict and may only be revealed through continued long-term monitoring. For example, recent work utilising other long-term datasets suggests a link between changes in plant species abundance and declining populations of bumblebees[2].



***▸ Trends in butterfly, moth and beetle populations from 1993 to 1998, surrounding the drought years of 1995-96.** Total numbers of individuals (bars), and total numbers of species (points). Data were only included where a complete time series was available. Butterfly data for 7 ECN sites, macro-moth data for 8 sites, carabid beetle data for 9 sites.*

- Between 1994 and 1996, the total number of plant species recorded increased by 10% from 147 to 162
- Significantly more plant species increased in number than decreased. The increase was principally among vascular plants. Seedling numbers for most tree species increased in 1996 compared to 1994
- Among the herb species that increased, proportionally more were annuals or biennials rather than perennials, particularly short-lived species in grasslands
- Ground beetles showed no clear pattern of change in either overall numbers of individuals or of species in 1995 and 1996. In fact, for the studied years, the highest number of ground beetle individuals at most of the sites were recorded during 1997, a wet summer at all sites
- The beetle species showing a sustained decrease tended to occur at cooler sites and on soils with a higher soil water content
- Most species of butterfly and moth increased in numbers during 1995 and 1996
- Typically it was the butterfly species with a more southerly European distribution, or the more mobile species, which increased in abundance: the conditions did not tend to favour the more northerly species or those which were less mobile

Biological effects of the drought

To everything there is a season

climate impacts on frog breeding times

Data from ECN sites show that frogs are responding to milder springs by breeding earlier

Frogs and toads are sensitive to environmental change and their populations have suffered widespread declines, even extinctions, in recent decades. Climate change is one possible cause of this, and the predicted drier summers and lower soil moisture in the UK are expected to further impact amphibian populations. Warm dry weather may reduce the surface area, depth and number of ponds in which amphibians breed, whilst increased exposure of embryos to the sun's ultraviolet radiation - as a result of lower water levels - increases vulnerability to parasites.

One effect of climate change, seen in many plant and animal species, is a change to the timing of lifecycle events. These *phenological* changes are important because they can result in the decoupling of dependent processes within ecosystems. Hence the birth of young may be synchronised with an abundance of food, for example; but if hatching is brought forward by warmer weather in spring, food may be in short supply, and this may in turn affect the survival of young.

ECN monitoring of the common frog, *Rana temporaria*, the UK's most common amphibian, has revealed phenological impacts of climate change. Measurements include the date when breeding congregation begins, the date of first spawning, spawn quantity, evidence of spawn disease, the progress of embryo development and the date when froglets leave the pond. Eight ECN terrestrial sites have frog ponds suitable for monitoring, and there are records from 1994 for most of these sites.

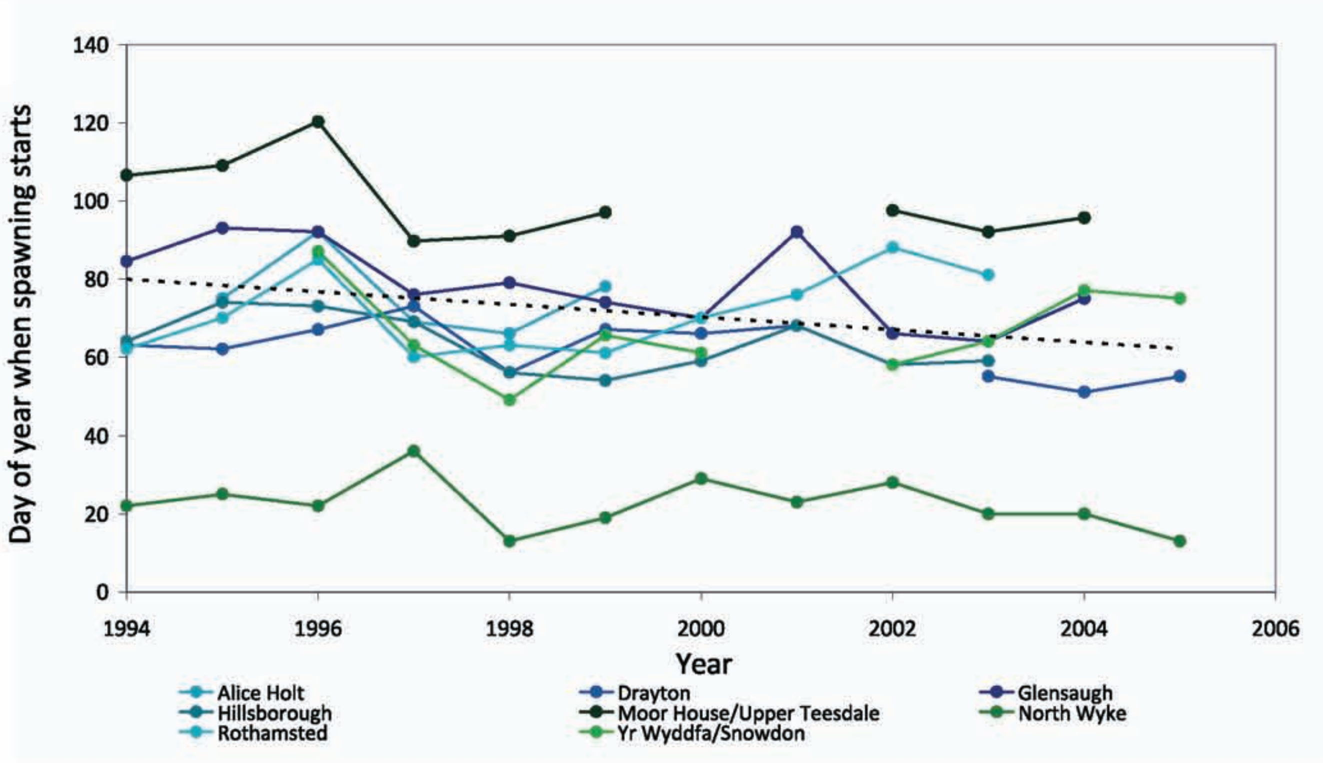
The time at which frog breeding starts in the UK varies greatly; in some years it may begin during December in Cornwall compared with April at high altitudes in the Pennines and in Scotland. In a particular pond, however, annual variation in spawn date tends to be relatively low. This can be seen in the ECN data, as shown in the figures opposite.

Analysis of ECN data shows that, throughout the UK, key events in the common frog's reproductive cycle are occurring earlier and over an extended duration, as shown in the table. A variety of weather variables were investigated as the possible cause of these trends. The results are similar for congregation, spawning and hatching; there are strong negative correlations with air and soil temperatures and weak positive correlations with surface wetness. The observed temporal trends over the last 12 years are apparently due to rising mean temperatures at ECN sites.

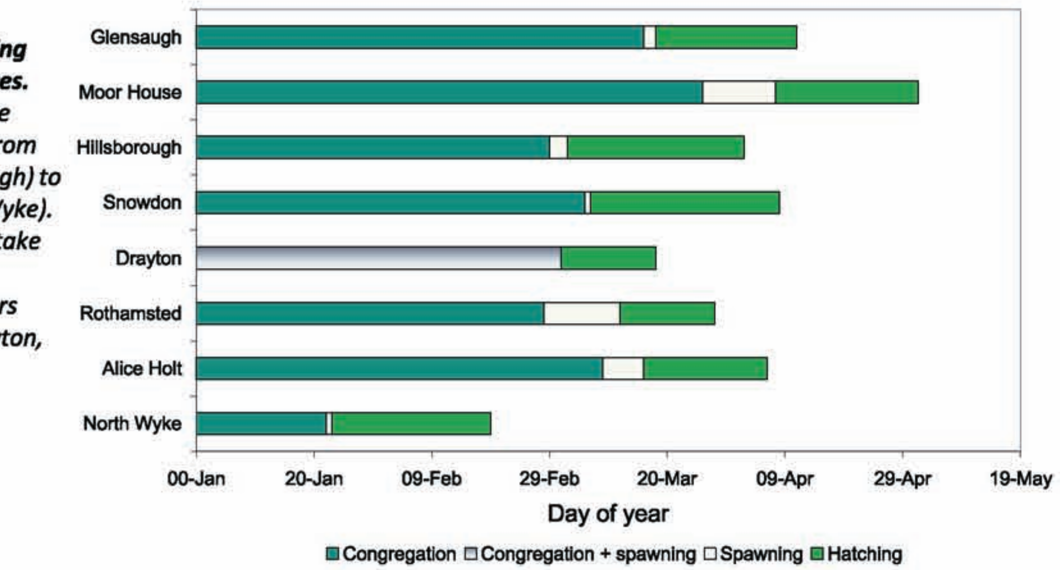
Lifecycle event	Number of days... ... by which the event start has advanced between 1992 and 2006	... by which the interval between events has lengthened	... of advancement per °C rise in temperature
Congregation	17.3		9.4
		⇕7.7	
Spawning	9.6		5.4
		⇕10.4	
Hatching	7.0		4.5

▲ ***Summary of the changes in timing of key frog lifecycle events.*** *From data recorded at ECN sites with frog ponds over the period 1992-2006*

The ECN results, when taken in conjunction with previous studies[1], suggest that the reproductive cycles of all monitored British amphibian species are becoming earlier in response to rising temperatures, and that this has been happening since at least the late 1970s. Such a widespread and long-term phenomenon indicates that the impacts of climate change are well underway in the UK.



▲ ***Trend in date when frog spawning begins at ECN sites.*** *The black line shows the linear trend for all the sites. Eight terrestrial ECN sites have ponds where frogs are found.*



▸ ***Differences in frog breeding cycle dates between ECN sites.*** *Mean annual dates. Sites are shown in latitudinal order, from the most northerly (Glensaugh) to the most southerly (North Wyke). Not only do lifecycle events take place at different times, the duration of events also differs across the network. (At Drayton, congregation has not been recorded).*

Seeds of change

changes in vegetation at ECN sites

ECN is providing data about year-to-year changes in plant communities, information vital to understanding how climate change and other pressures are affecting vegetation

Vegetation composition is perceived to be relatively stable, but this assumption is rarely tested. There is evidence that some plant communities can change on a year-to-year basis, particularly in response to weather conditions. Plant species that tolerate stress and those that thrive in disturbed sites (ruderals) tend to increase in response to warm, dry weather during spring and summer whereas competitive species increase after wet conditions. However there has been no systematic study of the extent of year-to-year variability - or indeed resilience - in contrasting vegetation types and its dependence on weather.

Annual monitoring of a subset of ECN vegetation plots, undertaken from 1996, provides information about short-term variation in vegetation over time. These data were valuable, for example, in interpreting Countryside Survey 2000[1,2] vegetation data. Any year-to-year variation in vegetation is not likely to be driven by land use changes, since the management of ECN sites is quite stable compared to the wider countryside.

For the present study, annual vegetation data from 1996-2006 were summarised in a number of ways to represent ecological characteristics of the vegetation. The parameters range from indicator scores for habitat condition to measures of the similarity of species composition in successive years. These 'summary measures' might be expected to show differing levels of variability over time. They may also respond differently from the separate species that form the vegetation type. For example, the *number* of species within a given plot could remain constant over a period of years during which the *actual* species within the plot change completely. Table 1 summarises the patterns of change found.

Short-term changes

Surprisingly, for most vegetation types, all the summary measures of vegetation appear to be relatively resistant to short-term (i.e. from one year to the next) fluctuations in external influences and require sustained pressure to change. The only vegetation types where this is not the case are crops and weeds[3] and fertile grasslands[3]. These are the two vegetation types most likely to change as a result of agricultural management.

In contrast, the measure of short-term change in species composition (the percentage agreement in species between successive years) indicates greater variability. Taking all the ECN sites together, approximately 55% of species are common to successive pairs of years. This figure varies considerably with both site (table 2) and vegetation type. Upland sites and upland vegetation types are the most stable.

Longer-term changes

Over the whole 10 year study period, substantial differences were found between the different groups of summary measure. Ellenberg indicators were particularly stable, showing little long- or short-term variability. C-S-R scores showed moderate degrees of variability with time, whilst the number of species showed substantial long-term variation compared with short-term stability.

In many respects these results are not unexpected. Ellenberg scores are intended to reflect relatively stable underlying abiotic environmental properties, so they should change little. In contrast, the mix and number of species could vary markedly in a plot, even if the basic properties do not change, as a result of short-term and local influences.

The ECN data reveal a clear distinction between upland and lowland sites. Upland sites and vegetation types have higher diversity (as reflected by number of species per plot) and they contain fewer ruderal species and more stress-tolerant ones. As a result they appear to be somewhat more stable than lowland sites or vegetation types. Whether their increased stability is a consequence of the increased biodiversity or whether both reflect other influencing factors remains to be determined.

Climate change is expected to impact plant species in many habitats[4]. However, the differences in stability of vegetation at ECN sites suggest varying degrees of resilience among different vegetation types. In the short-term, upland vegetation may be less impacted by climatic changes than lowland vegetation.

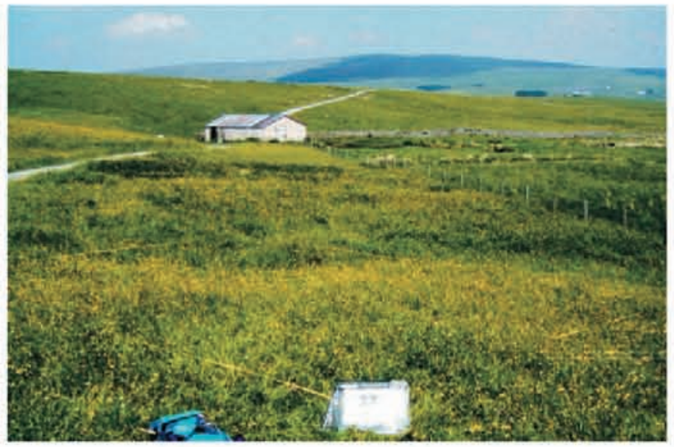
▼ ***Table 1: Summary of the patterns of change found amongst the different vegetation parameters considered***

Parameter	Short-term	Longer-term
Ellenberg scores for light, wetness, fertility and pH. Ellenberg scores are assigned to plant species and are a measure of the species' tolerance to abiotic conditions such as soil pH or nitrogen content[5]	Stable	Stable
C-S-R scores, the 'Competitor', 'Stress tolerator' and 'Ruderal' scores developed by Grime, which relate to different plant survival strategies[6]	Stable	Moderately variable
Number of species	Stable	Variable
% of species that are the same from one year to the next, a measure of the persistence of species in a monitoring plot	Moderately variable	Very variable

Sourhope	79.6
Glensaugh	63.7
Moor House	60.0
Rothamsted	55.3
North Wyke	54.4
Drayton	49.5
Wytham	48.7
Alice Holt	47.6
Porton Down	46.5
Hillsborough	44.5
All	54.5

↑ Increasing stability of plant community

▲ ***Table 2: Persistence of species between successive years.*** *(the number of species found in both years as a percentage of the total number of species in both years combined). A higher value indicates a more stable community.*



Site specifics

evidence of climate change from site-based research

Each ECN site is unique: together they are revealing significant trends, but many sites also support site-specific research, which is yielding more detail of the impacts of climate change. Over the next few pages, three example studies are described from the River Bush, Cumbrian lakes and Moor House sites

Is climate change affecting salmon survival?

Over the last decade a distinct downturn in the survival of Atlantic salmon in the marine phase of its lifecycle has been detected throughout its natural range. Evidence from monitoring the River Bush, an ECN site in Northern Ireland, suggests this may be an effect of climate change.

Marine survival rates of salmon leaving the River Bush have declined from around 30-35% in the 1980s and early 1990s to around 6% in 2007, with the start of this decline apparent around 1997 (see figure). Atlantic salmon use two distinct environments during their lifecycle; the juveniles inhabit freshwater before undergoing a physiological transformation known as smoltification to facilitate spring migration into the ocean. There the fish mature before returning to the river of their birth to spawn. During their short lifespans (typically 3-4 years for River Bush salmon), the salmon travel widely in the Atlantic, and are susceptible to changing environmental conditions. Because of this, the species may represent a useful indicator of potential shifts in climate.

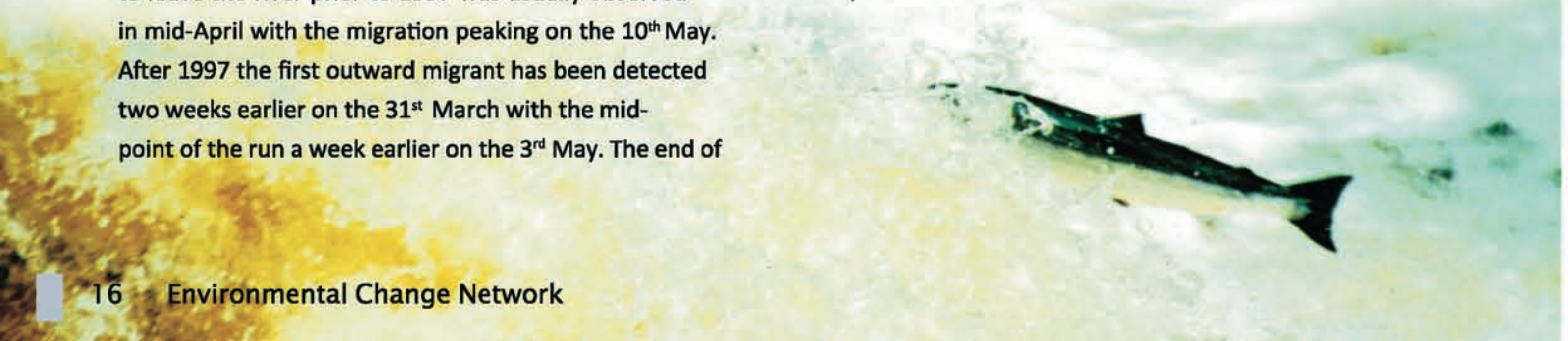
Salmon data from the River Bush indicate a step change in 1997 in the rates of marine survival. This coincided with a a distinct shift in the migratory period during which the young smolts emigrate from the river. The first smolt to leave the river prior to 1997 was usually observed in mid-April with the migration peaking on the 10th May. After 1997 the first outward migrant has been detected two weeks earlier on the 31st March with the mid-point of the run a week earlier on the 3rd May. The end of the smolt run has remained similar for both periods with the last outward migrants detected in early June.

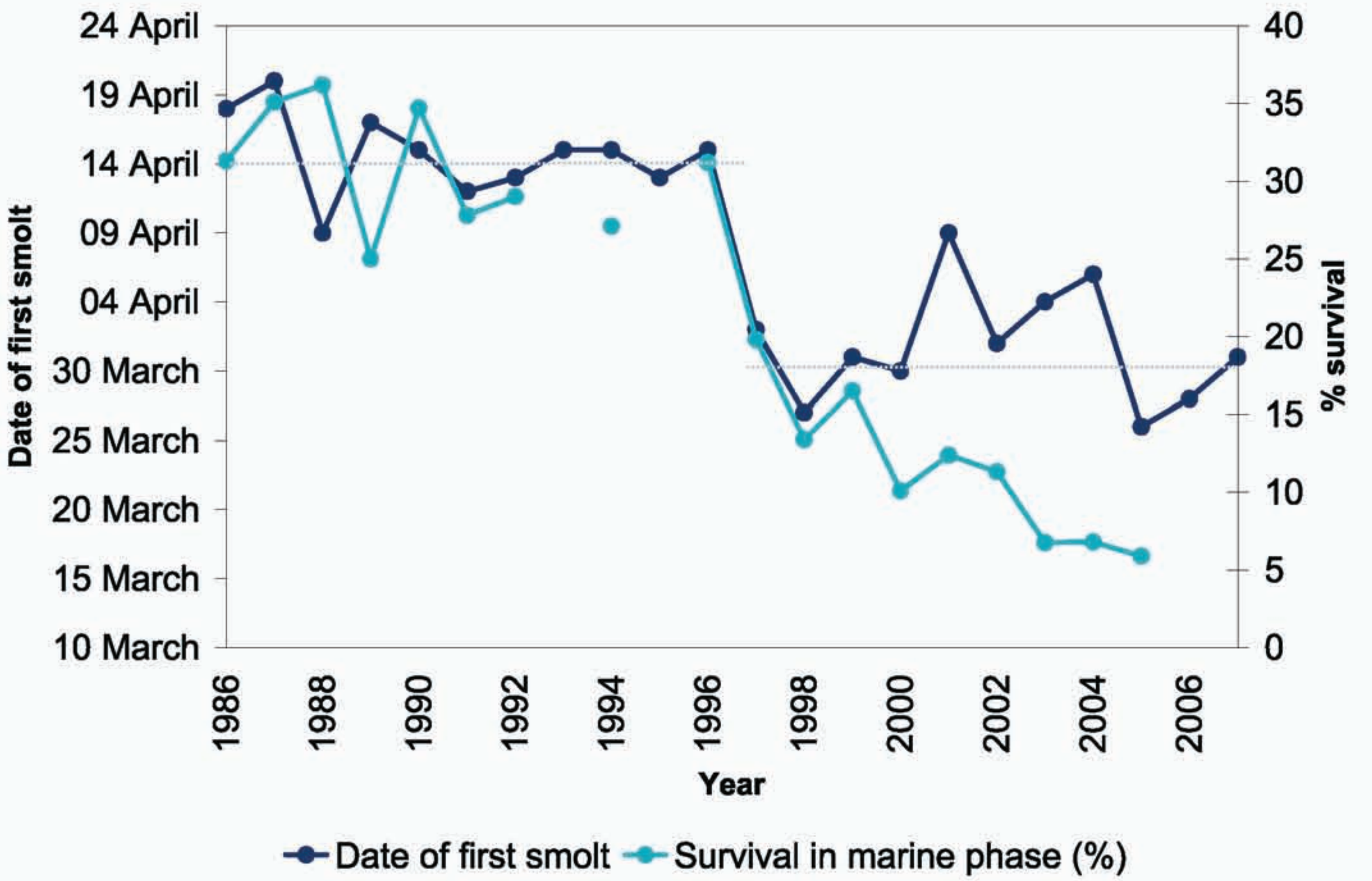
Example 1

Site: River Bush, Northern Ireland

Authors: Richard Kennedy, Gersham Kennedy and Walter Crozier, Agri-Food and Biosciences Institute

A strong correlation has been found between the date on which the first smolt is recorded and subsequent marine survival, with earlier smolt runs apparently strongly associated with reduced marine survival. One possible explanation is that earlier migration of smolts may result in a reduced ability of young post-smolts to survive in the marine environment. This may arise through the stress of thermal mis-match; earlier run fish migrate outside the normal "window" for migration and therefore experience a greater than usual difference between sea and river temperature.





▲ ***Date of first smolt migration and percentage survival rate.*** *The date the first smolt is observed at the sampling station on the River Bush is shown on the left axis. Mean migratory dates have been determined for two discrete periods (1986-96 & 1997-07) and are marked by the light grey dashed lines. The percentage survival rate of one year old River Bush salmon returning to Irish homewaters is shown on the right axis.*

Smolt migration is thought to be stimulated by a combination of photoperiod (day length), temperature and river flow. On the River Bush, slight positive increases have been detected in both average spring flows (March-May) and mean daily water temperature (April), perhaps indicating increasingly attractive migratory conditions earlier in the year. If recent abnormally early smolt migrations on the River Bush are being driven by climate change, then these impacts may be expected on a wider group of rivers, which, if persistent, may have significant impacts on future salmon stock status. The species may represent a sensitive indicator of the potential wider effects of climate change.

The River Bush Salmon Project[1] is a long term study of the population dynamics of the salmon in a typical coastal spate river. The study began in 1973, one of the longest datasets for Atlantic Salmon available in the North-Eastern Atlantic area. Accurate survival data are obtained using trapping facilities to record all salmon leaving the river and those returning to spawn.

As well as being an Environmental Change Network site, the Bush is an ICES (International Council for the Exploration of the Sea) index site.

The River Bush Salmon Project

Lakes in a changing climate

Long-term monitoring of four Cumbrian lakes confirms they are extremely sensitive to changing weather and climate, but different lakes respond in different ways.

Detecting and distinguishing the effects of climate change from those of other factors, such as eutrophication and invasion of non-native species, is made possible by analysing long-term records such as those for Cumbrian lakes. We have studied the response of four Cumbrian lakes to the North Atlantic Oscillation (NAO)[1]. The NAO is a regional change in air-pressure gradient in the North Atlantic which influences winter weather on the western European seaboard. A positive NAO produces wet, mild, windy winters, while a negative NAO produces dry, cold, relatively calm winters.

Removing the effect of increasing nutrient concentrations from the available data (see box below) revealed a strong

The Cumbrian long-term database on lake function is an internationally unique resource maintained by CEH. Data collection started in 1945 and is based on weekly or two-weekly sampling. Two sites - Windermere and Esthwaite Water - form part of ECN. For this study, data were supplemented by data jointly owned by the Freshwater Biological Association and CEH.

The Cumbrian lakes database

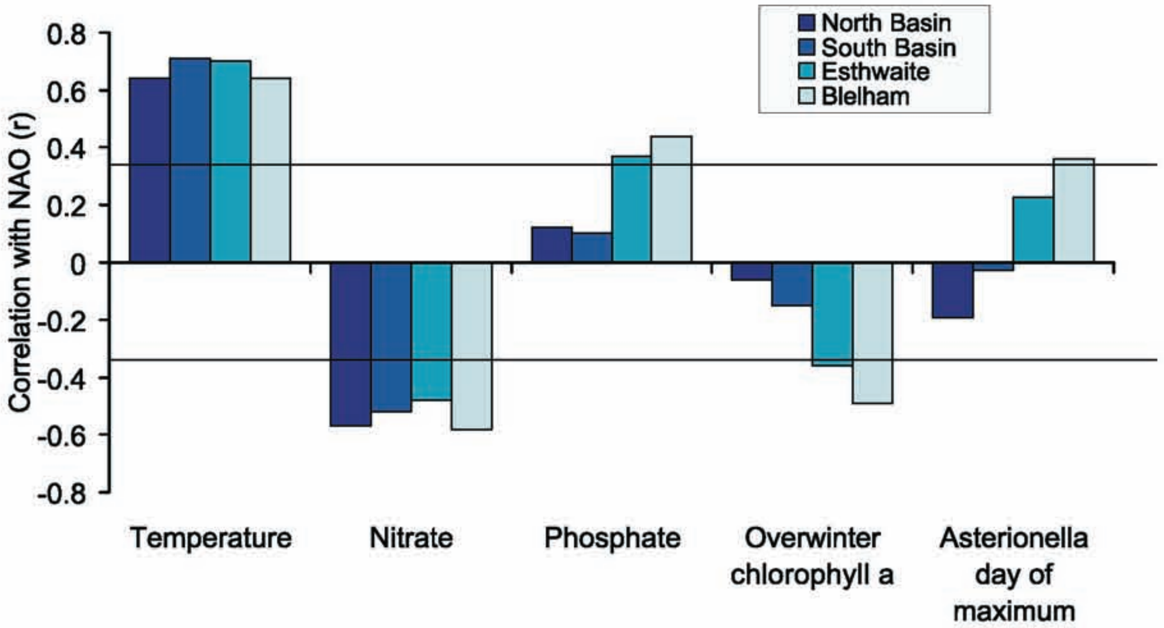
Example 2

Sites: Four Cumbrian lakes, England

Author: Stephen Maberly, Centre for Ecology and Hydrology

correlation between the winter lake temperature and the winter NAO in all four lake basins. More interestingly, the winter concentration of nitrate in the lakes was strongly negatively correlated with the NAO. This may result from the lower uptake of nitrate by the catchment in cold winters. Esthwaite Water and Blelham Tarn, the two smallest lakes, had significantly higher phosphate concentrations when the NAO was positive, linked to high rainfall bringing in more nutrient from the catchment. Conversely, the overwinter concentration of phytoplankton (expressed as chlorophyll *a* concentration) was lower in these lakes in a positive NAO winter as a result of flushing losses. The smaller lakes were more sensitive because they have shorter average hydraulic retention time (a measure of the average time that a substance remains in the lake). Finally, the timing of a keystone species, the planktonic diatom *Asterionella formosa,* was later in Blelham Tarn, the smallest, most rapidly flushed lake in wet winters.

At present, European Directives such as the Water Framework Directive and the Habitats Directive seek to restore damaged ecosystems or protect those of high quality but



▲ ***An overview of the sensitivity of winter conditions in different lakes to the winter NAO index.*** *Data are shown for Windermere (North and South basins), Esthwaite Water and Blelham Tarn. Bars that extend beyond the horizontal lines show a correlation significant at P<0.05*

they do not specifically refer to managing the effects of climate change. Management under future climate change may need to be more stringent to meet environmental standards. Restoration targets may need to be revised if climate change prevents the re-establishment of 'reference communities'. Long-term lake studies are invaluable to improve our understanding of lake ecosystem dynamics and to model the behaviour of lakes under different climate scenarios.

- Higher rainfall can increase levels of nutrients and suspended sediments, and alter the productivity of phytoplankton (microscopic, floating algae)
- Higher air temperatures are likely to increase the period of summer stratification (a warm, well-lit upper layer of water above a cooler, dark lower layer). This can lead to extended growth of phytoplankton
- At depth, stratification may result in a longer period for oxygen depletion and a greater build-up of limiting nutrients, such as phosphorus. When stratification breaks down these may be released to phytoplankton
- Higher temperatures may affect lake flora and fauna. Species adapted to cooler water, such as some salmonid and white fish, may not tolerate higher temperatures. Other species, including non-native species, may spread, with consequences for existing communities

Some climatic influences on lakes

Unravelling carbon losses from upland peatlands

Example 3

Site: Moor House - Upper Teesdale, England

Author: Joanna Clarke, University of Leeds

Peatlands account for half of all carbon stored in the UK's soils. However, this store is potentially vulnerable to climate change. Research at the Moor House ECN site has revealed that reducing one environmental pressure – acid rain - may be increasing this vulnerability.

Carbon has accumulated in the form of peat in many areas of the UK where the cold and wet conditions reduce the rate of decomposition of plant material. Carbon accumulation and retention in peatlands is, however, very sensitive to changes in climate. It has been suggested that warmer and drier summers could accelerate peat decomposition by stimulating microbial activity. This could result in an increased flux of carbon dioxide to the atmosphere and dissolved organic carbon (DOC) to drainage waters, a particular concern in upland areas (see box). Changes in the amounts and seasonal distribution of rainfall will also influence the rate of removal of carbon as DOC.

A study using ECN data from the Moor House-Upper Teesdale site - a substantial area of blanket peat bog in

Continued overleaf

Many reservoirs in and around upland areas of the UK collect water draining from peatlands. This water is rich in dissolved organic carbon (DOC) which stains water brown. Over the last few decades, water draining some of these areas has become more coloured, increasing the cost of water treatment and the possible health risks of trihalomethanes, by-products of the treatment process. This trend has also prompted fears that these net carbon sinks are becoming carbon sources, as carbon is being lost to rivers. However, increased DOC has also been associated with a decline in toxic forms of aluminium, which is good news for the health of aquatic organisms.

DOC in fresh waters

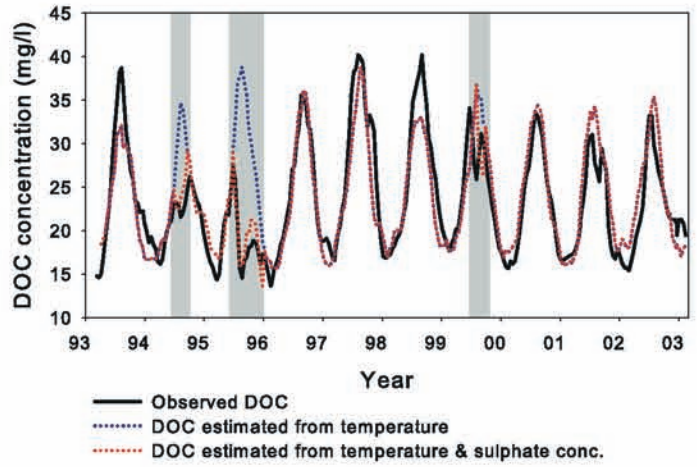
the North Pennines - demonstrated that the controls on DOC losses are actually more complex[1]. The black line in figure 1 shows that DOC concentrations in peat soil water were actually lower during years with prolonged warm, dry summer periods (1994, 1995 and 1999 - shown by the shaded portions) than during other 'normal' non-drought years. Furthermore, variation in DOC could not be predicted using a simple statistical model where temperature was the only driver of variation.

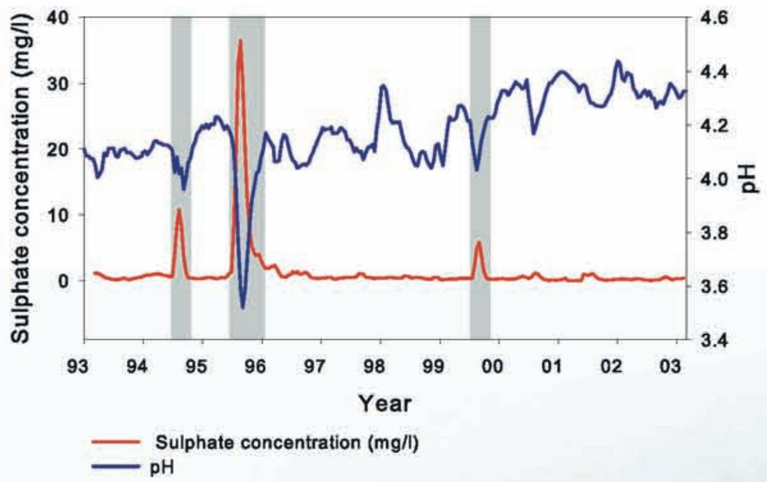
What else could be controlling DOC during years of drought? One theory is that during dry periods, when the water table is drawn down from the surface, the presence of oxygen triggers chemical processes that raise sulphate concentration and soil water acidity and as a consequence reduce the solubility of organic carbon. The ECN data shown in Figure 2 clearly pick up simultaneous pulses in sulphate, and reductions in pH (i.e. increase in acidity) and DOC. By combining a 'sulphate effect' and temperature in the statistical model we were able to replicate variation in soil water DOC concentration during both 'normal' (non-drought) and drought years (dotted red line in Figure 1).

This theory linking trends in DOC and sulphate is supported by data for European and North American lakes, which shows DOC has increased most sharply at sites where sulphur deposition from 'acid rain' has declined most[2]. One possible implication is that the decline in acidic deposition over the last few years may have released a brake on DOC release from peat soils, and may make this process more vulnerable to future effects of climate change.

There is still a lot of uncertainty about the impact of climate change on carbon losses from peat systems. But if the reduction in acid rain is making soil organic carbon more soluble, then soil carbon dynamics may be becoming increasingly sensitive to short and long-term changes in

▼ ***Figure 1: Observed and modelled dissolved organic carbon (DOC) in peat soil water at 10 cm depth.*** *Shaded areas show drought periods*





▲ ***Figure 2: Acidic sulphate - SO_4 - ion concentration and pH in peat soil water at 10 cm depth.*** *Shaded areas show drought periods*

climate. Further research is currently underway at ECN and Acid Waters Monitoring Network sites to increase our understanding of what has happened in recent decades, and to improve predictions of what may happen in future. Long-term monitoring of peatland systems is - and will continue to be - an essential component of this work.

i

Many ECN sites support active research programmes, and research proposals that utilise the sites and/or their data are welcomed. To find out more about the ECN sites and other resources that support teaching and research, visit

www.ecn.ac.uk/research.asp

Globe watching

building the global evidence base

Long-term monitoring programmes provide valuable scientific evidence demonstrating the reality of climate change and its impacts. The UK's Environmental Change Network is one of many national Long-Term Ecosystem Research (LTER) initiatives. Over thirty such networks are members of the International Long-Term Ecological Research Network (ILTER[1]), the mission of which is "to improve understanding of global ecosystems and inform solutions to current and future environmental problems". The aims of ILTER include promoting cooperation and collaboration amongst member networks, and improving comparability of long-term ecological data. Other global observing systems exist to collect relevant data, such as the Global Terrestrial Observing System (GTOS) and the Global Climate Observing System (GCOS).

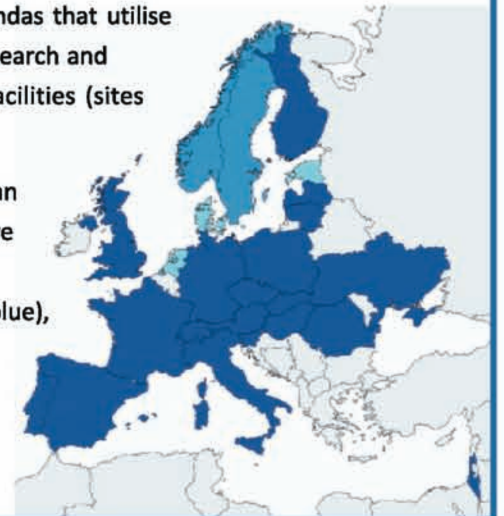
For its Fourth Assessment Report[2], the International Panel on Climate Change synthesised some 29,000 suitable data series from about 75 studies. More than 89% are consistent with the direction of change one would expect as a response to increased temperature. This synthesis of long-term data is significant, but it falls short of what could be achieved through more integrated monitoring and associated research, which has the potential to reveal not only trends but underlying causes and processes.

There is huge potential for the research of well-coordinated site networks to be integrated and translated into clear messages in relation to climate change and other global changes. To achieve this the different networks need to cooperate and share their data and knowledge. Because each network has been developed separately, with different purposes, measurement sets, protocols and data structures, this is a major challenge. We still have some way to go before the global community of long-term monitoring and research programmes can speak with one voice on the detection of climate change and its impacts.

Fortunately progress is being made. In Europe, ECN partners CEH and Macaulay are involved in ALTER-Net (see box), a European project which has established a pan-European network of long-term monitoring and research sites, LTER-Europe. Once this network is fully operational we will be able to access and analyse data from terrestrial and freshwater sites ranging from Norway to Israel, and from Northern Ireland to Ukraine. The sites will also form a research facility for large scale experiments. Work is in progress to demonstrate the potential for pan-European integrated monitoring and research. For example, ALTER-Net has coordinated a simple multi-site experiment (in which some ECN sites participated). There is also substantial effort to develop *InfoBase*, a powerful database collating data from LTER-Europe sites.

LTER-Europe[3] is a pan-European network of long-term research and monitoring sites, established by the EC-funded project, ALTER-Net[4]. ALTER-Net has defined criteria for LTER sites, developed the concept of larger 'LTSER' regions that include socio-ecological research and monitoring, and is addressing data management, sharing and access issues. It is also promoting interdisciplinary research agendas that utilise long-term research and monitoring facilities (sites and data).

Most European countries have formal networks (dark blue), or are establishing them (lighter blue shades).



ALTER-Net and LTER-Europe

Data access

making use of data and sites

A valuable data resource

High quality, long-term data are an important scientific resource and a national asset. The strength of ECN is that a wide range of driving and response variables are measured at a range of sites using common methods. These data are collated into a single database, providing the potential to compare data not just over time, but spatially. Data undergo a range of validation checks before they are entered onto the database, and we also conduct periodic quality assurance tests to ensure the data are of a high standard.

It has always been one of ECN's principles to make our data as widely accessible as possible. Provided they are used for *bona fide*, non-commercial, research purposes, ECN data are available at no charge, and are thus used by a wide range of researchers. Two levels of data access are provided:

- Summary data (monthly or annual means) are provided for most of the measured variables via a web-based interface (www.ecn.ac.uk/Database/index.html)
- Raw datasets are available under licence.

The summary data interface enables users to select any combination of dataset, sites and time period. The system queries the database, and summary results are presented graphically and in tabular form. They may also be downloaded as a file.

Sites for research

Active research by university departments and others is undertaken at many of the sites. Several sites have a long history of research. The availability of ECN's long-term biological, physical and chemical data make the network's sites attractive locations for many kinds of research, concerning not just the impacts of climate change but also other important topics, such as air pollution, population dynamics, biogeochemistry of soils and ecosystem services and function.

Much research undertaken at ECN sites, or using ECN data, is published in the scientific literature. We maintain a database of ECN-associated publications, available on the ECN website.

Strategically-driven research

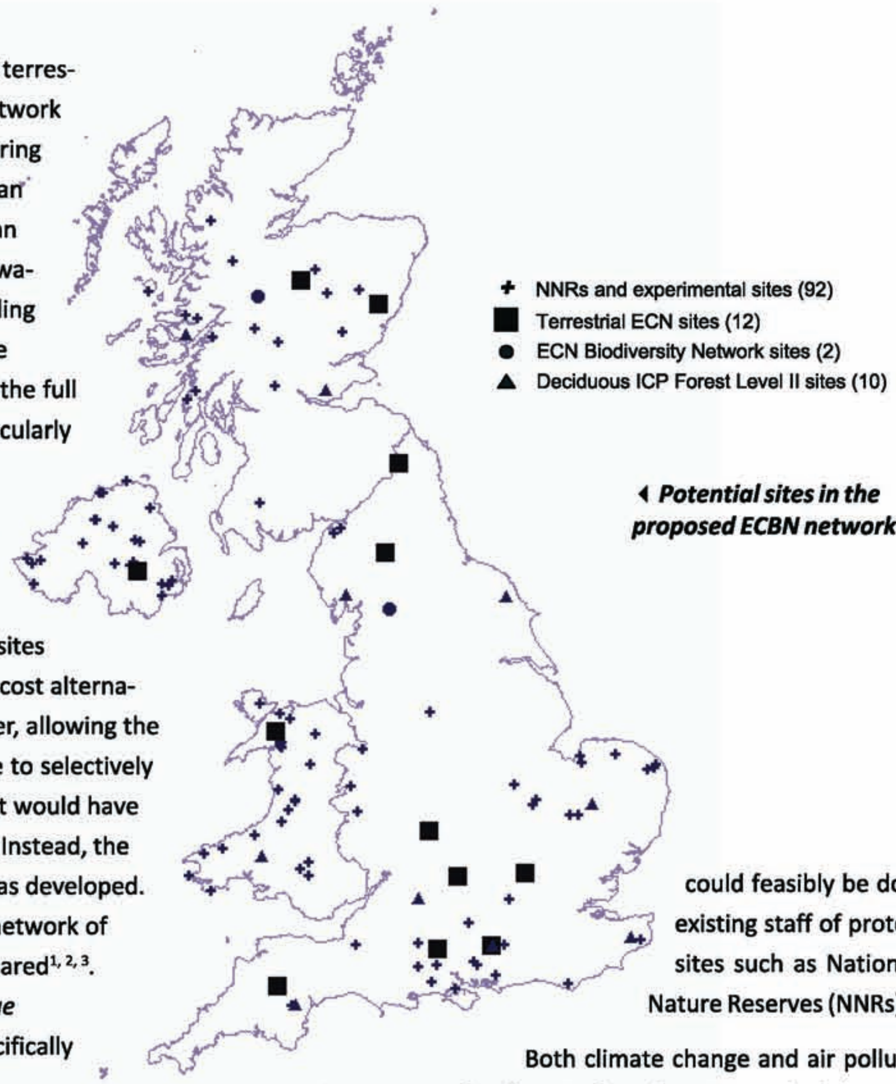
To really make the most of ECN requires a concerted effort. ECN's Research and Development Strategy[1] provides a framework enabling researchers, policymakers and others collectively to address key scientific questions. By combining research, datasets and expertise, we can extract the most from the national asset that is ECN.

- ECN Summary data are available from the ECN website, *www.ecn.ac.uk*. Click on *ECN data*. You can also find the raw data use request form here
- Since the summary database was launched in 1998 it has been accessed over 9200 times and we've registered over 1000 data downloads
- To date we have serviced over 600 requests for raw data
- Details of ECN sites are available by clicking *About ECN*, then *Sites*
- Information about ECN measurement protocols are available by clicking *About ECN*, then *Protocols*
- The ECN publications database is available by selecting *Publications* from the home page. Other ECN publications are also available here
- To discuss research ideas, please contact the ECN Research Coordinator, Don Monteith, at CEH Lancaster (E-mail: donm@ceh.ac.uk)

Tapping the ECN resource

Extending the network: ECBN

Since monitoring began at the first terrestrial ECN sites back in 1992, the network has expanded. We are now monitoring at 12 terrestrial sites (two more than in 1992) and 45 freshwater sites (an increase of seven from when freshwater monitoring began in 1995). Adding new sites increases the value of the data resource. However, operating the full set of monitoring protocols - particularly at terrestrial sites - requires a sizeable commitment in staff time and financial resources, limiting the network's rate of growth.



◂ ***Potential sites in the proposed ECBN network***

To extend ECN monitoring to more sites we needed a new approach, a low-cost alternative to full ECN monitoring. However, allowing the operators of any potential new site to selectively choose what monitoring to conduct would have yielded a very fragmented dataset. Instead, the concept of 'targeted monitoring' was developed. Using this model, plans for a new network of sites across the UK have been prepared[1, 2, 3]. The proposed *Environmental Change Biodiversity Network* (ECBN) is specifically designed to enable the impacts on biodiversity of two drivers, climate change and air pollution, to be distinguished from one another in sites with known management. The additional sites would also extend the habitat coverage of ECN sites. By basing the new network on ECN, it is possible to build on the wealth of experience and expertise within ECN, in areas such as monitoring methods, data management and engagement with policymakers and the research community.

At sites in the ECBN a smaller range of measurements would be conducted than at existing terrestrial ECN sites. Wherever possible, these measurements would use existing ECN protocols. The monitoring effort and associated costs would be much less (there would be no need for costly chemical analyses, for instance), and the work could feasibly be done by existing staff of protected sites such as National Nature Reserves (NNRs).

Both climate change and air pollution impact upon biodiversity but there is very little long-term data available to help distinguish the effects of the two drivers or to reliably determine the causes of observed changes. Based on statistical analyses, between 40 and 90 new sites would probably be needed in order to separate the effects of climate change and air pollution. Potential sites - mainly NNRs - were identified from existing biologically significant sites which have a history of relevant monitoring (see figure).

Other initiatives are underway to better integrate the UK's environmental monitoring capability, a move fully supported by ECN. The Environmental Change Biodiversity Network would extend and enhance ECN's long-term monitoring, providing the UK with two closely inter-related networks of monitoring sites.

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- To establish and maintain a selected network of sites within the UK from which to obtain comparable long-term datasets through the monitoring of a range of variables identified as being of major environmental importance
- To provide for the integration and analysis of these data, so as to identify natural and man-induced environmental changes and improve understanding of the causes of change
- To distinguish short-term fluctuations from long-term trends, and predict future changes
- To provide, for research purposes, a range of representative sites with good instrumentation and reliable environmental information

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