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The UK Environmental Change Network

ROTHAMSTED RESEARCH

UK Environmental Change Network

North Wyke
The first 20 years (1993-2012)

The U.K. Environmental Change Network

North Wyke
The First 20 years (1993-2012)

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Contents

Key changes at North Wyke during the first two decades of ECN monitoring

Climate

- Temperature and rainfall did not change significantly over the first two decades, but there was an indication that summers are becoming progressively wetter.
- Wind speed reduced significantly.
- Solar radiation levels increased during spring.

Pollution

- Concentrations of sulphate, nitrate and chloride in rainfall have decreased.
- Concentrations of sulphate and chloride in deep (55cm) soil solution samples have also decreased and soil pH has increased.
- Concentrations of sulphate in the River Taw have decreased and its pH increased.
- Concentrations of nitrogen dioxide in the atmosphere have decreased.

Biodiversity

- The abundance of some taxa such as butterflies and moths have fluctuated in response to short term weather patterns.
- The total abundance of larger (macro) moths has declined; the cause of this is unclear.
- The majority of resident and partial/short distance migrant bird populations have remained stable or increased, but species that migrate over longer distances have declined.
- There was an indication that a switch from silage to hay production benefitted several butterfly species and increased plant diversity.
- Ground beetle diversity declined at two locations and abundance at one location, possibly as a result of a less intensive grazing regime.






The Environmental Change Network

During the 1980s concerns grew about the state of the environment relating to issues such as biodiversity loss, widespread air and water pollution and climate change. The need for a national, long-term, integrated monitoring and research programme became apparent and the UK Environmental Change Network (ECN) was launched in 1992 to monitor UK environmental change over time. The ECN is a collaborative multi-agency initiative funded by a consortium of 14 government departments and agencies, consisting of 12 terrestrial and 45 river and lake sites (Fig. 1). The geographical distribution of the terrestrial sites ensures a range of climates, air pollution concentrations, altitudes, habitats, soils and management practices are represented. All the ECN terrestrial sites monitor a core set of parameters (Table 1) using standard protocols so that the data are comparable across the network. Data is quality assured and stored in a central database (http://www.ecn.ac.uk/data). The variety and distribution of ECN sites enables the network to detect local, regional and national trends.

A major strength of the ECN is that it takes an integrated approach, monitoring both the principal drivers of environmental change (climate, pollution and land management) and the ecosystem responses (soil, water quality and a variety of species representing a range of trophic levels; higher plants, herbivores, insectivores). Monitoring a wide range of environmental parameters in an integrated way can help us understand the complexities of ecosystem processes and link the cause and effect of environmental change. This understanding can be used to develop tools to forecast environmental changes and assess their likely impact on key ecosystems services.

Many ecosystem processes and species take time to respond to environmental change and therefore short term projects are unable to capture these changes. There is inherent variability in natural systems; the environment is continually changing. The long-term environmental monitoring programmes at ECN sites can help to distinguish between natural inter-annual variations and longer-term trends caused by anthropogenic (human) activity.

The potential consequences of environmental change arising from climate, pollution and land management pressures on ecosystems continue to be of major concern. The ECN can help us to understand the patterns and causes of environmental change and aid policy makers and environmental managers to develop strategies in order to adapt to climate change, conserve plants and animals and improve air, soil and water quality.

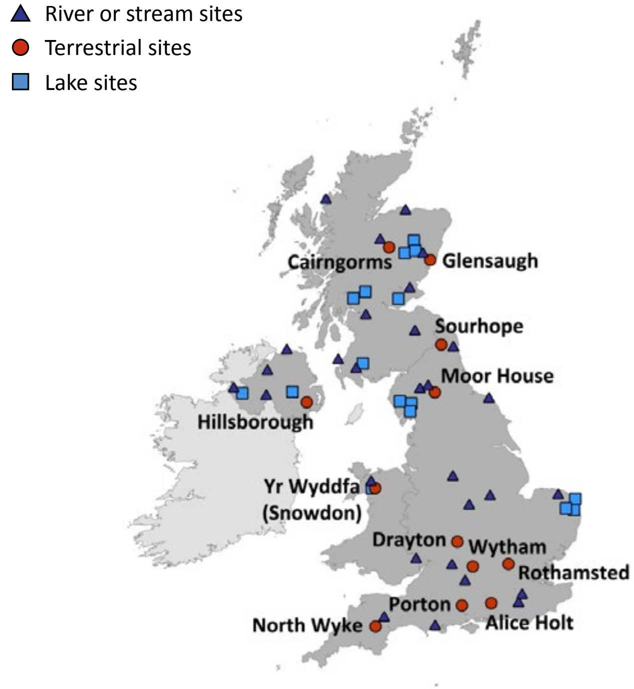


Figure 1. Map of Environmental Change Network sites in the UK

Table 1. Core terrestrial ECN measurements

Driver or Response variable	Measurement	Method	Frequency
Physical			
Meteorology	Temperature, precipitation, wind speed and direction, solar radiation	Automatic weather station	Hourly
Chemical			
Atmospheric chemistry	Nitrogen dioxide	Diffusion tubes	Fortnightly
Precipitation chemistry	pH, conductivity, alkalinity, Na, K, Ca, Mg, Al, Fe, NO_3, NH_4, PO_4, SO_4, DOC, Total N	Chemical analysis	Weekly
River water chemistry		Chemical analysis	Fortnightly
Soil solution chemistry		Chemical analysis	Fortnightly
Soils	Physical structure and chemistry	Physical and chemical analysis	5- and 20- yearly
Biological			
Vegetation	Fine-grain sampling	Quadrat counts	3-yearly
	Coarse-grain sampling	Quadrat counts	9-yearly
Invertebrates	Butterflies	Butterfly Monitoring scheme	Weekly (Apr-Sep)
	Moths	Rothamsted Insect Survey	Daily
	Ground beetles	Pitfall traps	Fortnightly (Mar-Oct)
	Spittle bugs	Quadrat counts	Twice yearly (Jun, Aug)
Vertebrates	Bats	Activity on two transects	Four times yearly (Jun-Sep)
	Birds	Breeding Bird Scheme	Twice yearly
	Deer & Rabbits	Dung counts	Twice yearly (Mar, Sep)
	Frog Spawning	Timing of lifecycle events	Weekly during season

North Wyke history

North Wyke was an experimental farm from 1955-1981, belonging to Fisons Fertilisers, before the Grassland Research Institute acquired the site in September 1981 to study the efficiency of grassland production on heavy soils under high rainfall in SW England. A period of restructuring of research institutes resulted in the formation of the Institute of Grassland and Environmental Research (IGER) in 1990. In March 2008 IGER ceased to exist and North Wyke was temporarily known as North Wyke Research before becoming part of Rothamsted Research in August 2009.

North Wyke has established itself nationally and internationally as a research centre for pastoral livestock production (http://www.rothamsted.ac.uk/northwyke). Both the North Wyke and Harpenden (Rothamsted) ECN sites are part of the Long-term Experiments National Capability (LTE-NC) that is supported by the Biotechnology and Biological Sciences Research Council (BBSRC) and the Lawes Agricultural Trust for the wider benefit of the science community.

The North Wyke ECN site

North Wyke (latitude 3° 54' W; longitude 50° 46'N) lies in undulating countryside 7 km to the north of Dartmoor National Park, midway between the villages of South and North Tawton (Fig. 2). The River Taw marks the western boundary and flows northwards through the site. At an altitude of 120 m to 180 m the site covers 250 ha, of which 200 ha are grassland and 50 ha are deciduous woodland. The area is underlain by the Carboniferous Crackington Formation, comprising of clay shales forming clay soils of the Hallsworth, Halstow and Denbigh/Cherubeer soil series, collectively known as the Culm Measures. Alongside the River Taw deposits of gravel and sandy alluvium form a narrow band of well drained soils of the Teign series.

All ECN sites have a Target Sampling Site (TSS) where destructive sampling is kept to a minimum and the management is kept consistent for the duration of the ECN programme. The North Wyke TSS is a 0.66 ha paddock of permanent grassland where no nitrogen fertiliser has been applied since at least 1984. The TSS and surrounding area, known as Rowden Moor, have been generally managed less intensively than the rest of North Wyke. Some small pockets of semi-natural grassland and the deciduous woodlands have been left relatively unmanaged. Land management at North Wyke from 1992 to 2012 did not change substantially. However some disturbance took place to farm field boundaries in 2010 during the installation of the Farm Platform (http://www.rothamsted.ac.uk/farmplatform).

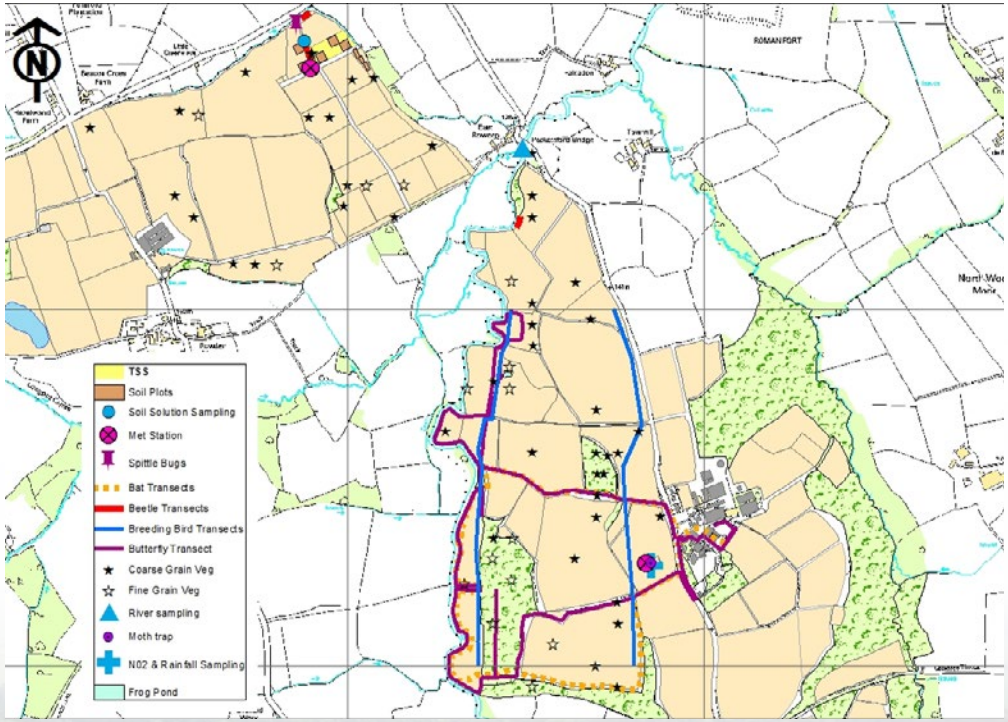


Figure 2. Map of North Wyke ECN sampling sites

Climate

It is now widely accepted that human activities are inadvertently changing the earth's climate, mainly by emitting carbon dioxide and other greenhouse gases into the atmosphere causing the temperature of the earth's atmosphere to increase. Meteorological data from the ECN automated weather station (AWS) showed a statistically significant increase for both average annual air temperature and total annual precipitation over a relatively short time period (1996-2007). A warming trend and an increase in annual precipitation were recorded across the whole ECN terrestrial network between 1993 and 2007 (Morecroft et al., 2009). However, when a longer period was considered (1993-2012) neither average monthly air temperature nor total monthly precipitation changed significantly at North Wyke or any other terrestrial ECN site with the exception of increasing precipitation at Glensaugh (Monteith et al., 2016).

Average monthly wind speed declined significantly at North Wyke and three other southern ECN sites; Drayton, Rothamsted and Wytham (Monteith et al., 2016). Surface winds have been reported to be declining globally and the cause has been attributed to changes in atmospheric circulation patterns and also increased surface roughness resulting from an expansion of urban and forested areas.

The only statistically significant seasonal change at North Wyke over two decades was increasing solar radiation in spring. This corresponded with a decline in spring rainfall and a rise in spring temperatures. If this trend continues the timing of key plant and animal lifecycle events such as flowering and breeding may change. The data in Tables 2 and 3 are for a 31-year period, 1982-2012, obtained from the Met Office station at North Wyke.

Table 2. Annual, seasonal and monthly air temperatures (^{o}C) (Met Office 1982-2012)

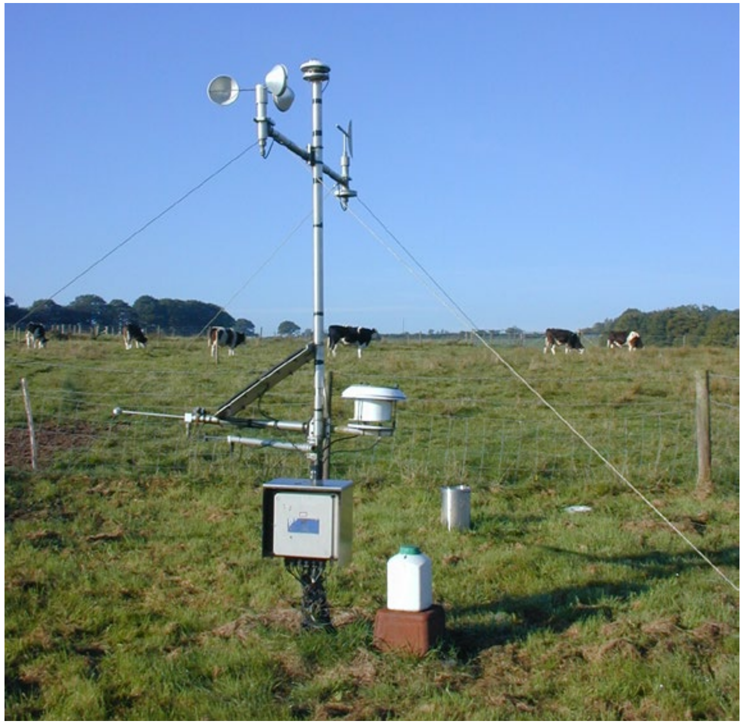
	Winter (Dec-Feb)	Spring (Mar-May)	Summer (Jun-Aug)	Autumn (Sep-Nov)	Annual (Jan- Dec)
Mean Maximum Air Temperature					
Warmest	9.8	14.0	21.8	14.9	14.53
Coldest	4.8	10.2	16.4	11.8	11.10
Year (Warmest)	1988/89	1990	1983	1997	1989
Year (Coldest)	2009/10	1986	2011	2012	2010
Mean Minimum Air Temperature					
Warmest	5.5	7.3	13.6	10.4	8.42
Coldest	0.6	3.4	10.4	5.5	5.43
Year (Warmest)	2006/07	2007	2006	2006	2007
Year (Coldest)	1990/91	1984	1986	1993	1986
Mean Air Temperature					
Warmest	7.1	10.2	17.0	12.8	10.87
Coldest	3.3	6.9	13.9	8.7	8.64
Year (Warmest	2006/07	2007	1983	2006	1989
Year (Coldest)	2009/10	1986	1986	1993	1986

Monthly mean air temperature

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Warmest	8.18	7.6	7.9	8.5	11.6	13.6	15.3	19.7	18.9	16.4	13.6	10.7
Coldest	0.6	1.2	-1.1	4.4	5.2	9.0	12.0	14.1	12.8	11.2	8.0	4.8
Year (Warmest)	1988	1990	1990	2012	2011	1989	2006	1983	1995	2006	2001	1994
Year (Coldest)	2010	1987	1986	1984	1986	1996	1991	1988	1986	1986	1993	1985

Table 3. Annual, seasonal and monthly rainfall totals (mm) (Met Office 1982-2012)

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Annual
Wettest	292.9	240.8	251.2	148.8	179.4	156.2	158.6	128.4	148.6	152.3	230.9	237.8	1331.7
Driest	15.6	20.5	4.6	23.0	13.4	10.9	7.8	14.3	14.6	23.6	25.6	34.1	699.0
Year (Wettest)	1999	1984	1990	2001	2012	2007	2012	2009	2004	1998	2000	2009	2000
Year (Driest)	2010	1997	1986	2011	1984	1989	1984	1996	1995	2003	2007	1998	2003
	Winter (Dec-Feb)			**Spring (Mar-May)**			**Summer (Jun-Aug)**			**Autumn (Sep-Nov)**			
Wettest	636.8			318.0			339.2			527.3			
Driest	122.9			73.6			66.8			143.4			
Year (Wettest)	1989/90			1983			2007			2000			
Year (Driest)	1991/92			2011			1983			1985			



From 1982 to 2012 the amount of rainfall and number of total rain days (>1mm) in summer appeared to increase (Fig. 3) although neither of these trends were statistically significant. Seasonal and monthly rainfall is highly variable (Table 3). The three wettest summers 2007 (339.2mm), 2012 (317.8mm) and 2008 (275.0) were 82.6%, 71% and 48% respectively above the annual long term summer mean of 185.8mm (1982-2012). In contrast to summers becoming wetter, the driest spring was recorded very recently in 2011 (73mm), 65% below the spring long term average of 214mm.

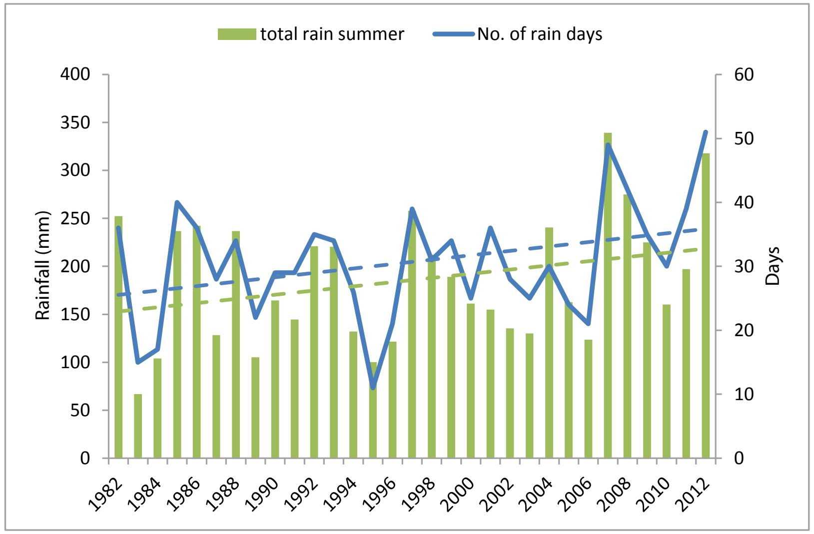


Figure 3. Summer total rainfall and number of rain days at North Wyke (met office 1982-2012).

In contrast to climate model predictions, there was no clear signal of warming or increased rainfall at North Wyke at either annual or seasonal levels over the first twenty years of ECN monitoring. However, twenty years is a relatively short time to study climate trends. Because of the substantial inter-annual variation, longer term-term datasets are likely to be required to separate human induced climate change from natural cycles. Morecroft et al, (2009) and Monteith et al, (2016) reported differing climate trends for the ECN sites depending on the time period studied. The UK weather is influenced by fluctuations in the difference of atmospheric pressure at sea level between the Azores and Iceland known as the North Atlantic Oscillation (NAO). Monteith et al, (2016) suggest the increase in summer rainfall observed across the ECN network over the first twenty years is linked to a prolonged summer NAO negative index from 2008 onwards, typically associated with cooler, wetter conditions as opposed to a positive NAO summer index characterised by warm, dry weather.

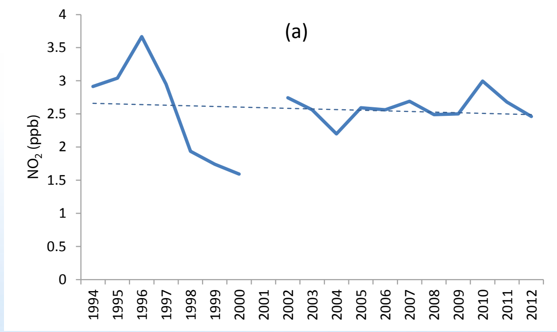
Atmospheric pollution

Sources of anthropogenic air pollutants include livestock (ammonia, NH_3), fossil fuel power stations (sulphur dioxide, SO_2; nitrogen oxides, NO_x) and vehicle emissions (nitrogen oxides, NO_x). These 'primary pollutants' react with the atmosphere to produce secondary pollutants as particulates and aerosols (sulphate, SO_4; nitrate, NO_3; ammonium, NH_4) and as acids (sulphuric acid, H_2SO_4; nitric acid, HNO_3; and hydrochloric acid, HCl). Atmospheric pollution is a major driver of environmental change and can damage human health. Therefore, since the mid-1950s, UK and European legislation and treaties have been implemented to reduce air pollutants. ECN data show that these have been effective.

Nitrogen dioxide

The main anthropogenic sources of nitrogen dioxide (NO_2) originate from fuel combustion in motor vehicles, power generation, heating plants and industrial processes. NO_2 is a respiratory irritant and is involved in the formation of photochemical smog and acid rain. Nutrient-poor habitats such as species rich hay meadows and moorlands are particularly sensitive to eutrophication from atmospheric nitrogen.

North Wyke is situated in a rural area, approximately 3km from the nearest village and therefore NO_2 emissions are relatively low compared with more urban ECN sites such as Rothamsted (Harpenden). Over the first two decades NO_2 concentrations fell significantly at North Wyke (Fig. 4a) and at most ECN sites (Monteith et al., 2016) and can be mainly attributed to the switch from coal to natural gas generated electricity and the improvements in fuel quality and catalytic converters on road vehicles. Peak annual mean NO_2 concentrations occurred in 1996 (3.7 ppb) with the lowest recorded in 2000 (1.6 ppb), a reduction of 57%. The current rate of change in NO_2 concentration reductions at North Wyke appears to be slower than earlier on in the monitoring period. According to the RoTAP (2012) report, emissions have not decreased recently as much as predicted, especially those from transport, possibly because of an increase in the use of diesel vehicles. A clear seasonal pattern was seen (Fig. 4b) with the highest NO_2 concentrations recorded in winter corresponding to increased demand for domestic heating.



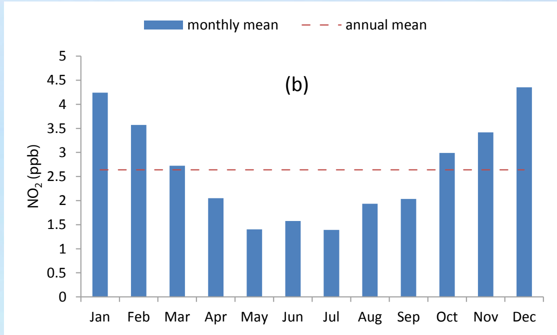


Figure 4. Average (a) annual and (b) monthly atmospheric NO_2 concentrations at North Wyke (1994-2012). (Note: data for 2001 incomplete due to foot and mouth epidemic.)

Ammonia

Ammonia monitoring is not a core ECN protocol, but most sites monitor concentrations on behalf of the UK National Ammonia Monitoring Network (NAMN) established in 1996 (http://uk-air.defra.gov.uk/networks/network-info?view=nh3). Ammonia (NH_3) is primarily emitted to the atmosphere from agricultural sources, i.e. the production, storing and spreading of animal manure and to a lesser extent from artificial nitrogen fertilisers. Ammonia can damage ecosystems through eutrophication and also acidification via nitrification of NH_3 deposited in the soil. Plants can exhibit enhanced sensitivity to NH_3 during drought and cold and vegetation may become more vulnerable to insect or pathogen attack, or to strong winds after exposure to NH_3.

Concentrations of ammonia exhibit a large spatial variability, depending mainly on farming activities. Land management at North Wyke has not undergone any major changes during the duration of ECN and, consequently no clear trend in NH_3 concentrations was observed at North Wyke (Fig. 5a). However, there is a clear seasonal pattern relating to farming practises, with higher NH_3 emissions and hence measured concentrations, in spring and summer than winter (Fig. 5b).

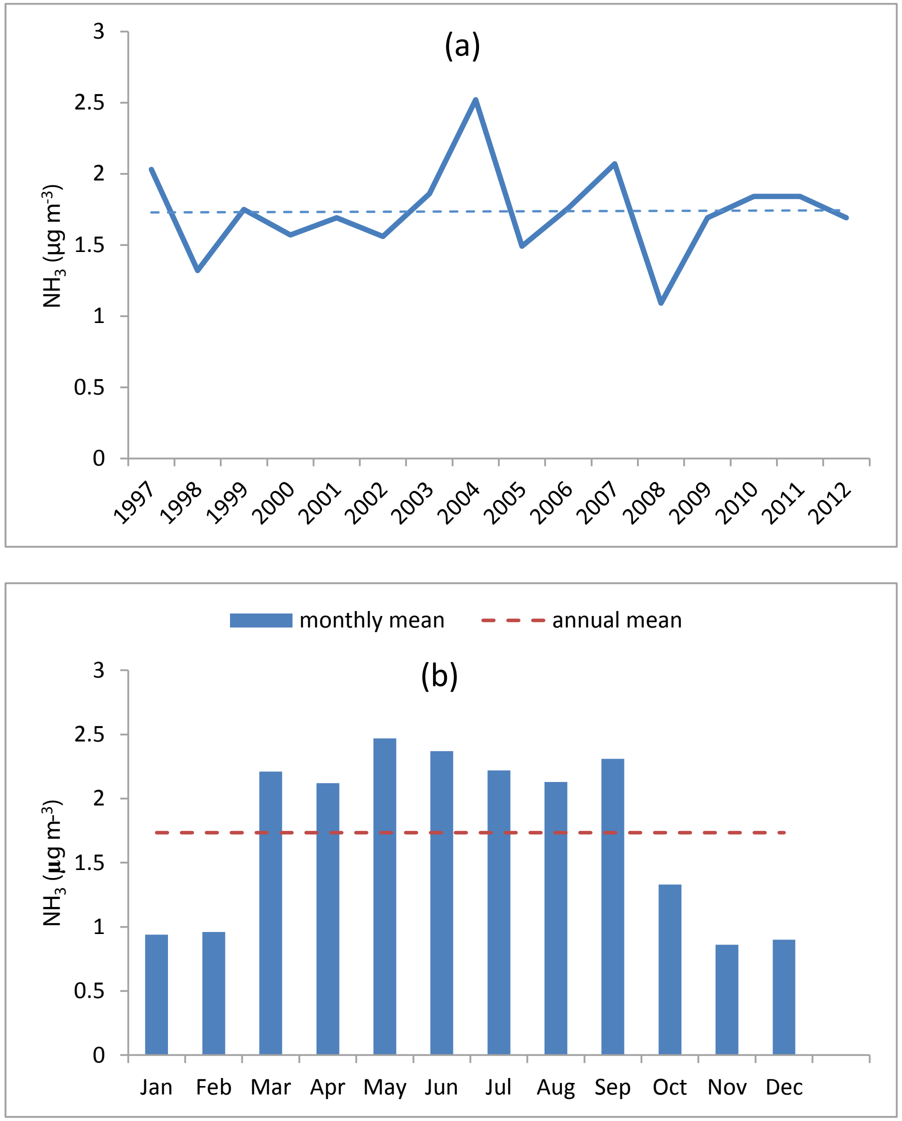


Figure 5. Average (a) annual and (b) monthly atmospheric NH_3 concentrations at North Wyke (1997-2012). Data provided courtesy of the UK Eutrophying and Acidifying Atmospheric Pollutant project's National Ammonia Monitoring Network.

Precipitation Chemistry

Precipitation (rain, snow, hail, fog, mist) chemistry can vary depending on natural sources such as biological decay, lightning, forest fires and volcanic eruptions and also anthropogenic sources. Precipitation is naturally slightly acidic (typically pH 5-5.6) due to the presence of carbon dioxide in the atmosphere which reacts with rainwater to form carbonic acid. Emissions of SO_2, NO_x and chloride (Cl) to the atmosphere derived from both natural sources and anthropogenic sources such as the combustion of fossil fuels increase the acidity of precipitation.

Acid deposition across the UK and Western Europe has been sustainably reduced in response to national and international control measures on sulphur (S) and nitrogen (N) emissions. As with the majority of ECN sites, concentrations of SO_4 and NO_3 in precipitation have significantly declined at North Wyke (Fig. 6a). Chloride concentration also decreased significantly, probably because of reduced sea-salt deposition reflecting reduced wind speeds, and also the decline in hydrogen chloride emissions in the UK of 94% between 1990 and 2006, largely as a result of decreased coal use. Reductions in precipitation acidity occurred at all ECN sites except North Wyke (Monteith et al., 2016). No clear trend was observed at North Wyke, however precipitation became less acidic during the late 1990s and early 2000s (Fig. 6b). In contrast to NH_3 concentrations, ammonium (NH_4) concentrations in precipitation declined, but not significantly (Fig 6a).

Several ions exhibited seasonal variability. Average concentrations of Cl, magnesium (Mg) and sodium (Na) ions associated with seawater salts were highest in winter and lowest in summer, suggesting a relationship between marine sources and seasonal rainfall patterns. Highest concentrations of NO_3 and NH_4 in precipitation were found in spring, possibly linked to fertiliser and manure applications.

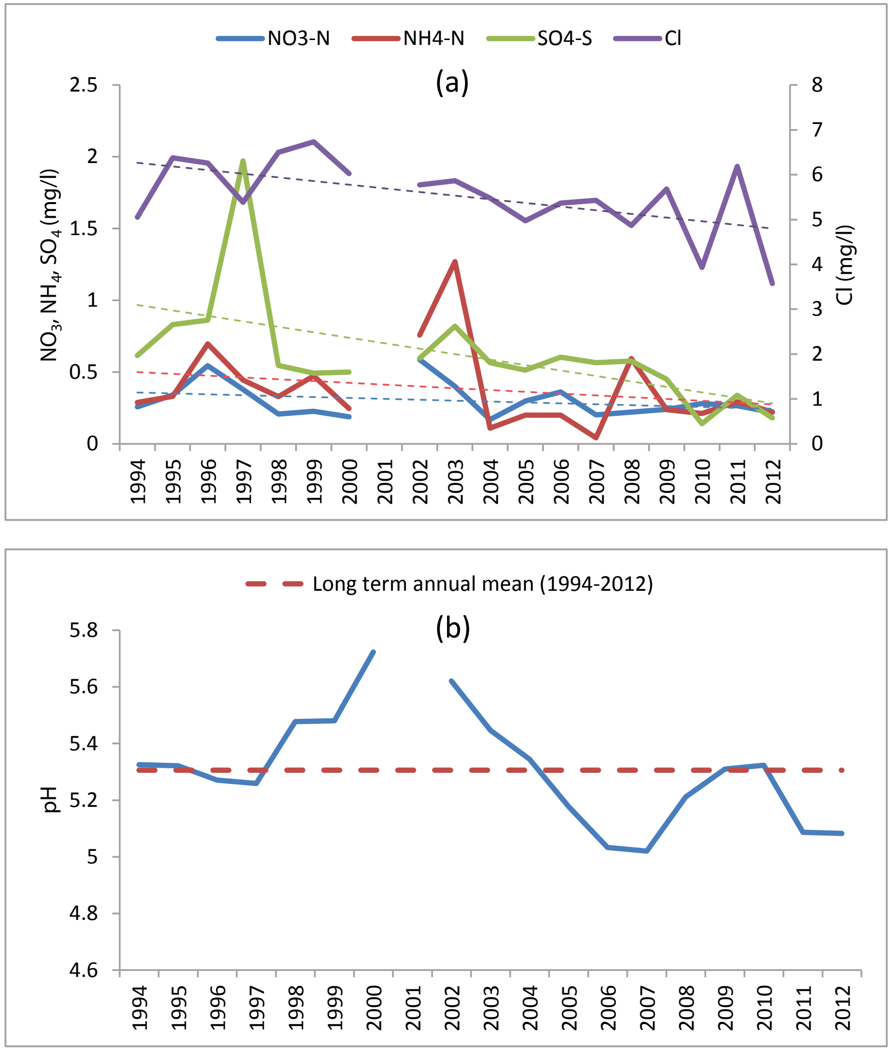


Figure 6. Average annual (a) ammonium (NH_4), chloride (Cl), nitrate (NO_3) and sulphate (SO_4) and (b) pH volume weighted concentrations in rainfall at North Wyke (1994-2012). (Note: data for 2001 incomplete due to foot and mouth epidemic.)

Soil Solution Chemistry

Soil solution samples are collected at depths of 15cm in the soil A horizon (shallow) and 55cm in the soil B horizon (deep) in an area that is extensively grazed by cattle and has received no N fertiliser inputs since at least 1984. Despite the (non-significant) decline in precipitation pH at North Wyke, soil solution pH in the deep samples significantly increased, although there was no clear trend in the shallow soil solution (Fig. 7a). The same trend of increasing pH in soil solution from deep samplers but no overall change in the shallow samplers was exhibited across most of the ECN network during the first fifteen years of monitoring (Morecroft et al., 2009). The increase in soil solution pH at depth reflects the decline in SO_4 (Fig. 7b) and Cl (Fig. 7c) concentrations at depth. As with pH, Cl concentrations in the shallow soil water exhibited considerable annual variability but no overall trend, and SO_4 concentrations increased (Figs 7b and c).

Increasing pH and decreasing SO_4 and Cl in the deep soil solution is indicative of the soil recovering from acidification at North Wyke following atmospheric emission control measures and reflects the changes seen in precipitation composition. Organic matter in soil can tightly control the release of organic acids and, as organic matter content is higher in the A horizon, this may explain why soil solution pH in the upper soil surface shows no change. There was no evidence of a reduction in NH_4 or NO_3 concentration at either soil depth despite significant declines in atmospheric NO_2 and precipitation NO_3.

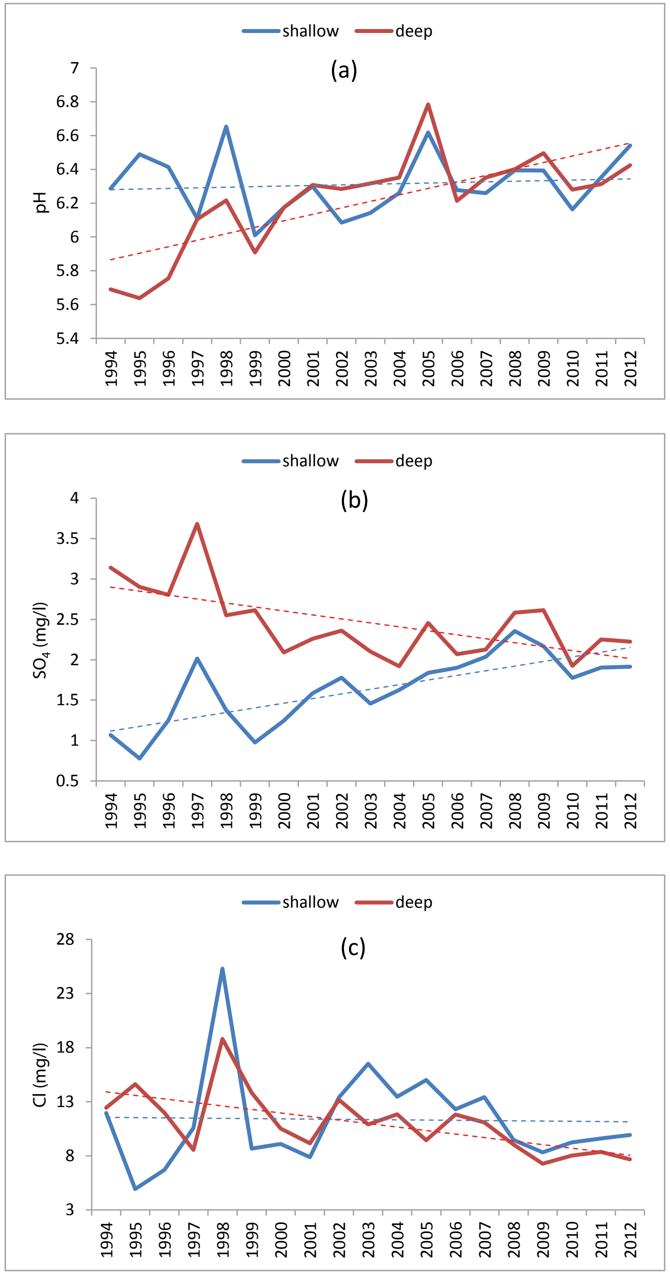
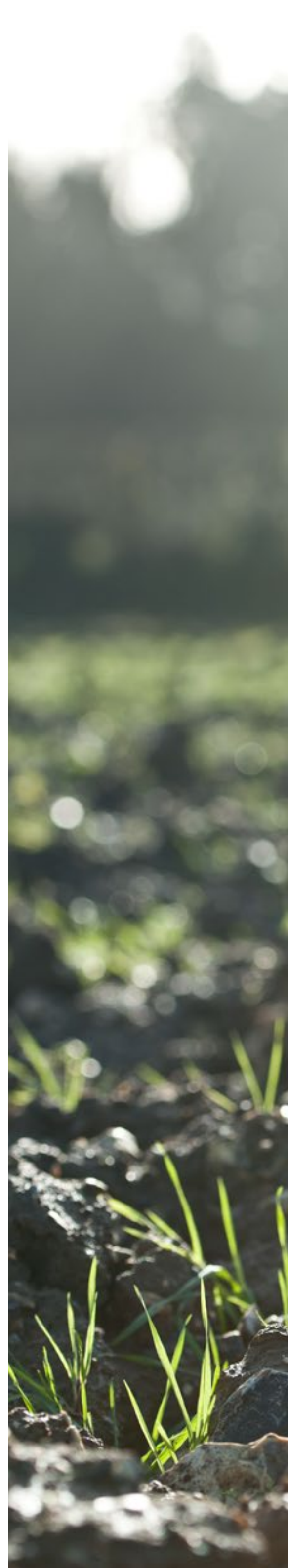


Figure 7. Average annual (a) pH (b) sulphate (SO_4) and (c) chloride (Cl) volume weighted concentration in shallow and deep soil solution at North Wyke (1994-2012).



Surface Water Chemistry: The River Taw

The River Taw originates at Taw Head in Dartmoor National Park and flows for 72 km until it reaches the Bristol Channel on the north coast of Devon. It is a surface water catchment with > 95% clay and clay loam soils, so most rainfall tends to run-off due to the low permeability of the soils. The catchment is largely agricultural, predominately covered by grassland. In 2002 the Taw catchment was designated a nitrate vulnerable zone (NVZ) on the grounds that the estuary is eutrophic. Dip samples from the River Taw are collected once a fortnight and analysed for the same chemical and physical variables as for precipitation and soil solution.

As with the deep soil solution, River Taw SO_4 concentration has significantly decreased whilst pH has significantly increased (Fig. 8a). The most likely explanation of higher river pH is the reduction in the atmospheric deposition of SO_4.
Despite being in a NVZ, NO_3 and NH_4 levels have not significantly changed at the North Wyke monitoring point. However, the long term annual mean (1994-2012) for NO_3 concentration (0.82 mg/l) and the highest monthly mean of 6.84 mg/l recorded in October 2005 are well below the Drinking Water Directive (75/440/ECC) permitted maximum of 50mg/l.

River samples are analysed for ortho-phosphate (ortho-P), a form of phosphate that is readily available to biological communities and contributes to eutrophication along with N compounds. No clear trend for ortho-P concentration at North Wyke was observed (1994-2012), with a long term annual mean of 0.04 mg/l making it a Grade 2 (low) river. Both NO_3 and ortho-phosphate exhibit a seasonal pattern in concentrations (Fig. 8b): NO_3 concentrations are higher in the winter due to fertiliser and manure runoff from fields, and ortho-P levels peak in summer, with higher concentrations occurring during low river flow, which suggests point source inputs (e.g. drains, sewage).

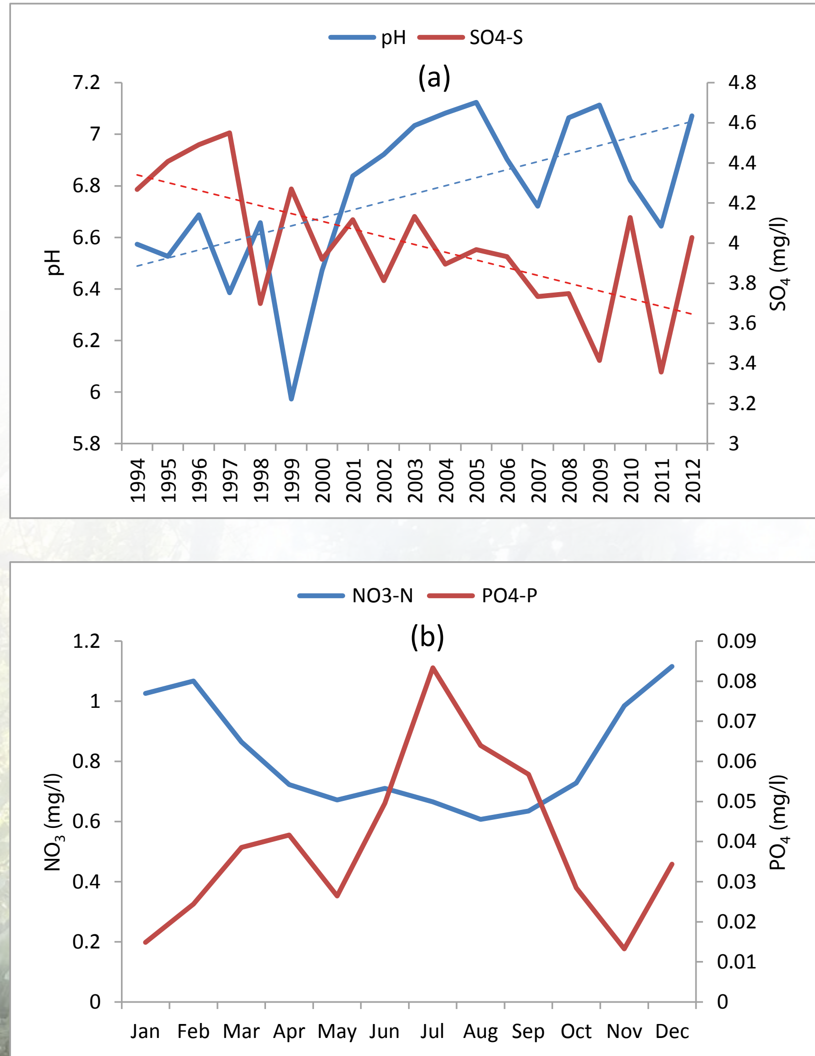


Figure 8. Average (a) annual pH and sulphate (SO_4) and (b) monthly nitrate (NO_3) and sulphate (SO_4), concentration in the River Taw, North Wyke (1994-2012).

Biodiversity

Species differ in their responses to environmental change; some species may be more tolerant to a specific environmental stress than others. The ECN monitors a range of contrasting species with different distributions, life histories (reproduction rates, life span etc.), mobility and ecological requirements. The network detects regional differences of the occurrence and abundance of species over time. The relationship between drivers and their impacts on biodiversity are extremely complex; often there are multiple pressures on an ecosystem with a vast array of interactions. By long-term monitoring of a wide variety of abiotic and biotic parameters, the ECN can contribute to our understanding of how groups of organisms, individual species and ecosystems respond to environmental pressures.

Vegetation

At North Wyke the community composition of vascular plants falls into three broad habitat types; lowland deciduous woodland (field layer), neutral grassland and fen-meadow. These were usually monitored at three-year intervals. The management of some of the neutral grasslands changed from a silage system to a hay system after the ECN began. In order to capture management changes, data for the improved grassland habitat was spilt into two categories, silage grassland and hay meadow.

To investigate if vegetation had been influenced by factors such as air pollution, climate or land management several systems of classifying plant species characteristics were used. The Ellenberg system, adjusted for British plants (Hill et al., 1999) allocates a score to each plant species according to their environmental preferences in terms of nitrogen, an indicator of fertility (Ellenberg N), water availability (Ellenberg W), soil pH (Ellenberg R) and light levels (Ellenberg L). The CSR scheme devised by Grime (1988) identifies three primary survival strategies plants have evolved in response to external factors that affect growth: competition for resources (competitors (C), fast growing species typical of environments with high resource availability), stress through lack of resources (stress-tolerators (S), slow growing species in resource limited environments) or disturbance (ruderals (R), opportunistic species with short generation times and high dispersal rates capable of colonising recently disturbed habitats).

Temperature ranges for plant species were calculated using the mean January and July temperatures taken from the PLANTATT dataset (Hill et al., 2004) based on the UK 10 km grid squares each species occurs in. Mean species richness (the number of different species found in each habitat type) was also calculated. The different mean vegetation characteristics over the course of the ECN for each of the four broad habitat types are given in Table 4.

Table 4. Mean plant community scores for silage grassland, hay meadow and fen-meadow (1994-2011) and lowland deciduous woodland (1996-2011).

Scores	Lowland deciduous woodland	Silage grassland	Hay meadow	Fen-meadow
Ellenberg N (Fertility)	5.33	5.5	5.43	4.58
Ellenberg W (Water)	5.8	5.83	5.44	7.42
Ellenberg R (pH)	5.66	6.01	6	5.36
Ellenberg L (Light)	5.03	7.17	7.11	6.75
Competitor	2.98	2.85	2.64	3.15
Stress-tolerator	2.72	1.91	1.94	2.3
Ruderal	1.68	3.03	3.25	2.18

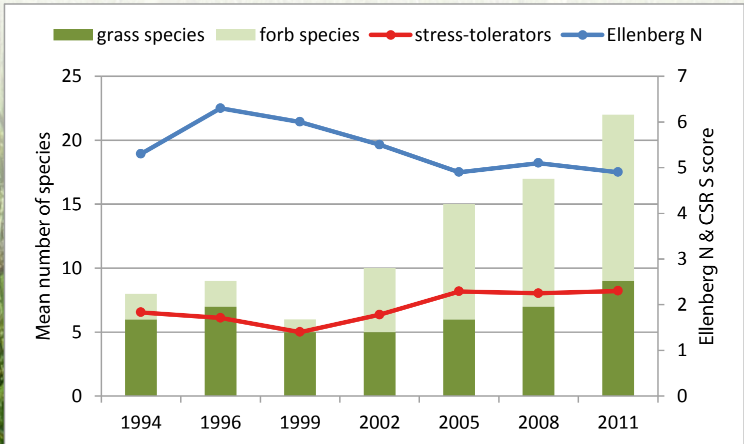
Comparison of the habitats detected significant contrasting changes to mean species richness, Ellenberg and CSR values. No significant trends in the field flora in lowland deciduous woodland were detected. In the silage grassland category, Ellenberg W values increased indicating a shift towards species of wetter habitats and competitive species also increased. Ruderal species declined in the fen-meadow habitat. Both species richness and stress-tolerators increased in the hay meadow.

There was no evidence to suggest that plant communities at North Wyke were shifting towards plant species with either lower or higher temperature preferences, agreeing with the lack of any significant temperature change at North Wyke. A shift towards species associated with wetter habitats only occurred in the silage grassland category, possibly reflecting a trend towards wetter summers. Competitive plant species which dominate agricultural grasslands (mainly grass species) and thrive when water resources are not limited, also significantly increased in the silage grassland category. The UK Countryside Survey also reported an increase in competitive species and species preferring wetter conditions between 1998 and 2007 in improved and neutral grasslands (Carey et al., 2008).

As noted above, the management of several fields switched in 1999 from a silage/grazing system to a hay system with after-grazing. The hay meadows have also been the location for two experiments, one established in 1999 and the other in 2008, both aimed at increasing the botanical diversity of agricultural improved, nutrient rich grasslands. ECN monitoring occurred outside the experimental plots.

Before 1999 the sward was dominated by two competitive grass species, rye-grass (*Lolium perenne*) and rough meadow-grass (*Poa trivialis*). Species richness increased by 63.6% (1994-2011), stress-tolerators significantly increased and Ellenberg N values declined indicating a shift towards less nitrogen demanding plant species although this reduction was not statistically significant (Fig. 9). These plant community changes reflect a reduction in soil fertility accompanying the ceasing of the application of artificial fertilisers and the continuing removal of nutrients in the hay. Grazing in late summer/autumn and early spring is likely to have created suitable gaps for seeds in the seed bank and seeds from sown species to germinate. Gradually 4 grass and 7 forb species sown in the experiments were recorded in the ECN plots and, once established, all of these species persisted.

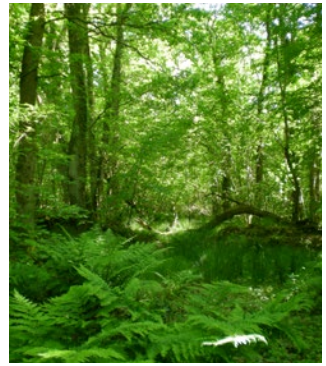
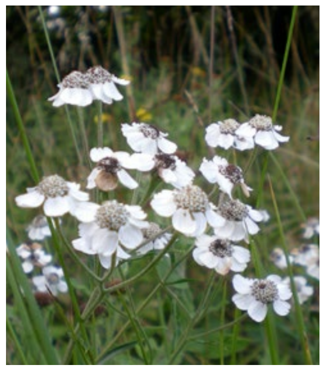
Figure 9. Mean species richness, stress-tolerators and fertility scores for the hay meadow at North Wyke.

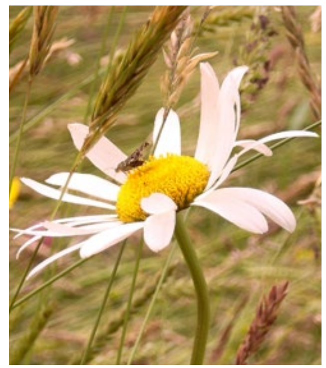


The fen-meadow habitat at North Wyke is a remnant of an unimproved wet pasture known in Cornwall and Devon as culm grassland. In the past 100 years the majority of culm grassland has been lost in the UK caused mainly by agricultural improvement (drainage, reseeding, fertiliser application), afforestation, abandonment and habitat fragmentation. Livestock grazing of the fen-meadow at North Wyke ceased at least 25 years ago. It is unlikely that the fen-meadow will be grazed again by livestock due to the presence of Hemlock Water-dropwort (*Oenanthe crocata*), a poisonous plant, but deer sporadically graze the area. Without active management, over time the tall herb-fen community will change to scrub and eventually woodland through natural succession. However, so far the only detected significant change is a decline in CSR R values, possibly reflecting a lack of disturbance to the vegetation and wetter summers in recent years resulting in fewer gaps for ruderals to colonise.

Nitrogen is a limiting nutrient for plant growth in unimproved habitats such as the fen-meadow at North Wyke where mean Ellenberg N levels are relatively low (Table 4). There was no clear evidence that plant assemblages have become less nitrogen demanding as a result of reduced nitrogen deposition in any of the four habitat types at North Wyke. Despite a reduction in soil water acidity at depth (55cm) there was no corresponding shift in plant communities with a preference for less acidic conditions. It is likely that many of the plant species are mainly influenced by upper soil surface pH, which has remained relatively stable.





Invertebrates

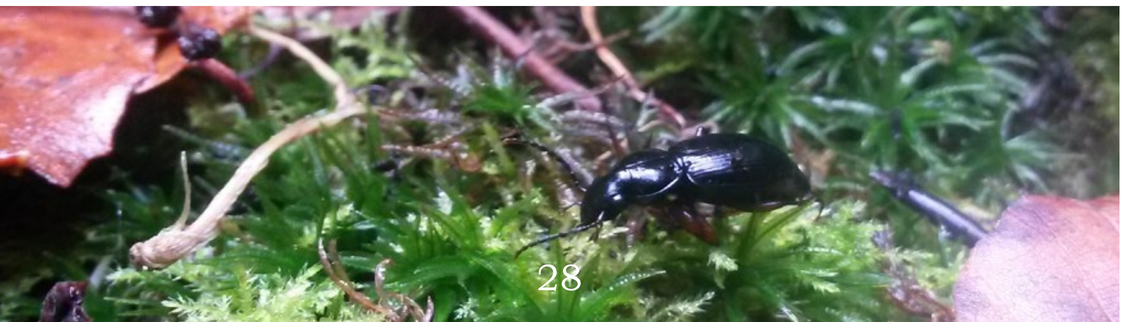
Beetles

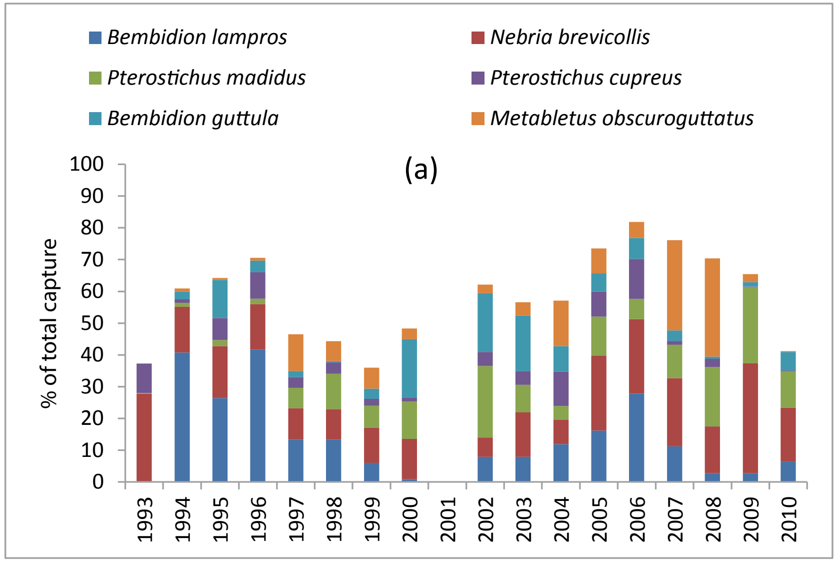
Ground beetles (*Carabidae*), also known as carabids are a large, diverse family of beetles with around 350 species in Britain. Studies have demonstrated that carabids are sensitive to climate and habitat management. Individual species have different preferences for temperature, shade and soil moisture, so changes to grazing intensity for example, can alter the sward height which in turn can alter the microclimate affecting the local carabid population dynamics. As carabid beetles are essential components of terrestrial food webs, are sensitive to changes in environmental conditions and contribute to food production by consuming agricultural pests and weed seeds they are an important group of insects to monitor.

Carabids are monitored along three transects: Transect 1, Between roadside woodland strip and permanent pasture; Transect 2, Along fence line between two permanent pastures; Transect 3, Between river with woodland strip and permanent pasture. The three pitfall trap transects captured 79 species of carabid beetles at North Wyke (1993-2010). The six most common species accounted for 63% of the total catch: *Bembidion lampros* 24%, *Nebria brevicollis* 16%, *Pterostichus madidus* 6%, *Pterostichus cupreus* 6%, *Bembidion guttula* 6%, *Metabletus obscuroguttatus* 5%. The relative proportions of the six most common species varied considerably from year to year (Fig. 10a). Many species were caught sporadically with less than 100 individuals recorded for 69% of species, suggesting that these are uncommon and exist in low densities at North Wyke.

Both the total number of individuals and species richness of carabids exhibited no statistically significant trend (Fig. 10b), as found by an earlier study examining ECN carabid data (Morecroft et al., 2009). However, the three individual transects demonstrated contrasting trends, with carabid abundance significantly declining at transect 2 and species richness significantly declining at transects 1 and 2, whereas transect 3 appeared to be stable for both abundance and diversity. The management of the pastures adjacent to transects 1 and 2 has recently been more sporadic with infrequent topping and/or grazing, which may have changed the vegetation structure and consequently impacted on carabid populations, whereas the management adjacent to transect 3 has been relatively consistent.

Carabid communities at North Wyke and other ECN sites have demonstrated that they respond to localised perturbations affecting habitat structure and microclimates as well as wider-scale drivers such as climate and that woodlands and hedgerows are important habitats for maintaining populations (Brooks et al., 2012).





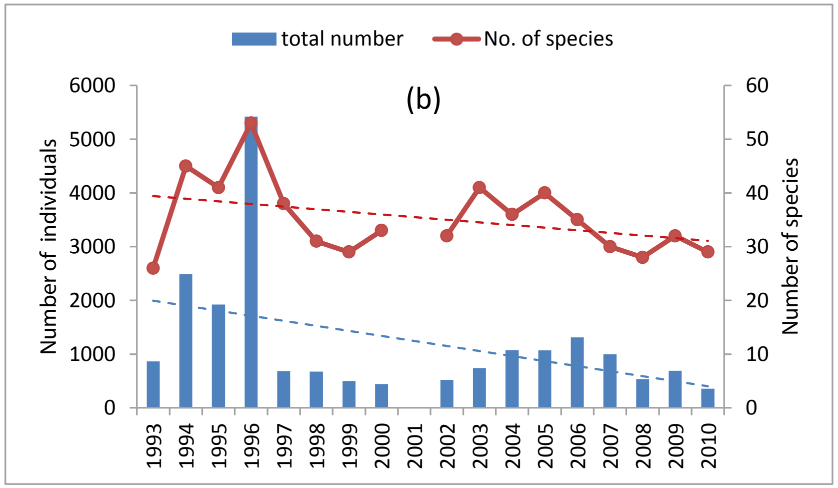


Figure 10. Annual (a) proportion of the six commonest carabid beetle species and (b) total number of carabid beetles and total number of carabid species captured at North Wyke (1993-2010). (Note: data for 2001 incomplete due to foot and mouth epidemic.)

Butterflies

North Wyke and the surrounding landscape provide a variety of habitats such as woodlands, wet grassland, hedgerows and field margins providing shelter, nectar sources and a range of larval foodplants suitable for many butterfly species found in Britain. Of the 59 resident butterfly species in the UK, 22 have been recorded at North Wyke. A further three species, the Clouded Yellow (*Colias croceus*), Painted Lady (*Vanessa cardui*) and Red Admiral (*Vanessa atalanta*) that are regular migrants have also been observed. The ten most commonly recorded species at North Wyke are shown in Table 5. Both total abundance and the number of species varied considerable and tended to decrease, although not significantly (Fig. 11).

Table 5. The ten commonest butterfly species at North Wyke (1993-2012)

	Butterfly category	% of total butterfly count (1993-2012)
Meadow Brown	wider countryside	17.8
Gatekeeper	wider countryside	13.1
Green-veined White	wider countryside	11.5
Ringlet	wider countryside	11.1
Speckled Wood	wider countryside	10.9
Small White	wider countryside	9.5
Small Tortoiseshell	wider countryside	8.6
Peacock	wider countryside	3.2
Red Admiral	regular migrant	2.7
Painted Lady	regular migrant	2.6

Butterfly species were allocated to three categories: wider countryside species (use habitats and foodplants that are relatively common in the landscape and are usually relatively mobile), habitat specialists (thrive in a narrow range of environmental conditions so colonies are restricted and often occur in small, isolated areas) and regular migrants. Only two habitat specialist species, the Brown Hairstreak (*Thecla betulae*) classed as a vulnerable species according to the red list of British butterflies, and last seen in 2004 at North Wyke, and the Silver-washed Fritillary (*Argynnis paphia*) were recorded. Wider countryside butterfly species accounted for 94.3% of the total sightings, followed by regular migrants (5.5%).

Individual species have experienced contrasting fortunes with the abundance of eight species (Brimstone, Gatekeeper, Large White, Red Admiral, Small Skipper, Small White, Speckled Wood and Wall) significantly decreasing, and two (Meadow Brown, Orange Tip) significantly increasing. Since the 1990s, the Wall (*Lasiommata megera*) has seen a dramatic population decline in the UK, the cause of which is not understood, and is now a British red-listed near threatened species.

Much of the year to year variation of butterfly populations can be attributed to weather conditions. The second most abundant year for butterflies was 1995 and corresponded with the highest mean summer temperature and the driest mean summer recorded between 1992 and 2012. In 1995, the Small White (*Pieris rapea*) accounted for 40% of the total butterfly numbers; its resident population is likely to have been boosted by an influx of immigrants from mainland Europe. The second driest summer, 1996, was the most abundant year for butterflies, with peak numbers of the Brimstone (*Gonepteryx rhamni*), Gatekeeper (*Pyronia tithonus*), Large Skipper (*Ochlodes venata*), Marbled White (*Melanargia galathea*), Painted Lady, Peacock (*Inachis io*), Red Admiral, Small Skipper (*Thymelicus sylvestris*) and Small Tortoiseshell (*Aglais urticae*). Both the winter and spring preceding the summer of 1996 were the second coldest, and the winter was the third driest, conditions which may have benefitted the overwintering survival of some species by reducing fungal attack. The second lowest numbers of butterflies were recorded in 2012, a relatively cool summer and the second wettest summer, with a decline of 60% in the total abundance compared with the previous year.

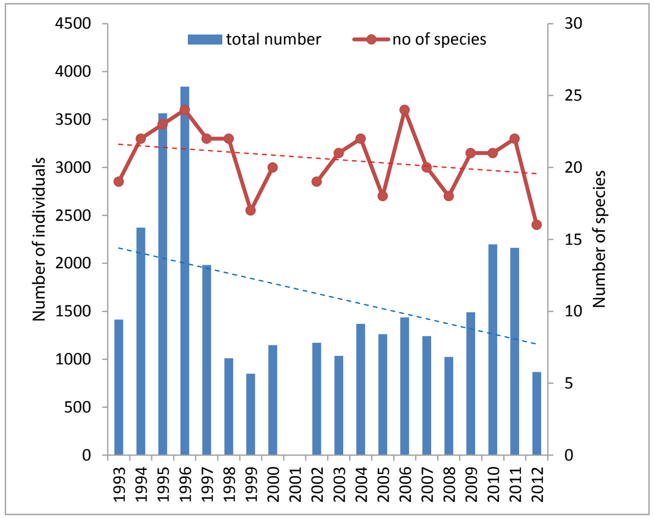


Figure 11. Total number of butterflies and total number of butterfly species at North Wyke (1993-2012). (Note: data for 2001 incomplete due to foot and mouth epidemic.)

It is difficult to know why some wider countryside species are declining whilst others are thriving at North Wyke, as climate and land use management has remained largely unchanged over the study period. The only substantial change in management was that from silage to a hay in 1999, which seemed to benefit the two species that significantly increased at North Wyke, the meadow brown (*Maniola jurtina*) and orange tip (*Anthocharis cardamines*) with an average increase of 61% and 65%, respectively, since 1999 in these areas.

Moths

In Britain there are over 2,500 species of moths of which approximately 900 are larger moths (macro-moths). North Wyke is part of a national network of standard Rothamsted light traps operated by the Rothamsted Insect Survey (RIS) to study the population dynamics of macro-moths. The total abundance of macro-moths declined significantly at North Wyke from 1993 to 2012 (Fig. 12). Three families, the *Arctiidae*, *Geometridae* and *Noctuidae* accounted for 11.5%, 13.5% and 69.3%, respectively, of all the moths captured at North Wyke. Total abundance of both the Noctuids and the Geometrids significantly declined. Some 303 species were recorded with 12 belonging to the Arctiidae family, 127 Geometrids and 125 Noctuids. The ten most frequently caught macro-moths are shown in Table 6 of which the Small Square-spot (*Diarsia rubi*), Smoky Wainscot (*Mythimna impura*) and Square-spot Rustic (*Xestia xanthographa*) declined significantly. Of the 33 species with more than 100 captures over the time series only two, the Muslin Moth (*Diaphora mendica*) and the Setaceous Hebrew Character (*Xestia c-nigrum*) exhibited a significant positive trend, whilst ten declined. No significant trends were detected for species richness for either total captures or for the three dominant families.

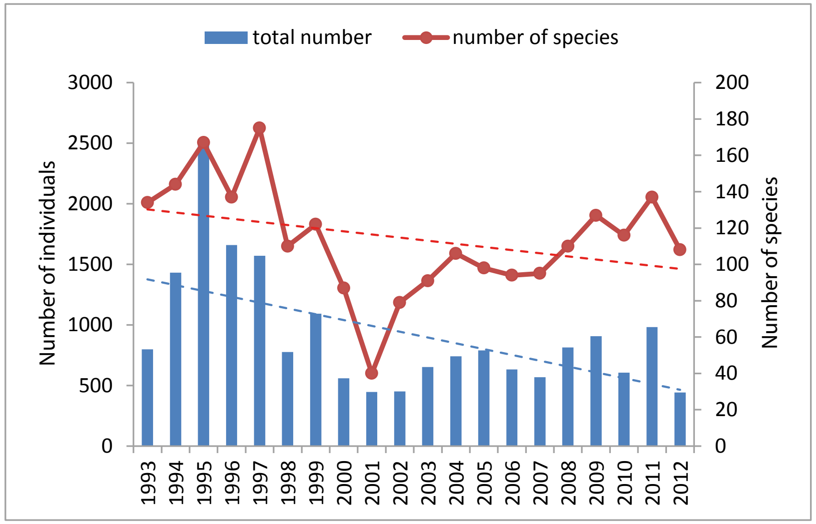


Figure 12. Total number of moths and total number of moth species at North Wyke (1993-2012).

Table 6. The ten commonest moth species at North Wyke (1993-2012)

	Family	% of total catch
Small Square-spot	*Noctuidae*	22.4
Lunar Underwing	*Noctuidae*	7.9
Common Footman	*Arctiidae*	7.7
Rosy Rustic	*Noctuidae*	3.6
Heart & Dart	*Noctuidae*	3.6
Common Rustic	*Noctuidae*	2.9
Hebrew Character	*Noctuidae*	2.5
Flame Shoulder	*Noctuidae*	2.2
Smoky Wainscot	*Noctuidae*	1.9
Square-spot Rustic	*Noctuidae*	1.9

As with butterflies, large inter-annual fluctuations are normal for moths as the success of each stage of their lifecycle is reliant on suitable weather conditions. Peak macro-moth abundance coincided with the warmest, driest summer in 1995 (1993-2012), whilst lowest numbers were recorded in 2012, the second wettest summer. General land use, management and climate at North Wyke have seen no major changes during ECN monitoring so it is not clear why populations of some macro-moths are stable, others are declining whilst a minority of species appear to be thriving. Interestingly, during the first 15 years of monitoring, North Wyke was the only ECN site where change was observed with a decline in the total number of individuals and *Noctuidae* (Morecroft et al., 2009).

Vertebrates

Bats

Different bat species have various dietary and habitat requirements linked to their size, echolocation and wing morphology. With a mild climate and diverse range of habitats, Devon is a suitable environment to support a variety of bats: of the 17 breeding bat species in the UK, 16 have been recorded in Devon. The North Wyke farm consists of pasture, woodland, ponds and a river providing a variety of foraging areas, hedgerows that provide connectivity of the landscape for bats commuting between feeding areas, and a mixture of old and new buildings as well as trees for roosting sites.

Ten bat species were recorded at North Wyke. Pipistrelles: Common Pipistrelle (*Pipistrelle pipistrellus*) and Soprano Pipistrelle (*Pipistrellus pygmaeus*) were the most abundant species accounting for 76.5% (1993-2012) of the total number of bat passes. Common and Soprano Pipistrelle bat passes were combined as they were not formally identified as separate species until 1999. The Common Pipistrelle is the most widespread and abundant species in the UK and is a generalist species using both buildings and trees for roosting sites and feeds over a variety of habitats. The Daubenton's Bat (*Myotis daubentoni*), a species that mainly feeds over lakes, rivers, ponds and ditches were the second most recorded species (10.3% of the total bat passes). The third most common bat species (1.9% of total bat passes) was the Noctule (*Nyctalus noctula*), which roosts in tree holes and forages over a variety of habitats including pasture, water, open parts of woodland and woodland edges. Brown Long-eared (*Plecotus auritus*) bats roost in trees or old buildings and have a preference for foraging in deciduous woodland were the fourth most frequently detected species (1.5% of total bat passes). The other five recorded species; Barbestelle Bat (*Barbastella barbastellus*), Leisler's Bat (*Nyctalus leisleri*) Natterer's Bat (*Myotis nattereri*), Serotine (*Eptesicus seratinus*) and Whiskered Bat (*Myotis mystacinus*) were observed only on a few occasions. Species richness did not significantly change during the sampling period.

The total number of bat passes and those for combined Pipistrelle (common and soprano) species alone did increase between 1993 and 2012 but the change was not statistically significant (Fig. 13). All of the species monitored from the late 1990s by the National Bat Monitoring Programme are either stable or increasing (Anon, 2012) suggesting a recovery from the declines that occurred in the twentieth century. Results from a national field survey show that the Common Pipistrelle has increased by 65.3% from 1998-2011 (Anon, 2012). British bats and their roosts are protected by law and are likely to have benefitted from targeted conservation projects and agri-environment schemes. North Wyke, compared to many other areas of the UK, has provided relatively stable and favourable habitats for bats over the course of ECN and there have been no major changes to the climate, so it is unlikely that large changes in bat activity would have been seen.

Thinning of trees along a stretch of the River Taw in 2003 contributed to the decline in bat observations in that year as there was a noticeable dip in activity by the river. The tree canopy over the river forms a sheltered corridor for bats to commute and forage and tree thinning produced a less favourable habitat. In subsequent years bat activity began to increase in this area corresponding to vegetation regrowth. Declines in bat activity also occurred in 2008 and 2009 but there are no obvious explanations for these. As bats are highly mobile covering several kilometres in a single night the cause may well have occurred off site.

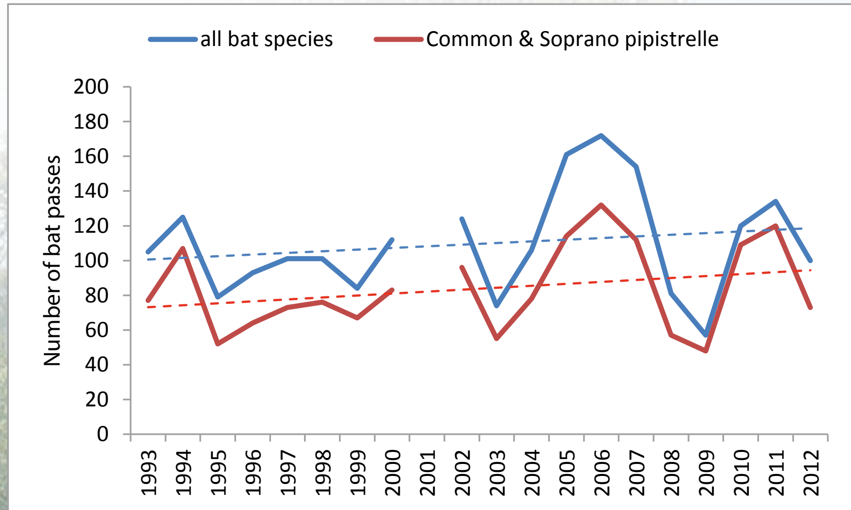


Figure 13. Total bat and combined Common and Soprano Pipistrelle activity at North Wyke (1993-2012). Note: no data recorded for 2001 (foot and mouth outbreak).

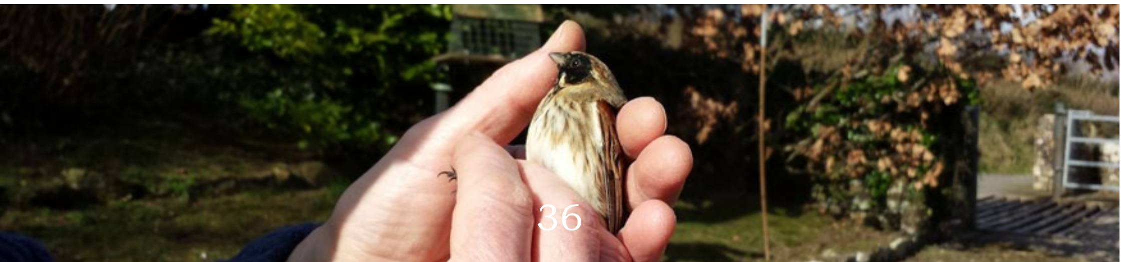
Birds

Since the early 1970s substantial declines in many bird populations have been documented, the reasons including habitat loss, agricultural intensification and lack of woodland management. At North Wyke 66 species were recorded during the breeding bird surveys (1997-2012), the top ten commonest species are shown in Table 7. No significant change was observed for total numbers but species richness did significantly increase (Fig. 14).

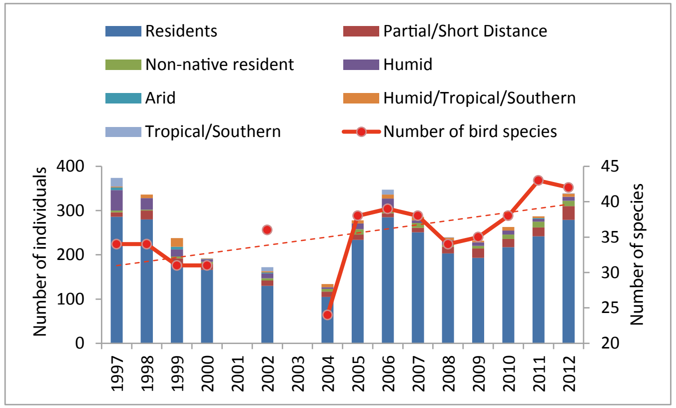
Bird species were allocated into a group according to their migratory strategy as identified in the state of the UK's birds (SUKB) 2014 report (Anon, 2014). Overall humid zone species significantly declined at North Wyke, including both the House Martin and Willow Warbler. This reflects the national trend, with the humid zone species declining by just over 70% since the late 1980s (Anon, 2014). Only 3 species observed at North Wyke overwinter in arid sub-Saharan Africa (Redstart, Sedge Warbler and Whitethroat) and a significant decline was observed for the arid zone indicator group, again agreeing with national data. Groups of species that migrate furthest south (tropical southern zone, represented only by the Swift at North Wyke and the humid tropical southern zone, only the Spotted Flycatcher and Swallow present at North Wyke) declined as observed nationally, although not significantly. Overall, species that winter north of the Sahara (partial/short distance), such as the Chiffchaff, have slightly increased in numbers, although not significantly, again mirroring national data. Numbers of resident species increased, as did those of non-native residents due to a rise in Pheasant abundance.

Table 7. The ten commonest bird species at North Wyke (1997-2012)

Species	Wintering zone	% of total bird count (1997-2012)
Blue Tit	Resident	10.61
Wren	Resident	10.27
Chaffinch	Resident	8.11
Robin	Resident	6.75
Blackbird	Resident	6.08
Carrion Crow	Resident	5.79
Woodpigeon	Resident	5.63
Great Tit	Resident	4.67
Blackcap	Migrant (partial/short distance)	3.17
Goldfinch	Resident	2.80

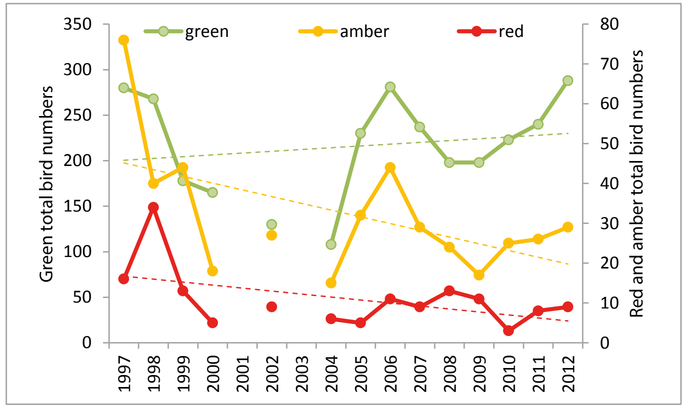


> Figure 14. Total number of birds (separated by migratory category) and total number of bird species at North Wyke (1997-2012). (Note: no data recorded for 2001, foot and mouth outbreak & 2003).



The total abundance of birds predominantly associated with farmland, such as the Skylark, Goldfinch and Yellowhammer, fluctuated considerably but with no clear trend. Species were categorised by their conservation status as defined in 'The Birds of Conservation Concern 3' (Eaton et al., 2009) and assigned to one of three levels; red-listed (greatest concern), amber-listed (moderate concern) and green-listed (least concern). At North Wyke 32 green-listed, 16 amber-listed and 12 red-listed species were recorded, representing 81%, 12% and 4% of the total sightings respectively. Both amber-listed and red-listed species declined in abundance, although only amber-listed species fell significantly whilst green-listed species abundance and species richness increased (Fig. 15).

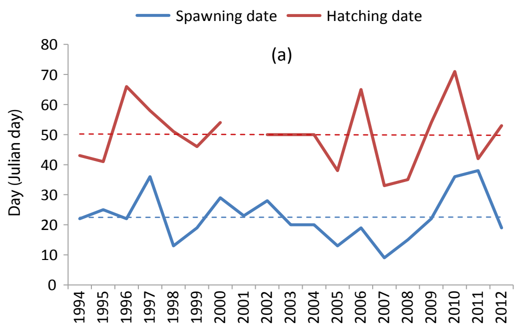
> Figure 15. Total number of green, amber and red-listed bird species at North Wyke (1997-2012). (Note: no data recorded for 2001, foot and mouth outbreak & 2003).

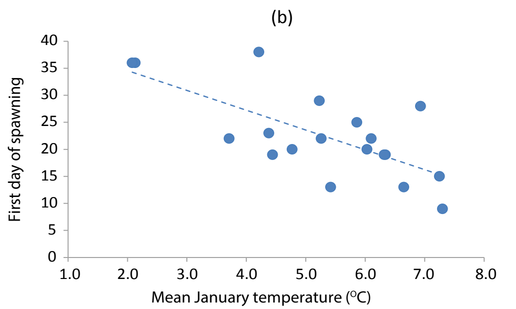


However allocating bird species to specific groups can mask individual trends. Both the House Sparrow and Starling, resident species, were once common in the UK but are now red-listed and have not been recorded at North Wyke since 2007 and 1998 respectively (1997-2012). The numbers of Wrens observed, a resident, green-listed species, have halved even though no major changes to land use and climate have occurred at North Wyke. There are multiple pressures and complex interactions on bird populations with some species benefiting and some losing and because of their mobility it is often unclear what the cause/s of the changes are. However with long-term monitoring it may be possible to disentangle the effects of a range of drivers.

Frogs

Amphibians are particularly sensitive to environmental change due to the permeability of their skin making them vulnerable to pollution and as they are poikilothermic (body temperature varies with ambient temperature) they are also vulnerable to surrounding temperature changes. Warmer drier weather can alter amphibian habitats by lowering water levels or completely drying out ponds and ditches in which they breed whilst lower soil moisture can make habitats less hospitable to adults. Climate change can also influence food availability, predator-prey relationships, pathogen survival rates, disease transmission and the timing of life cycle events (phenology). The ECN monitors the first spawning and hatching dates of the Common Frog (*Rana temporaria*) in order to detect phenological shifts and the physical characteristics of the pond, such as water depth and pH, which may affect breeding success.





Frog breeding cycles vary across the UK with the first frogspawn occurring in the southwest where the winter months are generally warmer. This pattern of spawning was observed across the ECN network, with North Wyke consistently being the earliest site for spawning and hatching. No evidence was found for either earlier spawning or hatching at North Wyke between 1994 and 2012 (Fig. 16a), corresponding with no overall mean January temperature changes. However, the substantial variation in both the timing of spawning (range of 29 days) and hatching (range of 38 days) at North Wyke highlights the importance of long-term monitoring for distinguishing short-term patterns from long term trends.

Spawning was negatively correlated with mean January air temperature (Fig. 16b), suggesting that adult emergence from hibernation and breeding activities are at least partially triggered by winter temperature. The Common Frog is capable of changing the timings of breeding and metamorphosis in response to environmental conditions such as temperature and water volume. Therefore predicted climate change and extreme events will have a significant impact on Common Frog populations.

< **Figure 16.** (a) First spawning and hatching dates of the common frog (*Rana temporaria*) and (b) first spawning dates of the common frog (*Rana temporaria*) plotted against average January temperatures at North Wyke (1994-2012)

Environmental change at North Wyke

The first two decades of ECN monitoring revealed marked changes in the environment at North Wyke. Following legislative emission controls a reduction in atmospheric pollutants, particularly sulphate concentration in rainfall, was observed leading to increased soil pH. There were also changes in plant communities and beetle and butterfly populations in localised areas possibly as a consequence of changed management practices. Variable weather conditions contributed to substantial temporal fluctuations in butterfly and macro-moth numbers, but an overall decline in macro-moth abundance was observed, demonstrating the importance of long-term monitoring to distinguish between natural episodic patterns and long term trends. The causes for some of the biodiversity changes at North Wyke are unclear. Ecological processes are complex: there are often multiple drivers of change in operation, species have different survival strategies, there are knock-on-effects between different trophic levels and mobile species are affected by environmental conditions further afield making it difficult to disentangle the cause/s of change. The ECN provides us with a valuable platform and in conjunction with other networks and research will help us to improve our understanding of why and how rapidly components of ecosystems are changing, what the effects of these changes are and how quickly components recover to their original state after the implementation of new policies and management practises. In an ever changing world, the ECN continues to provide information on the health of our ecosystems and the ecosystem services vital to human well-being that they deliver.

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