Climate change impacts

evidence from ECN sites

Edited by

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Environmental Change Network

ECN partners

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  - *Institute of Grassland and Environmental Research, North Wyke*
  - *Rothamsted Research*
- Cyngor Cefn Gwlad Cymru - Countryside Council for Wales
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- 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*

Contents

References to source material are indicated by superscripts in the text, and are listed on pages 24-25

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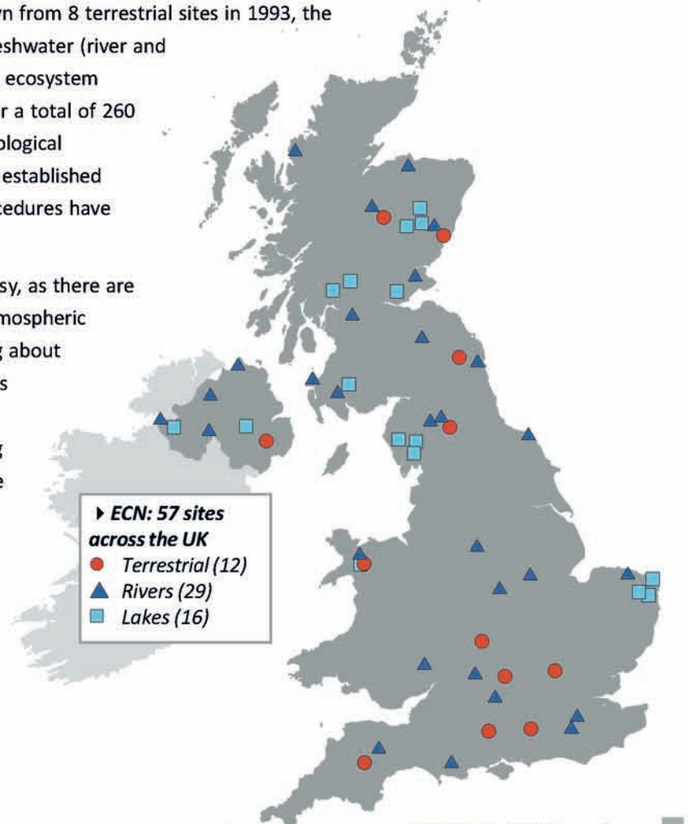
Climate change impacts: Evidence from monitoring

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.

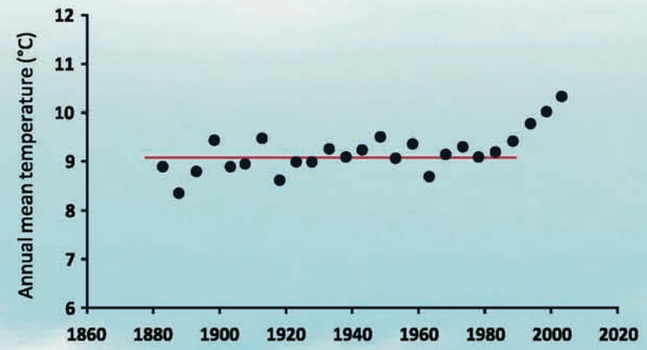
Climate predictions

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.

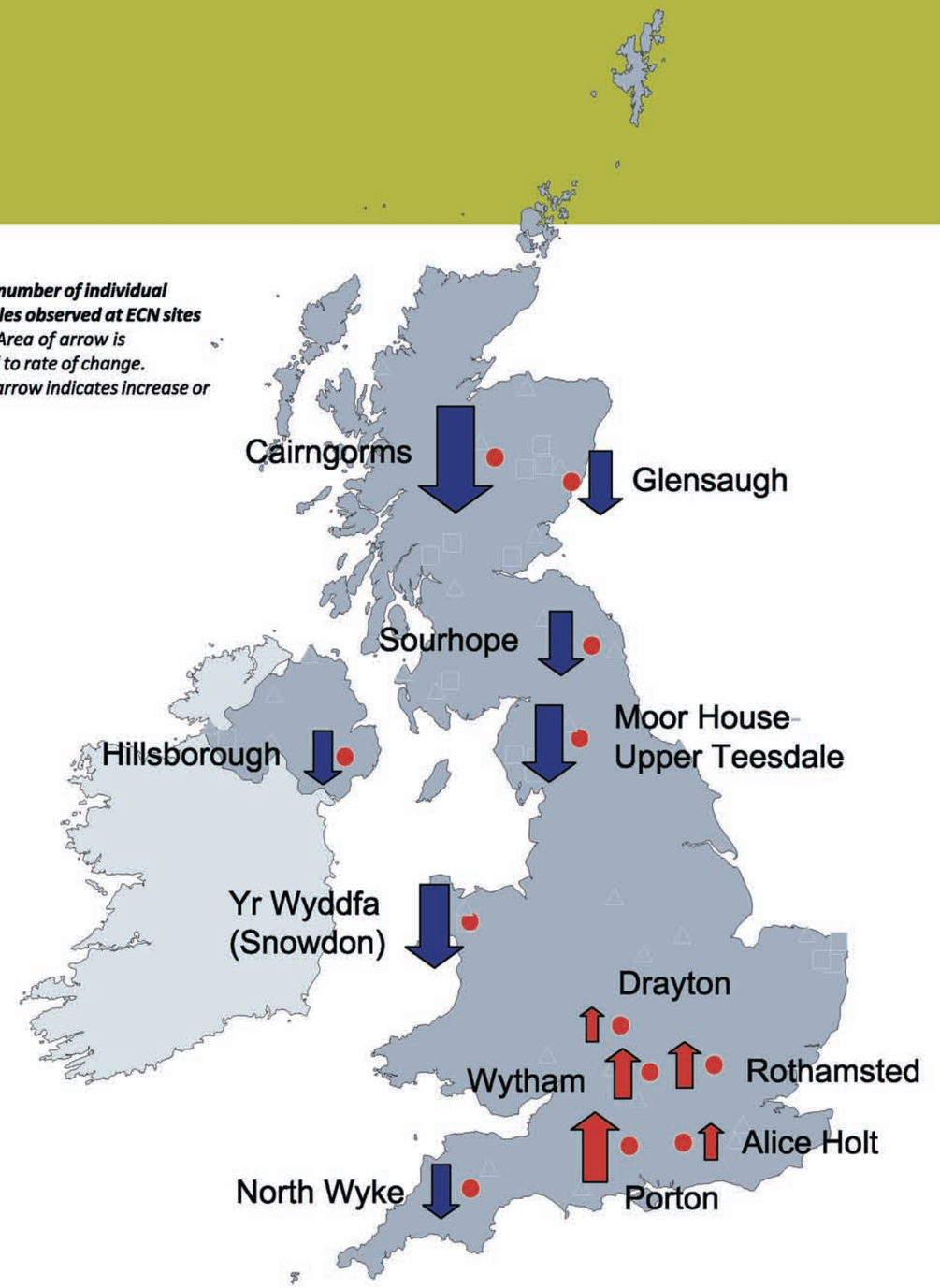
North-south divide

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

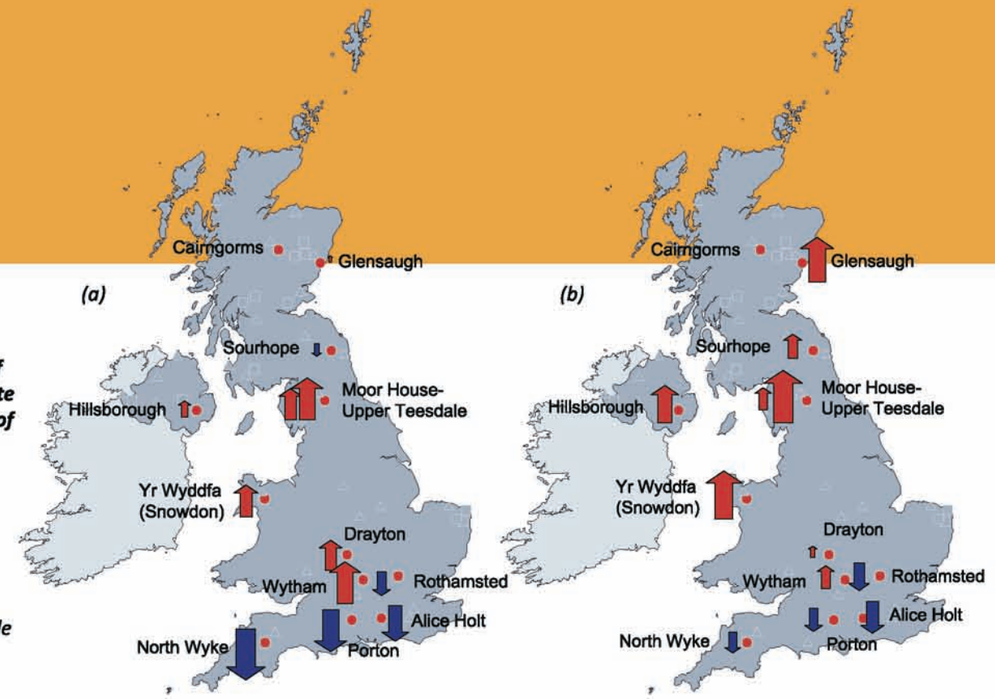
Butterflies are valuable indicators of environmental change in the UK. Seventy percent of the 59 species currently resident have range boundaries within the UK and many are highly specialised in terms of habitat and/or food plant requirements. The combination of these two factors means that many species 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.*

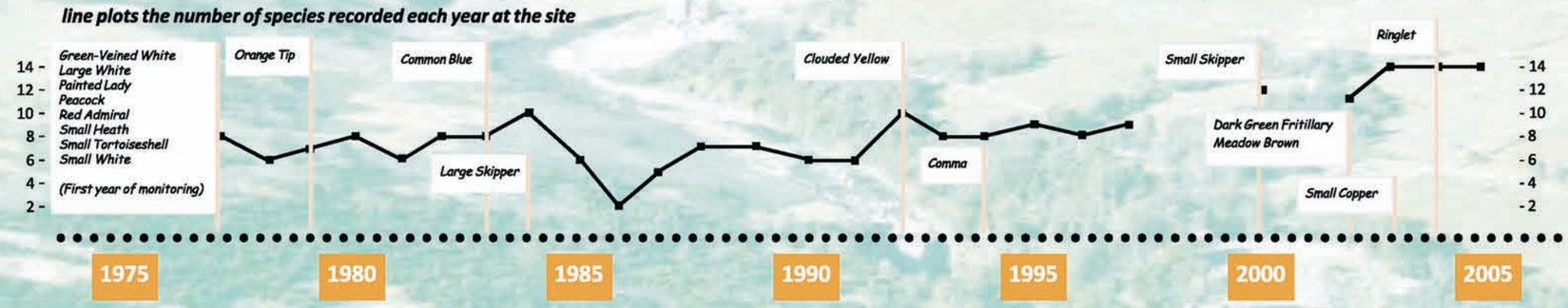
Further evidence of spatially different trends comes from data on number of species observed per site. The direction of change is mixed (map b); four sites show significant recent increases in species and three significant recent losses. A spatial divide can again be seen, with sites in the south of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

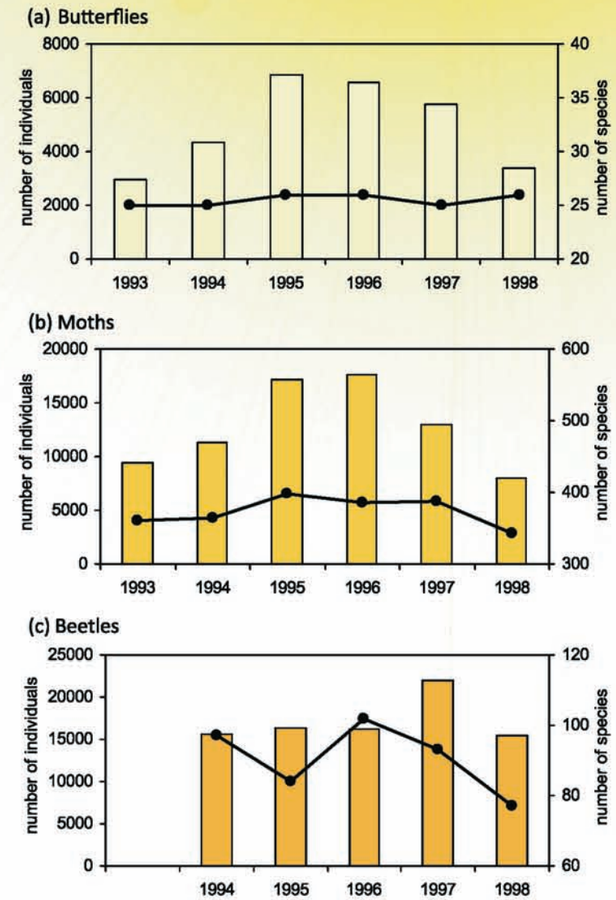
The ECN study showed contrasting responses to drought conditions over the range of plants and animals monitored. Overall there was an increase in most butterfly and moth species, and in plant species, particularly 'weedy' annual species in some grasslands. However in all the groups studied, some species 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.

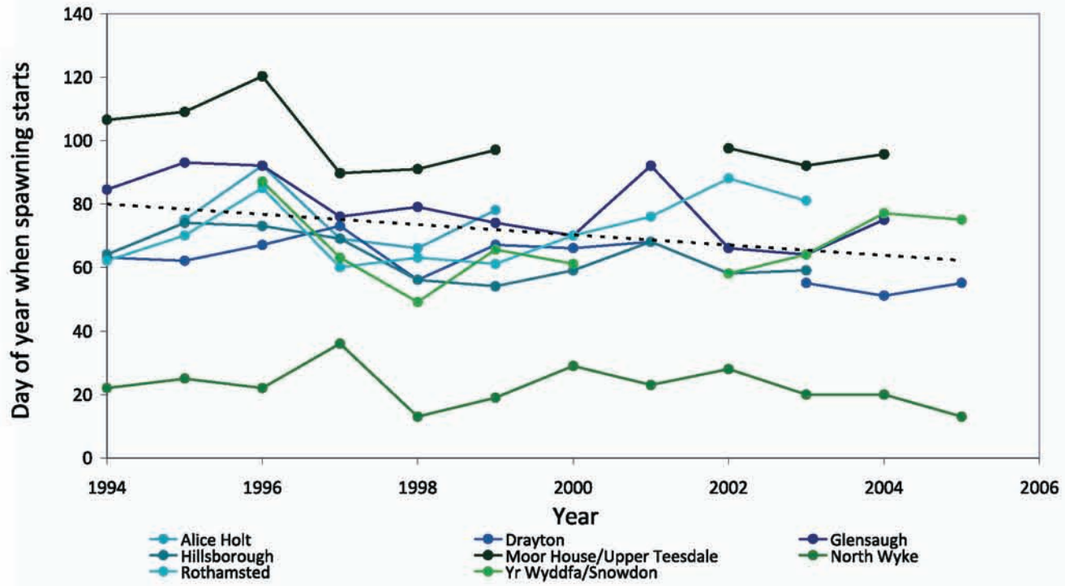
The time at which frog breeding starts in the UK varies greatly; in some years it may begin during December in Cornwall compared with April at high altitudes in the Pennines and in Scotland. In a particular pond, however, annual variation in spawn date tends to be relatively low. This can be seen in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

	Number of days...		
Lifecycle event	... 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).*