

## **Biodiversity climate change impacts report card technical papers**

### **7. Evidence of climate change impacts on populations using long-term datasets.**

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## EXECUTIVE SUMMARY

- Studies based on analyses of long-term monitoring data, which are largely derived from national monitoring schemes, are reviewed to assess the impacts of climate change on populations and communities of terrestrial biodiversity.
- Although the details vary between species, these studies provide a compelling body of evidence that temperature and precipitation can have a strong impact on wild species populations and on ecological communities (**high agreement, robust evidence**).
- Population changes in many insect populations are strongly influenced by variation in temperature and precipitation, with the best available evidence shown to affect butterfly, moth, aphid and tipulid populations (**medium agreement, medium evidence**).
- Long-term changes in butterfly population and community trends can be linked to climate change, although the strength and significance of effects varies between studies (**low agreement, medium evidence**). Long-term declines in moth populations can be partly related to observed temperature and precipitation patterns, although the details vary between studies (**medium agreement, medium evidence**).
- Declines in some ground beetle populations may be driven by warming (**medium agreement, limited evidence**). Increases in temperature have increased aphid (**high agreement, medium evidence**) and tick (**low agreement, limited evidence**) populations.
- A number of key studies have increased the evidence base associated with understanding the impacts of climate change on birds, leading to **high agreement, robust evidence** that changes in bird populations are linked to variation in temperature and precipitation. Specifically, warming has contributed to increases in many common and widespread resident bird populations (**high agreement, robust evidence**), which populations of long-distance migrants have not benefitted from so much (**medium agreement, robust evidence**). Instead, they are driven largely by changes in precipitation on their African wintering grounds (**high agreement, robust evidence**).
- Recent changes in ecological communities, as measured by changes in diversity and divergent trends in warm-associated southerly species and cold-associated northerly species, are consistent with the effects expected from recent climate change (**high agreement, robust evidence**). However, the strength of evidence attributing these changes to climate change is less, due to potentially confounding effects of other environmental drivers (**medium agreement, medium evidence**).

## 1. Evidence of climate change impacts derived from long-term monitoring.

The scope of this document is to examine the impacts of climate change on terrestrial species' populations in the UK. For most taxa, this assessment is based upon analyses of large-scale monitoring data most relevant to national-scales, although where relevant, more specific studies are also referred to. The nature and scope of these monitoring schemes is already summarised by Pearce-Higgins (2013), and therefore not repeated here. The most robust evidence is based upon the results of analyses that describe the impact of changes in climatic variables upon long-term population or community trends, although reference is also made to other studies that link inter-annual changes in populations to climatic variables as required. Most studies have focussed on the impacts of temperature and precipitation upon these trends. Potential changes in other climate variables, such as snow cover, soil moisture or wind speed are relatively unstudied, leading to the focus in this paper on changes in temperature and precipitation. This means that the potential impacts of climate change upon species populations and communities mediated through other climatic mechanisms may be under-estimated, although this issue is covered by Evans & Pearce-Higgins (2015).

### **Insects**

Analyses of annual indices of 31 butterfly species from 1976 to 1997 showed that the majority (28 species) fluctuated significantly in response to variation in temperature and precipitation. Positive effects of summer (June-August) temperature, both in the year of survey and the previous year were apparent, whilst precipitation had a negative effect in the year of the survey but a positive effect in the previous year (Roy *et al.* 2001). Thus, the relationships between population change and temperature and precipitation change varied through the year. Despite these strong correlations, for only eight species did multivariate models based on data from 1976-1990 show good predictive ability when used to predict population change from 1991-1997. Longer-term fluctuations in gatekeeper *Pyronia tithonus*, marbled white *Melanargia galathea* and wall brown *Lasiommata megera* populations over two centuries, based upon a collation of historical records, also appeared well predicted by the models. Further analyses of a longer time-series of these data replicated the positive relationship between summer temperature in the year of survey and the numbers of butterflies recorded during surveys (Pearce-Higgins *et al.* 2011), but suggested more strongly than Roy *et al.* (2001) that cold winters may be beneficial for many butterfly species. Continued analyses has further emphasised the negative effects of winter temperature, but positive effects of summer temperature, upon populations, whilst precipitation has a widely negative impact on abundance (Pearce-Higgins *et al.* 2015a). This analysis also suggested that negative effects of warm, wet winters appear greatest in species that overwinter as caterpillars or pupae.

For most southern and widespread butterfly species in the UK, which comprise the larger part of British butterfly fauna, climate change has probably resulted in an improvement in climatic conditions. This expectation matches predictions from bioclimate models (Warren *et al.* 2001, Hill *et al.* 2002), and there is good evidence that populations and distributions of a number of southerly-distributed generalist species have expanded northwards in response to recent warming. For some of the best studied species, such as brown argus *Aricia agestis*, there is good mechanistic understanding linking population and range changes to temperature-related changes in plant-host specificity (Pateman *et al.* 2012). In relation to butterfly species of conservation concern, the majority are probably being limited by habitat loss and degradation, rather than climate change, with the only exceptions being three northern and upland butterflies; Scotch argus *Erebia aethiops*, mountain ringlet *Erebia epiphron* and northern brown argus *Aricia artaxerxes*, which have suffered recent declines in range at least partly as a result of climate warming (Franco *et al.* 2006). Both habitat and climate have probably acted together to alter butterfly populations and distributions, although the relative importance of both has changed through time (Mair *et al.* 2014). More broadly, across butterflies as a whole, there has been no overall change in their abundance. Although

population fluctuations for individual species may be related to changes in temperature and precipitation variables, these effects do not sum to an overall positive or negative effect of recent changes in temperature and precipitation on butterflies as a group (Pearce-Higgins *et al.* 2015a).

The Rothamsted light trap network has highlighted considerable evidence for large-scale population declines in macro-moth populations, with 21 % having experienced a rate of decline of > 30% / decade. Population declines have been particularly marked in southern Britain, whilst those in the north have been largely stable (Conrad *et al.* 2006). Complementary data on the frequency of occurrence across Great Britain from 1970-2010 also show evidence for decline, with 260/673 species showing individually statistically significant declines compared to 160 showing significant increases (Fox *et al.* 2014). Of restricted range species, northern species with a southern range-margin in the UK tended to decline, but southerly-distributed species with a northern range-margin remained stable. Fox *et al.* regarded these trends as consistent with expected latitudinal shifts in species' distributions in response to climate change. Conversely, of widespread species found across the UK, occurrence trends in the south were strongly negative, but stable in the north, which the authors' regarded as consistent with the expectation from land-use change, but not climate change, which they assumed would be unlikely to reduce the abundance of these widespread species which occur much further south across Europe.

More detailed analyses of population trends through time provides evidence that population declines in at least one widespread species, the garden tiger moth *Arctia caja*, may be at least partly in response to warmer, wetter winter and spring weather, which may affect overwinter survival (Conrad *et al.* 2002). This is supported by further analysis of 265 widespread moth species surveyed by the Rothamsted light trap network (Pearce-Higgins *et al.* 2015a). Populations of these species have declined by an average of 1.4% per annum from 1975-2010. Individual species models linking population growth rates of these species to temperature and precipitation suggest that responses to changes in these variables through time would be sufficient to account for 2/3rds of this decline, with very strong declines in 9 species of more than 30% matching the expectation from their models. This potential difference in interpretation between the Fox and Pearce-Higgins studies may be accounted for by the fact that population trends of these species are not closely and positively related to temperature, as might be expected from their distribution. Thus, on average, although the abundance of these species is enhanced by warm summer temperatures, there is evidence for negative effects of winter and early spring warming consistent with that found for *A. caja*, and for strong negative effects of precipitation through the year (Pearce-Higgins *et al.* 2015a). It is therefore possible that in the relatively oceanic climate of the UK, it may be changes in precipitation (either in isolation, or in combination with warmer winter temperatures) that have had a negative impact on moth population trends and outweighed any positive effects of warming. Although there remains some uncertainty about the magnitude of climate change impacts on moth populations, both studies do provide evidence that climate change has significantly impacted population trends of at least some species, although how much of the decline of widespread moth species in the south is attributable to climate change or land-use change probably requires more specific analysis to tease that apart, as achieved for birds by Eglinton & Pearce-Higgins (2012).

The Rothamsted suction trap network provides data on the phenology and abundance of aphid populations across the UK. Analyses of these data have shown significant advances in the timing of first capture in response to warming, but little change in the timing of last capture (Harrington *et al.* 2007, Bell *et al.* 2014). As a result, the mean duration of the flight season has extended by about 3 days per decade. These phenological changes are linked to changes in winter conditions, as measured by December to March North Atlantic Oscillation (NAO) and temperature during the spring and summer (as measured by

accumulated degree days above 16 °C). Positive NAO values (indicative of warmer winter conditions) and higher spring temperatures advance the timing of first capture, whilst continued high temperatures subsequently reduced the length of the flight period, but by less than the initial advance (Bell *et al.* 2014).

Partly as a result of the expansion in flight period, there has been a relatively weak increase in aphid populations through time (Bell *et al.* 2014, Pearce-Higgins *et al.* 2015a). If this is modelled as a function of temperature, it appears strongly related to warming, particularly during the spring and summer, accounting for about 60% of the long-term trend in aphid populations (Pearce-Higgins *et al.* 2015a). Given their short generation time, the mechanism underpinning these response is probably that warming increases the number of generations possible within a year, leading to both phenological and abundance changes (Harrington *et al.* 1995, Yamamura & Kiritani 1998). Similar positive effects of warming, potentially mediated through more rapid development, also appear to have contributed to increasing tick *Ixodes ricinus* populations. Although perceived population increases across the UK may have been at least partly caused by increasing deer populations (Scharmellann *et al.* 2008), quantitative analyses of data from two monitoring sites in Wales and Dorset suggests that warming may also have contributed to some of this increase, with potential implications for human health. The potential mechanism is that warming could lead to more rapid development rates (Dobson & Randolph 2011).

The UK Environmental Change Network (ECN) comprises 12 sites across the UK, representing a wide-range of locations, habitats and management regimes. Importantly, data on a range of taxa and the physical environment are collected. Invertebrate population trends have varied between sites. In general, butterflies, particularly warm-adapted species at northern sites, have become more numerous through time, matching expectations given the warmer temperatures observed. Whilst there have been no overall changes in moth abundance or diversity, southern or lowland moth species have tended to increase in abundance, whilst northerly distributed or upland species have tended to decline (Morecroft *et al.* 2009). Further, as outlined previously, moth and butterfly population trends on these sites tend to be negatively correlated with warm, wet winters (and springs in moths) but positively with warm summer temperatures, and in moths, negatively with summer precipitation (Pearce-Higgins *et al.* 2015a). Analyses of ground beetle data from ECN sites shows that in response to the hot, dry summers of 1995 and 1996, invertebrates with a more southerly distribution tended to increase, whilst those with a northern distribution tended to decline in abundance (Morecroft *et al.* 2002), although overall ground beetle populations tended to decline in response to warming (Pearce-Higgins *et al.* 2011). Recent analysis of ECN data from Scotland suggests that declining species were those which have failed to advance their phenology (Pozsgai & Littlewood 2014).

Analyses of Tipulid (cranefly; largely *T. paludosa*) time-series from Northumberland (Milne *et al.* 1965), Northern Ireland (Blackshaw & Perry 1994) and western Scotland (McCracken *et al.* 1995) each showed negative effects of autumn drought on subsequent larval abundance, probably as a result of the dessication of early larval instars (see also Blackshaw & Petrovskii 2007). The same negative effects of dessication also appeared to reduce the abundance of spring-emerging craneflies (largely *Tipula subnodicornis*), whose abundance was negatively correlated with temperature in the previous August (Pearce-Higgins *et al.* 2010), a relationship probably driven by soil moisture (Carroll *et al.* 2011).

## **Birds**

Correlations between population change or survival and winter weather have been found for a range of bird species in the UK (Peach *et al.* 1995, Catchpole *et al.* 1999, Yalden & Pearce-Higgins 1997), with a positive relationship between winter temperature and population growth holding for most common and widespread resident and short-distance

migrant species (Pearce-Higgins *et al.* 2015b). Overall, this suggests that climate change is likely to have increased the over-winter survival rate, and therefore the abundance, of many UK resident bird species, is associated with milder winter weather. Populations of long-distance migrants breeding in the UK are affected by over-winter survival rates, but these are driven by changes in weather conditions on the African wintering grounds (Peach *et al.* 1991, Baillie & Peach 1992, Robinson *et al.* 2008). Thus, populations of trans-Saharan migrants which winter in the semi-arid Sahel are positively correlated with measures of rainfall in that region (Ockendon *et al.* 2014), and in response to drought during the 1970s, populations of many of these species declined, but in many instances, have at least partially recovered (Pearce-Higgins & Green 2014). In contrast to residents, it is not temperature which drives variation in long-distance migrant populations, but rainfall (Pearce-Higgins & Green 2014).

In addition to winter, birds are also sensitive to weather variables in the breeding season. Warm conditions from April to June tend to increase breeding success in resident species, leading to positive population changes by the following year (Pearce-Higgins *et al.* 2015b). These effects appear most apparent in precocial insectivores such as waders and grouse; the latter also being particularly vulnerable to negative effects of rainfall during the chick-rearing period (Pearce-Higgins & Green 2014). The breeding success of migrant species may benefit less from warming due to potential effects of trophic mismatch (Both 2010). Whilst there is some evidence for this affecting some long-distance migrant populations across Europe (Møller *et al.* 2008, Both *et al.* 2010), the evidence for this being generalizable across species is currently limited (Pearce-Higgins & Green 2014). However, recent analyses of long-term population trends from England suggests that population growth across a range of migrant species may show a negative relationship with May temperature, matching the expectation were mismatch reducing productivity (Pearce-Higgins *et al.* 2015b). This issue is discussed further in Evans & Pearce-Higgins (2015). Some studies suggest that weather effects from the wintering grounds and migratory routes may carry-over to impact on reproductive parameters, although recent cross-species analyses of long-distance migratory passerines from the UK suggest that such effects tend to be relatively weak (Ockendon *et al.* 2013, Finch *et al.* 2014).

There is additional evidence of negative lagged impacts of increasing summer temperatures and drought upon some species. In particular, studies of birds that rely on invertebrates associated with wet conditions, such as the song thrush (Robinson *et al.* 2004), blackbird (Robinson *et al.* 2007), golden plover (Pearce-Higgins *et al.* 2010) and ring ouzel (Beale *et al.* 2006) all find negative impacts of increasing summer temperatures or measures of drought upon populations, survival or productivity; effects which appear generalizable across thrush species (Pearce-Higgins & Green 2014). More widely, population trends of upland birds which feed on invertebrates most sensitive to drought conditions have declined more than species which feed on other prey (Pearce-Higgins 2010). This signal of negative lagged effects of increasing summer temperatures upon bird populations is also apparent in an analysis of short- and long-distance migrant population time-series from England (Pearce-Higgins *et al.* 2015b).

To summarise, to the extent that climate change is generally associated with warmer winters, and warmer drier summers, it is likely to have increased the abundance of resident and short-distance migrant bird species in the UK through increasing survival rates and productivity, although for a subset of species reliant on drought-sensitive invertebrates, negative lagged effects of summer drought may at least partially counter-balance these benefits. The survival rates of long-distance migrants have not benefitted from improving over-winter conditions in the UK caused by winter warming, and due to their potentially greater vulnerability to trophic mismatch, appear to have benefited less from increases in spring temperature. Instead, their populations are highly sensitive to changes in precipitation

on their African wintering grounds. They may also be particularly vulnerable to negative impacts of summer drought.

### **Community changes**

Impacts of climate change on individual populations scale-up to alter the distribution of species and the composition of ecological communities. For example, in a warming scenario, species' populations whose growth is increased by warming will become more abundant relative to those associated with cooler temperatures. Studies examining changes in ecological communities through time may therefore provide an opportunity to detect the combined effects of multiple climate change impacts on a range of species.

Such community changes have been most studied in birds. In the context of recent warming across Europe from 1990-2008 has been equivalent to a 250 km northward shift in temperature (Devictor *et al.* 2012), there have been significant changes in bird communities. Species associated with warm temperatures that have a southerly-distribution have tended to increase relative to those associated with cooler temperatures (Devictor *et al.* 2008), including in the UK (Devictor *et al.* 2012). Across Europe, these changes are equivalent to a 37 km poleward movement in bird communities, but are much less than the estimated 249 km northward shift in temperature estimated over the same period (Devictor *et al.* 2012). Populations towards the higher latitude range-margin which experience low temperatures tend to exhibit more positive population growth rates than populations close to the thermal maxima experienced by that species (Jiguet *et al.* 2010). Related to this, population trends of species expected to benefit from climate change according to a bioclimate model have increased in abundance since the mid-1980s, whilst trends of those species expected to decline in response to future climate change, have declined (Gregory *et al.* 2009). Similar patterns are also apparent for rare breeding birds in the UK (Green *et al.* 2008). In the UK, there is a significant link between species' population responses to temperature and their spatial association with temperature, emphasising that population changes and species' distributions are both aspects of the same underlying ecological process (Pearce-Higgins *et al.* 2015b).

Equivalent analyses of butterfly population trends across Europe also suggested that butterfly communities at individual locations have become increasingly dominated by southerly distributed species which occupy warmer temperatures through time (Devictor *et al.* 2012), shifting by an average of 114 km northwards. However, subsequent reanalysis of these data for a different span of years, at least for the UK, suggests these changes may be much weaker than originally thought (Oliver *et al.* 2011, Pearce-Higgins *et al.* 2015a). This may be due to recent declines in southerly-distributed, warm-associated species which otherwise might be expected to increase. Butterfly community changes and range shifts in the UK are certainly lagging behind what would be expected in response to warming (Mair *et al.* 2012) as a result of stable or declining population trends in key species (Mair *et al.* 2014).

Although the community temperature index measure of Devictor *et al.* (2012) is an attractive single indicator of climate change impacts, some papers suggest that habitat-differences in the temperature associations of different species may confound some of the apparent trends. For example, in Catalonia, bird species most associated with cool temperatures, and therefore potentially most vulnerable to climate change, are associated with forest rather than open-habitat species, occupy rural rather than urban habitats, and are least tolerant to habitat disturbance. In addition, species with a narrow thermal niche breadth also have a narrow habitat niche breadth, in other words, habitat specialisation appears to match thermal specialisation (Clavero *et al.* 2011, Barnagaud *et al.* 2012). This means that non-climatic drivers of population change which act differently in these habitats may produce changes in these climate change indicators (Pearce-Higgins *et al.* 2015a). For example, despite the studies outlined above, there is little evidence for a strong climate change signal having

affected farmland bird populations in the UK (Eglington & Pearce-Higgins 2012). Because these farmland birds tend to have the greatest association with warm climates, non-climate-related reductions in these populations may actually drive a decline in the community temperature index on farmland habitats, instead of the expected increase (Kampichler *et al.* 2012) Therefore much more work is required to tease apart interactions between land-use, land-use intensity and climate change in driving population trends of birds and other biodiversity, which should be an important pre-cursor to accurate reporting of climate change impacts on biodiversity population trends.

Alongside these shifts, warming has also been associated with a general increase in species' diversity in both butterflies (Menéndez *et al.* 2006, González-Megías *et al.* 2008), and birds. From 1994 – 2006 in the UK, when spring temperature increased by 1.4 °C, the diversity of bird communities, as measured by the Simpson's diversity index, increased by about 8 %, a trend also mirrored by species' richness (Davey *et al.* 2012). Given the latitudinal gradient in bird diversity, which is apparent in the BBS data from Britain, this is suggestive of a simple northwards shift in the distribution of species, although the greatest increases in diversity have been in the west. However, at the same time, there has been a reduction in community specialisation, based on the extent to which communities are dominated by species with narrow or broad habitat preferences. Thus, warming has caused a homogenisation of bird communities, with specialist populations having declined in response to climate change, whilst generalist populations have increased (Davey *et al.* 2012). This appears driven by more positive effects of temperature upon the abundance of generalist species than specialists (Pearce-Higgins *et al.* 2015b). The same trend of increasing dominance of communities by ecological generalists is apparent in butterflies (Warren *et al.* 2001, Menéndez *et al.* 2006). Such losses in specialisation appear most apparent on agricultural habitats, and as outlined above, there are again likely to be some significant interactions between land-use and climate change.

## 2. Confidence in the science

Since the previous iteration of this report (Pearce-Higgins 2013), there has been significant additional research to document and understand the causes of long-term changes in butterfly, moth, aphid and bird populations and communities. For most groups, these studies have produced been largely complementary findings, adding to the confidence associated with assessments of the impacts of climate change on these groups. However, there are some particular issues of uncertainty that are worth highlighting. Whilst there is increasing evidence that climate change has also impacted moth populations, the interpretation of the severity of these impacts relative to land-use change and other drivers differs between studies, particularly for widespread southerly distributed species, and therefore remains uncertain (Fox *et al.* 2014, Pearce-Higgins *et al.* 2015a). The evidence for a link between climate change and recent changes in butterfly populations and communities has become more complex, due to reductions and stabilisation of a number of southerly-distributed species expected to increase, and disagreement in the significance of the community temperature indicator trend in the UK between studies (Oliver *et al.* 2011, Devictor *et al.* 2012, Mair *et al.* 2014, Pearce-Higgins *et al.* 2015a). Therefore, for both these groups, the link between observed population and community changes and climate change is given low or medium agreement. For other invertebrate taxa, there is more limited evidence, although greater confidence than before can be attributed to linking aphid population changes to warming due to recently published analyses of their long-term time series (Bell *et al.* 2014, Pearce-Higgins *et al.* 2015a). Significant additional progress has been made linking long-term bird population and community changes to climate change (Pearce-Higgins & Green 2014, Pearce-Higgins *et al.* 2015a, b), although more work is required to examine this in the context of other factors. Finally, it is clear that relatively simple metrics of community change with respect to climate change may be susceptible to potentially confounding impacts of non-climatic factors, which means that climate change indicators require careful interpretation

(Pearce-Higgins *et al.* 2015a). In this context, the following statements can be made from this report.

Changes in temperature and precipitation can have a strong impact on wild species populations and on ecological communities (high agreement, robust evidence).

Changes in butterfly, moth, aphid and tipulid populations are strongly influenced by variation in temperature and precipitation (medium agreement, medium evidence).

Changes in bird populations are strongly influenced by variation in temperature and precipitation (high agreement, robust evidence).

Observed changes in temperature and precipitation have impacted long-term butterfly population trends and community composition (low agreement, medium evidence).

Observed changes in temperature and precipitation have impacted long-term moth population trends contributing to observed population declines (medium agreement, medium evidence).

Observed changes in temperature have contributed to increases in aphid population trends (high agreement, medium evidence).

Observed changes in temperature have contributed to increases in tick populations (low agreement, limited evidence).

Observed changes in temperature have contributed to declines in some ground beetle populations (medium agreement, limited evidence).

Observed changes in temperature have contributed to increases in many common and widespread resident bird populations (high agreement, robust evidence).

Populations of long-distance migrant birds have not benefitted from warming in the UK to the same degree as residents, and may have suffered more negative consequences of climate change. (medium agreement, robust evidence).

Populations of long-distance migrant birds respond strongly to changes in precipitation on their African wintering grounds (high agreement, robust evidence).

Recent changes in ecological communities, as measured by changes in diversity and divergent trends in warm-associated southerly species and cold-associated northerly species, are consistent with the effects expected from recent climate change (high agreement, robust evidence).

Recent changes in ecological communities can be attributed to climate change (medium agreement, medium evidence).

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