BICCO-Net II

Synthesis report

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Note to the reader. This synthesis report presents a summarised overview of the BICCO-Net II final report that focusses on the key results and implications. For more information about the methods used, or more detail of the results, please consult the final report, or for particular sections, the associated appendices which describe each of the tasks in detail. To aid cross-referencing, each statement in the synthesis report ends with a numerical reference to the appropriate section from the final report.

Introduction

- Globally, the scientific literature provides increasing evidence that climate change is impacting species and their natural populations. Recent changes to the timing of biological events and in the distribution of species in response to climate change, have been summarised for the UK in the LWEC Terrestrial Report Card [2.1].
- Future impacts of climate change are projected to be much more marked than those already detected, and to increase with increasing amounts of change. For the UK, the MONARCH project predicted changes to the distribution of selected BAP priority species, CHAINSPAN assessed impacts on internationally important bird populations on Special Protection Areas, whilst other projects have examined likely impacts on priority and coastal habitats. An assessment of risks and opportunities for species in England as a result of climate change highlighted the particular vulnerability of upland species and bryophytes [2.1].
- Although significant proportions of species are projected to face local or global extinction under projected future scenarios of change, the evidence of climate change having caused substantial species' population declines and widespread ecosystem disruption remains limited. As a result, there is an urgent need for robust collation and analysis of long-term biodiversity monitoring data to allow the impacts of climate change on species populations and communities to be fully documented; the overarching aim of this project [2.1].
- The first UK Climate Change Risk Assessment (CCRA), established by the 2008 Climate Change Act, was published in 2012. However, comprehensive assessment of the risks to biodiversity was limited by the availability of studies which clearly identified population impacts. Furthermore, beyond the good evidence for phenological and range changes in response to climate change, many of impacts documented in the LWEC Terrestrial Report Card were associated with low confidence.
- There is a high policy demand for updated and enhanced evidence of climate change impacts on biodiversity to inform the 2018 CCRA and future report cards. Not only will such information address the requirements of the UK, Scottish and Welsh governments for evidence of climate change impacts, but it will inform the National Adaptation Programme (NAP) to deal with the risks and opportunities that climate change poses [2.2].

Aims

- In response to these scientific uncertainties and policy requirements, BICCO-Net II was established with a number of aims which can be summarised as follows [2.3].
    - To analyse national population trends in order to identify impacts of climate change on populations of terrestrial species.
    - To analyse population trends at individual sites in order to disentangle climate change impacts from other drivers of change.

- To identify the impacts of climate change on freshwater biodiversity, including on communities, family- and species-level distributions and abundances.
- To develop the most appropriate methods for the production of indicators which describe the impact of climate change on biodiversity.
- To assess the traits associated with population sensitivity to climate change.
- To disseminate project information.

- This synthesis report provides a summary of the main findings and achievements of the project. It is supported by a final report which provides more detail about the methods and results, including a series of short letter-style reports on each of the analytical components of the project. Comprehensive reports from each task form a series of appendices to the final report. For ease of cross-reference, each paragraph in this report ends with a numerical reference to the relevant section(s) in the final report.

Methods

- Data from national monitoring schemes, with extensive coverage from widely distributed or stratified random sampling (Table SR1), were analysed to examine the impacts of climate change upon national populations of mammals, birds, aphids, moths and butterflies, and upon the prevalence of freshwater macroinvertebrate families [3.1].
- Data from monitoring schemes comprising a large number of locations (these included data for birds, butterflies, freshwater macroinvertebrates) were analysed to look at finer-grain spatial variation in trends in relation to spatially variable climatic measures [3.1].

Table SR1. Sources of long-term monitoring data used

	National-scale data	Site-based data
Mammals	Breeding Bird Survey mammal recording National Bat Monitoring Programme	
Birds	Breeding Bird Survey and Common Bird Census	Breeding Bird Survey
Butterflies	UK Butterfly Monitoring Scheme	UK Butterfly Monitoring Scheme Environmental Change Network
Moths	Rothamsted Insect Survey – light traps	Environmental Change Network
Aphids	Rothamsted Insect Survey – suction traps	
Freshwater macroinvertebrates	Environment Agency family-level data	Environment Agency species-level data SEPA species-level data Upland Waters Monitoring Network Llyn Brianne Catchment

- Monthly temperature and precipitation variables were derived from either UKCP09 gridded datasets or recorded from individual monitoring locations. The modelled effects of these variables upon population abundance or inter-annual variation in abundance (population growth) may be regarded as a description of the effects of weather. The modelled effects of long term directional trends in the weather upon population trends are regarded as indicative of the impacts of climate change, although formal attribution requires a consideration of the extent to which observed changes in these climatic variables are due to anthropogenic forcing rather than natural variability [3.1].

- National population trends were produced from site-based monitoring by modelling site and year effects using standard approaches [3.2].
- Populations may be affected by climate change in a large number of potential ways. Two complementary analytical approaches were used to avoid creating over-fitted models with too many predictor variables relative to the number of years of data available [2.3].
- Principal Component Analysis (PCA) was used to distil multiple monthly mean temperature and precipitation variables into four variables (components) which were used to predict population growth in individual species [4.2], or to summarise patterns in biodiversity community responses to climate change [4.5, 4.7].
- Additionally, a novel method was developed to enable regression of population abundance data on a large number of monthly temperature or rainfall variables by constraining the series of regression coefficients to display damped, periodic oscillations (DPO) [3.2]. This DPO method was used to model abundance at both national and population levels [4.3, 4.5, 4.6, 4.8], and was used to robustly estimate responses to weather variables at different periods of the year. Both approaches included weather data from multiple years to account for potential lagged effects [3.2].
- The precise analytical methods used for the different tasks are described in detail in Appendix 2 of the final report and in each of the analytical Appendices (3 – 9), whilst the development of indicators of the impact of climate change on biodiversity are described in Appendix 11.

Results

Population changes

- Taxa varied in their response to temperature and precipitation-related variables (weather variables), with the greatest proportion of significant impacts detected for the national-scale analysis of terrestrial population trends. This probably reflects the greater stochasticity and uncertainty associated with the site-based analysis of individual populations used across the other studies [4.1].
- Mean population trends of aphids showed a national increase of 0.7% per annum from 1970-2010 whilst moths have declined by 1.4% per annum from 1975-2010. Mammals, birds and butterflies did not show significant long-term trends in mean populations across all species [4.2].

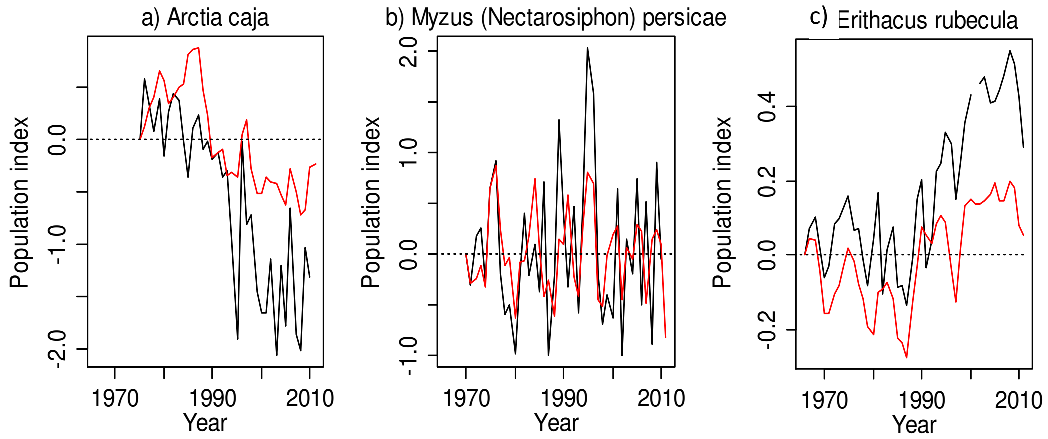


Figure SR1 Long-term trends (black) in garden tiger moth populations (a), and population fluctuations in the green peach aphid (b) and robin (c looks like h in panel!) are well predicted by models of weather-driven population growth (red).

- The models of population growth based on changes in weather variables accounted for from an average of 3% of the cross-species variation in population growth in birds, to almost 10% in butterflies. Model fit was good for species known from previous literature to be sensitive to the predictor variables (Figure SR1) [4.2].
- Predicted overall population trends based on these models accounted for 66% of the observed decline in moth abundance, and 60% of the observed increase in aphids (Figure SR2). The component of mean long-term population trends which could be accounted for by long-term changes in weather variables was much less in other taxa [4.2].
- Of 500 species examined, strong (>30% per decade) population declines in nine moth species were matched by modelled declines based on climatic trends, whilst models also predicted equivalent increases in five species across a range of taxa [4.2].
- Population declines in species of conservation concern were linked to both climatic and other factors, whilst differential impacts of climate change between trophic levels signal that future climate change may disrupt predator-prey relationships [4.2].

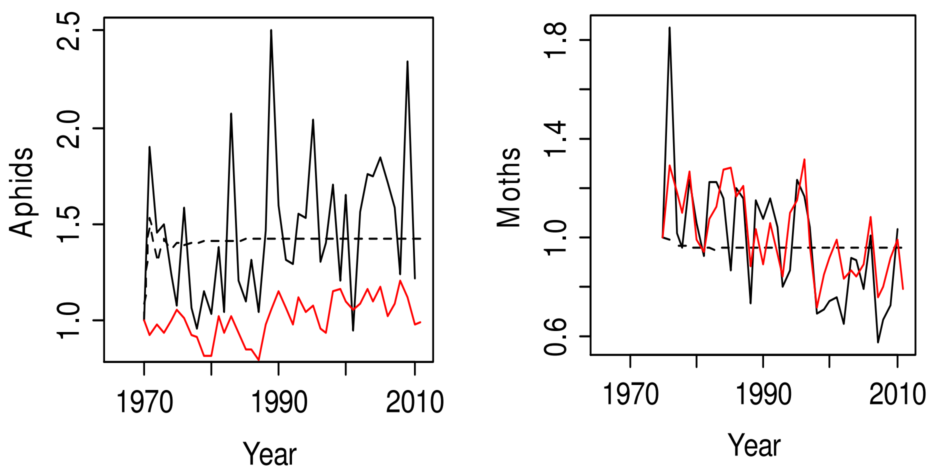


Figure SR2 Observed population indices (solid black lines) compared to estimates from models with no variation in weather variables (dashed black lines) and predicted from long-term trends in weather variables only (red lines) for aphids and moths.

- Models of moth and butterfly populations across 12 ECN sites monitored over the past two decades, suggested that longer-term declines in moths may be linked to recent increases in precipitation, but butterfly populations could have increased in response to warming [4.5].
- Annual population fluctuations in upland freshwater macroinvertebates from across the Upland Waters Monitoring Network (UWMN) correlated with climatic variables in 70% of cases [4.6]. Long-term data on species-level macroinvertebrate population abundances aggregated across lowland sites in Scotland and central / eastern England showed that 70 of 137 species were significantly associated with precipitation and 67 species with temperature [4.8].
- Long-term trends in macroinvertebrate community structure across England and Wales, as measured by family-level occurrence, can be largely explained by improving water quality, rather than climate change (Figure SR3). Water chemistry models accounted for just over a third of the variance in the observed changes in prevalence, successfully predicting the shift towards the lowlands by upland taxa which is opposite to that predicted from changes in temperature [4.7].

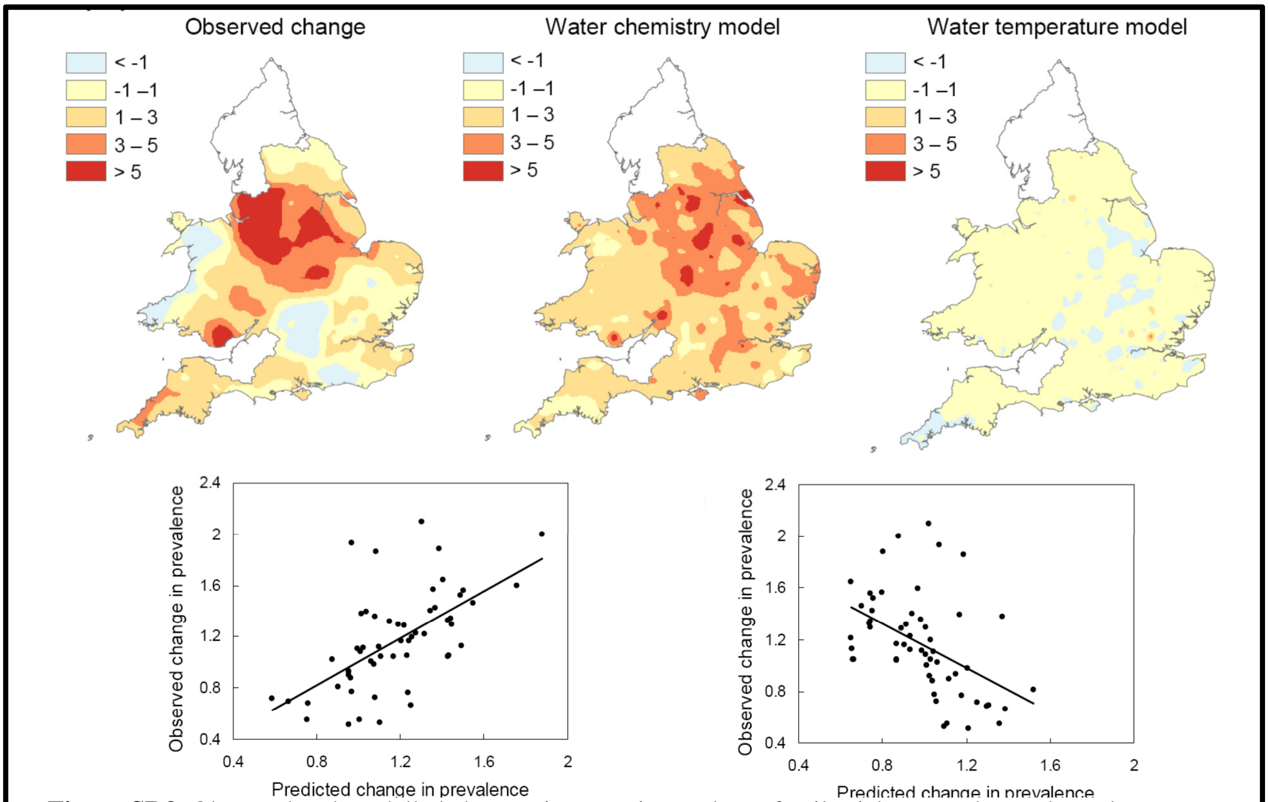


Figure SR3. Observed and modelled changes in macroinvertebrate family richness and prevalence between 1991/2 and 2006/8. Maps show observed (left) and predicted (centre and right) changes in richness smoothed across the 1565 sites surveyed (white areas indicate no data). Graphs show observed changes in prevalence compared to changes predicted based on water quality (left) and temperature (right).

- Although long-term trends in macroinvertebrate communities were predicted by water chemistry, short-term community responses to annual variation in discharge and temperature were apparent. For example, range expanding species appeared to benefit from wet conditions, warm springs and cool summers in the preceding year. These results indicate freshwater macroinvertebrates are likely to be sensitive to future climate change [4.7]

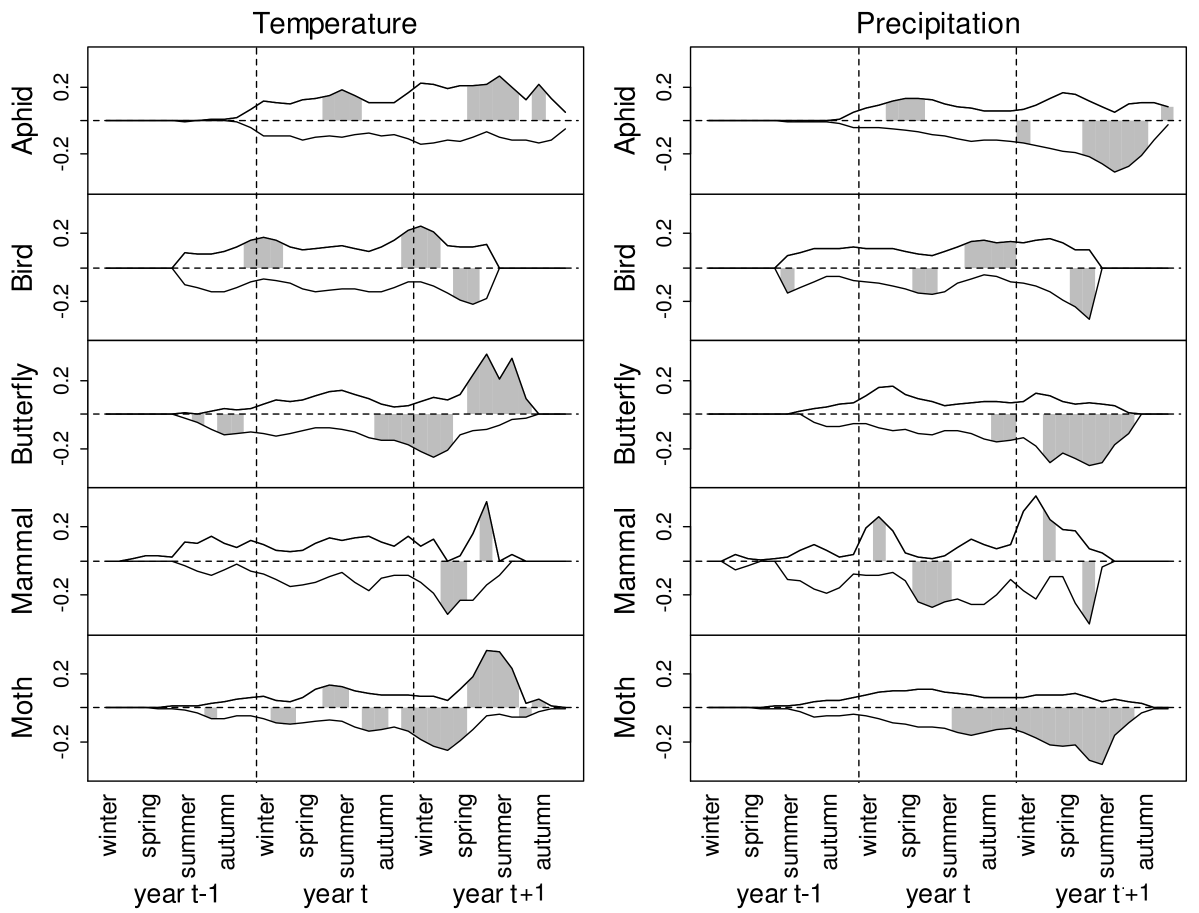


Figure SR4. Plots indicating the general responses of aphid, bird, butterfly, mammal and moth population abundances to temperature and precipitation over the 12 months leading up to the end of the survey period in year t+1. In each month, the contributing species were divided into negatively and positively responding species and the y-axis shows the sum of standardised monthly coefficients across these species divided by the total number of species within each taxon in this analysis. Months in which the mean of monthly coefficients was significantly above or below zero are highlighted in grey.

Responses to weather variables

- The DPO models were used to identify the periods of the year in which species were sensitive to weather effects. When applied to national terrestrial monitoring data, these models exhibited significant explanatory ability for 94% of species. Overall responses to temperature were positive for aphids, whilst responses to precipitation were negative for aphids and moths [4.3].
- There was significant variation in the times of year that different taxa were sensitive to weather variables (Figure SR4). Aphid abundances were positively related to temperature, particularly from May to October, and in the previous summer. Butterflies and moths both showed similar strong positive impacts of temperature during spring and summer months, when they were recorded, but negative effects of temperature during the preceding autumn and winter upon their abundances. Bird abundances were positively affected by winter temperature, although warm spring

temperature during the survey may counter this. Mammal population sizes were similarly negatively affected by early spring temperatures (March and April), but positively by June temperature [4.3].

- Summer precipitation was negatively correlated with the abundance of all invertebrate groups, effects which extended back into the winter and spring for moths and butterflies. Negative impacts of spring precipitation also appeared to affect the number of birds and mammals recorded, although autumn precipitation was positively correlated with subsequent bird abundance [4.3].
- Correlations between overall moth and butterfly population trends across 12 ECN sites and seasonal climatic variables largely supported these findings. Consistent negative effects of winter temperature and positive effects of summer temperature were apparent for both groups. Effects of precipitation were largely negative, but in different time-periods for butterflies (winter) and moths (spring and summer) [4.5].
- These patterns differed strongly with respect to overwintering strategy and migratory behaviour in birds, hibernating behaviour in mammals or overwintering strategy in moths and butterflies. In particular, the strongest negative effects of winter temperature and precipitation were on butterflies and moths which overwinter as caterpillars or emerge during the summer [4.3].
- Fine-scale analyses of terrestrial monitoring data examined the extent to which population responses to temperature at the site-level vary with mean climate suitability. This analysis, which is a precursor to potential future analyses of site-based factors influencing population responses to climate change, was focused on birds and butterflies, as the two taxa with the most extensive monitoring data [4.4].
- Butterflies showed stronger overall responses to temperature than birds, which tended to be positive, and stronger interactions between temperature response and spatial variation in temperature. This interaction term tended to be negative, indicating that the influence of temperature on population dynamics was strongest in cooler sites. This is likely to be because of the greater vulnerability of marginal populations in cooler climates to temperature fluctuations [4.4].
- Temperature effects upon upland freshwater macroinvertebates were more likely to be negative than positive, particularly during the summer (July to September) whilst effects of precipitation were mixed [4.6].
- Effects varied between different taxonomic groups. Two caddis families, the Limnephilidae and Polycentropidae, showed clear negative temperature coefficients, as did Chloroperlidae, Leuctridae and Taniopterygidae stoneflies. Temperature sensitivity, as assessed from our models was, correlated with an assessment of species' temperature tolerances through the collation of a range of European studies [4.6].
- Responses of lowland macroinvertebrate populations to temperature and precipitation varied strongly between taxonomic groups, but could be partly explained by feeding behaviour and sensitivity to temperature, water-flow and pollution. Strong interactions between pollution tolerance, water flow and temperature, all of which affect species' oxygen requirements, emphasise the importance of considering both

climatic and water quality changes when explaining freshwater biodiversity trends through time [4.8].

- The BICCO-Net project has examined species sensitivity to variation in precipitation and temperature across a wide range of both terrestrial and freshwater taxa. Comparing the multi-site species-level results across both terrestrial [Section 4.3] and freshwater [Section 4.8] environments to temperature shows widespread variation in species' responses to warming (Figure SR5). Aphids, moths and butterflies generally showed positive mean temperature sensitivity scores, suggesting that on average the species from these groups would be most likely to increase in response to warming [4.10].
- As previous results emphasise, this does not mean that moth populations have increased as a result of the general warming over the last 30 years. Their populations appear limited by strong negative impacts of precipitation particularly (Figure SR4), which were not included in the analysis of [4.10].
- For both butterflies and moths, the most widespread species tended to show more positive effects of temperature [4.10].

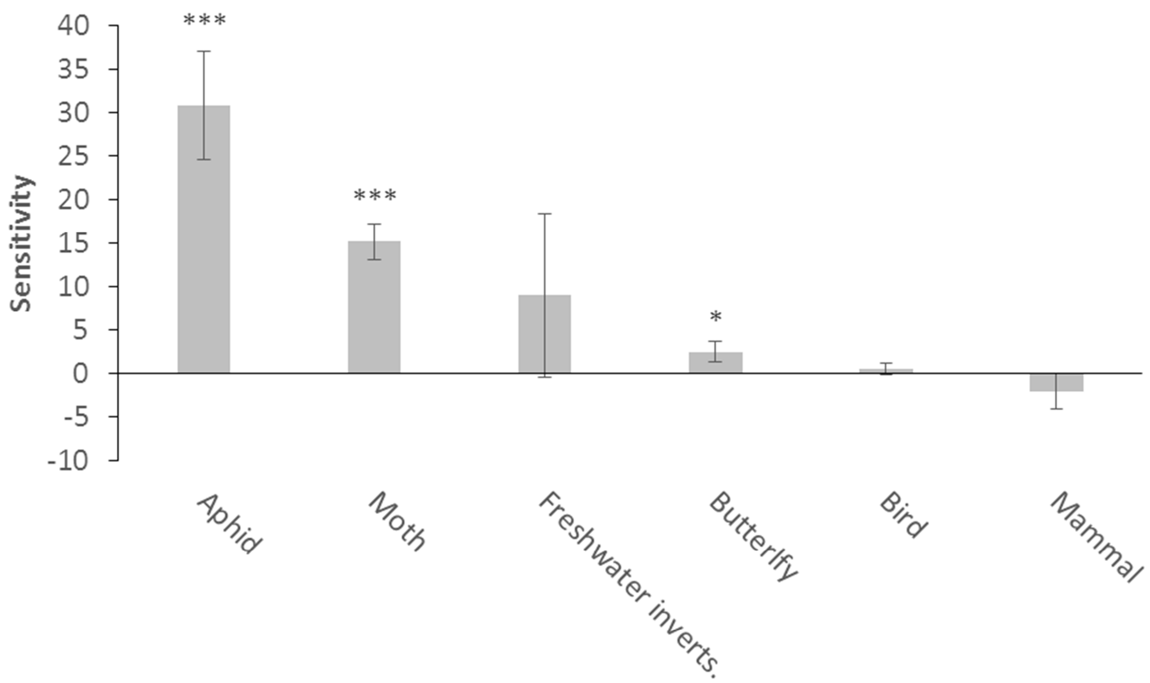
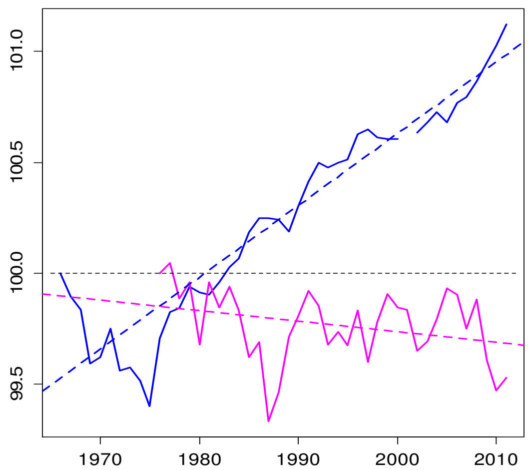


Figure SR5. The mean temperature sensitivity for each group included in the analysis, based upon mean population responses to a 1°C warming in year t+1, assuming no change in precipitation or flow rate. The standard errors of the mean are plotted with asterisks added to highlight those mean estimates that are significantly different from zero (* = p <0.05, ** = p < 0.01, *** = p < 0.001).

- There was no significant different in species' population sensitivity to temperature between terrestrial and freshwater habitats, or between primary and secondary consumers [4.10].

Indicators of climate change

- Three potential indicators of climate change impacts on populations were examined, each of which separated species by their likely responses to climate change, and then tracked the extent to which observed responses match that expectation.
- The Gregory *et al.* (2009) indicator used the results of bioclimate modelling to separate species likely to increase in response to climate change from those projected to decline before tracking the divergence in the population trends of the two groups.
- The Community Temperature Index (CTI) of Devictor *et al.* (2008) focussed specifically on temperature, and used the distribution of each species to calculate mean breeding season temperature across a species' range. The CTI is these values averaged for each species present at a location, weighted by abundance.
- The BICCO-Net I index separated species whose annual fluctuations in population growth are positively associated with temperature from those which are negatively affected, and used the divergent population trends of these two groups to indicate climate change impacts.



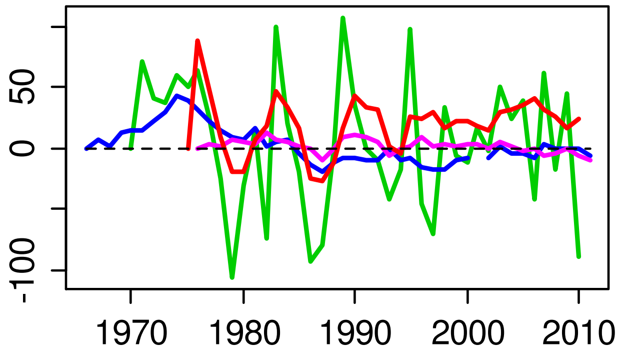


Figure SR6. CTI (left) and BICCO-Net indicator (right), summarising the impact of climate change onecological communities in the UK; aphids (green), birds (blue), butterflies (pink) and moths (red).

- Computer simulations were used to assess the likely sensitivity and specificity of three different approaches to indicators of climate change impacts on populations and ecological communities. All indicators were simulated to produce outputs that were correlated with each other, and with annual variation in temperature. They are therefore all sensitive to climate change [4.9].
- However, all were potentially vulnerable to impacts of confounding non-climatic trends, matching the conclusions of previous studies using observed community changes. Due to the non-random distribution of species within different habitats, non-climatic drivers such as habitat-change may result in changes in indicator values.
- Whether this lack of specificity renders climate change indicators misleading or, as suggested by the results of the freshwater macroinvertebrate prevalence, indicates that they can successfully track the extent to which biodiversity population trends are following the pattern expected from likely climate change impacts, is a question of interpretation. To resolve this, we suggest that a combination of all three indicators may have the greatest potential to track climate change impacts upon populations, but

will always require careful interpretation in the light of other potentially confounding non-climatic trends that may drive population changes [4.9].

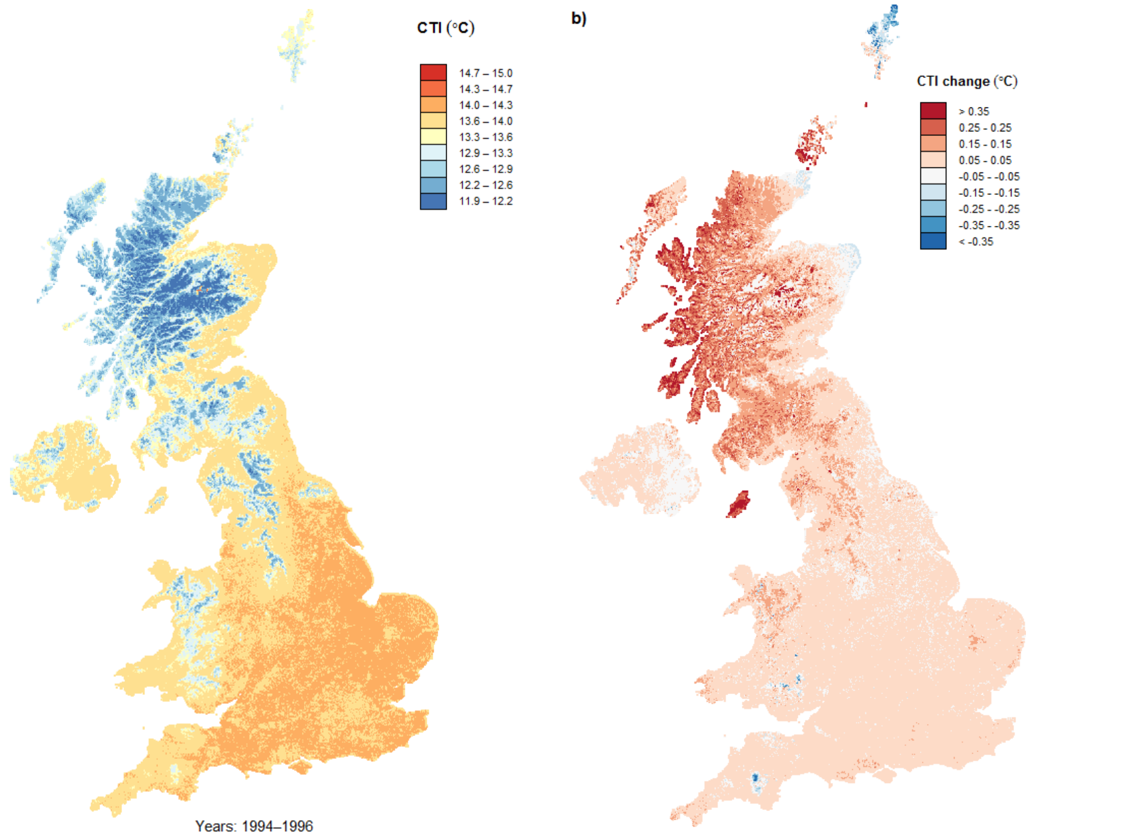


Figure SR7. Spatial variation in the Devictor index (CTI) across the UK for 1994-1996 (left) and trend in CTI from 1994/6 to 2007/9 (right).

- It was possible to produce exemplar CTI and BICCO-Net climate change indicators for the UK using the long-term population monitoring data analysed (Figure SR6). Both indicators were largely positive for birds, suggesting the relative population trends of different bird species have changed in the manner expected were they being driven by climate change. CTI and BICCO-Net indicators were both marginally negative for butterflies (opposite to expectation). Due to the lack of distribution data for aphids and moths, it was only possible to generate BICCO-Net-type indicators for these taxa, which showed non-significantly positive in trends [4.10].
- Spatial variation in CTI was mapped for the first time (Figure SR7), for birds, and shows the expected latitudinal and altitudinal gradients as well as highlighting that the Highlands and west coast of Scotland are the regions where the greatest changes have occurred [4.10].

Discussion

Main results

- This project presents what may be regarded as the most comprehensive single assessment of the impacts of climate change on UK biodiversity population trends that has been conducted to date [5.1].

- Across all the groups considered, significant long-term impacts of climate change on overall abundance trends across species were largely restricted to increasing aphid and declining moth populations. Long-term trends in freshwater macroinvertebrate prevalence were largely driven by improving water quality. Within groups, species-specific variation in population trends indicated that climate change had impacted on bird communities [5.1].
- Much additional information about the direction and timing of temperature and precipitation impacts on species was estimated. This identified generally positive effects of temperature upon terrestrial invertebrates during spring and summer, but negative effects of warm, wet winters on moths and butterflies and of precipitation at other times, and of hot summers upon upland freshwater macroinvertebrates [5.1].
- Indicators of the impact of climate change on biodiversity were sensitive to climate change, but may not be specific to it as they were also sensitive to effects of non-climatic effects. To maximise the ability of indicators to successfully track climate change impacts on biodiversity, we suggest that a number of indicators are adopted. These should be interpreted in the light of potential changes in non-climatic drivers, such as habitat quality and management, which may also affect the species included [5.1].

Limitations

- All these results are based on regression and correlation and therefore require careful interpretation. We attempted to minimise the risk of spurious correlations with weather variables by additionally including linear trends over time and where relevant, variables describing changes in water quality [5.2].
- These results were from a non-random selection of well-monitored species and therefore may not be applicable to all taxa. In particular, our poorer coverage of rare or northerly upland species, both of which may be more likely to be sensitive to climate change, may mean that our general results may underplay the potential impacts of climate change on UK biodiversity [5.2].

Applications

- The results from this project should inform the 2018 Climate Change Risk Assessment and updates of the LWEC report cards. They will also provide important evidence for the National Adaptation Programme. There is considerable species-level information about the likely sensitivity of the species analysed to changes in temperature and precipitation which could be disseminated to a range of audiences if an appropriate route were found. This could be particularly informative for conservation organisations and to assist with specific adaptation planning [5.3].
- Continued extensive monitoring of UK biodiversity, whether through existing citizen science schemes such as the butterfly monitoring scheme or breeding bird survey, or professional surveys, such as conducted by Rothamsted Research or the Environment Agency, is essential to track biological responses to climate change. The collection of associated environmental data, such as occurs on ECN sites, or through the analyses

of long-term data about other drivers, will improve the ability to attribute observed changes to climate change, or other drivers. This will be increasingly important in the future, not just to track the impacts of climate change, but also the potential success of adaptation measures in response [5.3].

Future work

- Building on the considerable progress made in this project, future work should address the following evidence needs [5.4].
    - Extending the analyses of the effects of non-climatic drivers of change to other habitats and taxa. This would provide a wider comparison of climate vs other environmental change in driving recent population changes and would assist with the production of climate change indicators and further inform adaptation.
    - Collating linkages between different biological responses to climate change from phenological to population and distribution change, and presenting that information to users at a species level. This would improve knowledge transfer from this project and set the results in a wider context of the impacts of climate change on each species.
    - Further developing the forms of models used to describe the relationships between species abundance and weather to give greater flexibility in response.
    - Extending the explanatory variables included in the population models produced by this project, to disentangle the contribution of anthropogenic climate change from climatic fluctuations.
    - Developing fine-scale analyses of terrestrial and freshwater taxa to inform adaptation, for example by analysing site-specific variation in population responses to weather variables as a function of different environmental variables.
    - Understanding impacts of extreme events upon species populations.
    - Developing and producing indicators of the impact of climate change on biodiversity.
    - Undertaking future projections of population responses to climate change using the models from this project to inform species' risk assessments.