Appendix 11: Producing climate change indicators for the UK

Abstract

Using long-term population monitoring data analysed as part of the BICCO-Net project, Devictor-type and BICCO-Net indicators are calculated for the UK for up to four terrestrial taxa (butterflies, moths, aphids and birds) from the late 1960s or 1970s onwards. Both indicator trends were largely positive for birds (broadly matching expectation) but negative for butterflies (opposite to expectation). For aphids and moths it was only possible to generate BICCO-Net indicators, which in both cases were non-significantly positive. Spatial variation in the Devictor-type indicator was mapped for the first time for birds, and shows the expected latitudinal and altitudinal gradients. The rate of observed community change through time was greatest in the Highlands and west coast of Scotland, potentially indicative of colonisation of these areas by warm-associated species. Contrasting indicator trends are likely to reflect variation in the importance of climate change in driving population trends between taxa, relative to other factors. Observed changes for birds most closely matched that expected from temperature, whilst those for aphids and moths were weakly consistent with expectation. Trends in the butterfly climate change indicators were opposite to expectation, probably because many southern (warm-associated) species have declined in abundance. It is currently unclear whether variation in indicator trends between taxa means that these climate change indicators are only appropriate for some taxa, or whether they indicate that the impacts of climate change vary significantly between the different ecological groups studied.

Introduction

Appendix 10 details the results of a review and simulation of potential indicators of climate change impacts on UK biodiversity. This demonstrated that whilst it is possible to criticise all the potential climate change indictors, in practice, they are likely to show similar patterns of change through time. Both Devictor and Gregory-type indicators (Devictor *et al.* 2008, 2012, Gregory *et al.* 2009) require spatial information which mean that they may only be applied to species supported by good distribution information. With respect to the species groups covered by BICCO-Net, this will be restricted to birds and butterflies (as reported on by Devictor *et al.* 2012). The BICCO-Net indicator can be produced from time-series data alone, although may be regarded as most likely to track the consequences of short-term fluctuations in response to climate change rather than the effects of more gradual longer-term ecological processes. Given ongoing developments in the Gregory indicator being led by RSPB and Durham University, we focus here on the production of the Devictor and BICCO-Net indicators for the UK.

The Devictor *et al.* (2008, 2012) index is based upon calculations using species distribution data. European data were used to calculate mean breeding season temperature across a species' range; the species temperature index (STI) value. These values are then averaged for each species present at a location, weighted by the abundance of that species, to give the community temperature index (CTI). The BICCO-Net indicator can be developed from the outputs of the damped Fourier oscillation models (Appendix 4) which can be summarised to give an overall assessment of the relationship between temperature and population growth across a year, and thus to separate species into those with a net positive correlation with temperature from those with a net negative relationship. Then following the approach of the Gregory indicator, separate collated population indices for the two groups can be generated, and the difference used as an indicator of climatic impacts.

Here, in this report, we present the first example indicators for the UK using the Devictor approach for birds and butterflies, and the BICCO-Net indicator for aphids, moths, butterflies and birds. In addition, we generate an example spatial output for birds, based upon the Devictor indicator.

Methods

Temporal variation in climate change indicators

We calculated the Devictor index (CTI) for English birds and butterflies as these were the taxa for which species temperature indices are already established, and the geographical area over which these trends to the 1970s were regarded as robust (Appendix 3). To create the Devictor index we first calculated the abundance of each species of bird and butterfly across England in each year of the time-series (birds, 1966 – 2011; butterflies, 1976 – 2011) by multiplying the annual species population index by a measure of the relative abundance of each species. Thus, population trends were weighted by abundance, as per Devictor *et al.* (2008, 2012) so they will equate to community composition. In birds the relative abundance was taken to be the overall count of the species across all years in the Breeding Bird Survey (BBS). In butterflies the abundance was measured as the UK density in 1990. We removed species which were not recorded for the entire time-series (largely wetland birds). We then created the Devictor index based on the community temperature index (CTI): the mean STI of all individuals within each taxon. Finally we divided the resulting Devictor indices by the first value in the time-series and multiplied by 100 to standardise between the two taxa.

We calculated the BICCO-Net index for birds, aphids, butterflies and moths. Mammals were excluded because of the short time-series available. To calculate the BICCO-Net index we divided species into ones predicted to increase with increasing temperatures and those predicted to decline with increasing temperatures. The predictions of population trend associated with increasing temperatures were obtained from modelling annual (log-transformed) population abundance against mean monthly temperatures from the previous ten years, population in the previous year and the year, with a first order autoregressive error structure. The population responses to mean monthly temperatures were constrained to a single decaying cycle each year, two decaying cycles each year or two decaying cycles over two years. The best fitting model was selected for each species by fitting the model to data from 1966 (or earliest record) to 2000 and determining which model best predicted population abundance from 2002 – 2011. The selected model was then fitted to all available data (see Appendices 2 and 4). Species response to temperature was the sum of the population response to monthly temperatures predicted by the model coefficients. Species with an overall positive response to temperature were predicted to benefit from climate change while those with an overall negative response were predicted to decline. We calculated the annual geometric mean of species population indices of species predicted to increase and of those predicted to decline. The final BICCO-Net index was obtained by subtracting the declining index from the increasing index.

For each taxon and each indicator type we modelled the index over time across the whole time series and over the last 20 years. Finally we examined the relationship between the species temperature index and the species response to temperature predicted from our temperature models for birds and butterflies. We used a general linear model to model STI against the sum of temperature coefficients, the taxon and the interaction between the two.

Spatial variation in climate change indicators

We generated an example spatial output of the Devictor index for birds by using estimates of population densities for 49 bird species across the UK from BBS data. Population densities were produced during previous research (BTO 2011) for two time frames (1994-1996 and 2007-2009) for all species that were detected in an average of at least 400 BBS squares each year during the Breeding Bird Survey. The CTI was calculated as the average STI of all individuals belonging to the 49 species for each 1-km square in the United Kingdom. Two maps were produced separately for the two time frames. We also mapped the difference between the CTI values in 2007-2009 and 1994-1996.

Results

Temporal variation in climate change indicators

The Devictor indices and BICCO-Net indices gave dissimilar results for birds and butterflies across the time-period. The Devictor index showed a long-term increase in STI for birds from the mid-1970s, but a long-term decline in STI for butterflies (Figure 1, Table 1). For these two groups, the BICCO-Net indicator showed evidence of long-term decline over the entire period which was sustained for butterflies, but reversed over the last 20-year period for birds (Figure 2, Table 1). There were no significant long-term trends in the BICCO-Net indicator for either aphids or moths, although both were positive for the final 20-year time-period. Interestingly, there was no correlation in STI and the sum of species temperature coefficients for the BICCO-Net index for birds, but there was a significant correlation between the two measures for butterflies (Figure 3). This suggests that annual fluctuations in butterfly population growth in the UK may be more closely related to large-scale distribution than in birds, although both butterfly indicator trends were in the opposite direction to that expected on the basis of warming.

Spatial variation in climate change indicators

Spatial variation in CTI highlighted the expected latitudinal gradients in both 1994-96 and 2007-2009, with communities in the south showing a greater dominance of more southerly-distributed, warm-associated species than those in the North (Figure 4a, b). This contrast was particularly marked with altitude, with cold associated species particularly concentrated in upland areas, especially the Highlands of Scotland, where CTI values were 2°C cooler than the southern lowlands. There were strong spatial gradients in CTI trend through time (Figure 4c). Although the majority of the country shows evidence of community changes that would follow from a warming trend, this appears most marked in the Highlands and west coast of Scotland, where increases in CTI of more than 0.35 °C were common. The magnitude of CTI change across lowland England was relatively small. Declines in CTI only occurred in Shetland (where the BBS sampling density is very low and population estimates unreliable), in north-east Caithness and the Buchan Plain, upland areas of the Brecon Beacons and south-west England.

Discussion

Following the recommendations of Appendix 10, we have generated example climate change indicators for the UK for terrestrial biodiversity, based upon the CTI of Devictor *et al.* (2008, 2012), and the BICCO-Net indicator. The former has previously been produced for the UK for both birds and butterflies, and shown to produce positive trends from 1990-2008 across Europe, and for the UK specifically, from these same data. Our results for birds matched those of Devictor *et al.* (2012), and extended this positive trend back to the 1970s. However, our result for butterflies was opposite to that of Devictor *et al.* (2012), suggesting that population trends of more cold-associated species were more positive than warm-associated ones.

For birds, the CTI increase from the mid- 1970s is approximately 10-years earlier than the upturn detected by the Gregory indicator for European birds (Gregory *et al.* 2009), and potentially earlier than might be expected on the basis of warming trends, which were particularly marked from the mid-1980s onwards (Table 2). Interestingly, it does match the timing of the strong decline in farmland bird populations as a result of agricultural intensification (Eglington & Pearce-Higgins), which will form a significant component of this community, although it is unclear why that should have preferentially favoured warm-associated species with a high STI over cold-associated species. We therefore conclude that the CTI trend for birds is in line with expectations based on warming, although the strong positive trend from the 1970s to 1980s suggests that it may also be influenced by other, non-temperature related factors. Thus, as suggested by Appendix 10, and other authors (Clavero *et al.* 2011, Kampichler *et al.* 2012), careful interpretation of the Devictor index is required because of its potential to be confounded by non-climatic drivers. For butterflies, the long-term negative trend appears to reflect population declines in many southern distributed butterfly species, potentially during this period for reasons of non-climatic factors (Fox *et al.* 2011). Other reasons for the differences between the index of Devictor *et al.* (2012) and that presented here are the fact that this is based on English only data, rather than those for the UK, particularly given more positive butterfly trends in Scotland (Fox *et al.* 2011). Analytical differences in how the indicator is calculated can also influence its trend and significance (Oliver *et al.* unpubl.), although appear to have little impact on these results. Finally, the overall decline is at least partly related to cold weather in the final two years of the time-series, as the trend from 1990-2008 was non-significantly positive.

Our presentation of a spatial indicator based on the CTI provides additional information about the trends for birds outlined by Devictor *et al.* (2012). In particular, although we highlight the strong latitudinal gradient in CTI previously demonstrated for France (Devictor *et al.* 2008), we show that the contrast with altitude is even more marked, emphasising the boreal / sub-arctic nature of our upland avifauna (Thompson *et al.* 1988). This is despite this analysis being derived from common and widespread species covered by BBS data, and therefore did not include data on the majority of true upland bird species, which may also be responding to climate change (Pearce-Higgins 2010); we may therefore have under-estimated these contrasts. Further, we also identified strong spatial patterns in CTI trend through time, as a measure of climate change impacts. These appear to have been greatest in upland areas, and particularly in the Highlands and west coast of Scotland. It is in these western areas that increases in species diversity have been most marked (Davey *et al.* 2012), and it appears that part of the driver of these observed trends is an increasing colonisation of upland sites by warm-associated generalist species, potentially at the expense of upland specialists (Pearce-Higgins 2010).

We also produced temporal indicator trends for the BICCO-Net indicator for four taxa. As with CTI, the BICCO-Net indicator for birds appeared to match expectation, with an initial decline in the indicator value until the mid- 1980s, and followed by a subsequent positive trend from 1991-2011 that approximately matches the pattern identified for Europe by Gregory *et al.* (2009). This suggests that in recent years, populations of species whose population growth tends to be positively associated with temperature have increased more, or declined less, than species which exhibit a negative temperature association. This positive trend for both the BICCO-Net indicator and Devictor indicator was apparent despite the species-level values on which both indicators were being uncorrelated (Figure 3). As with the CTI, the BICCO-Net indicator for butterflies also showed a negative indicator trend through time, suggesting that population trends of species more negatively affected by warming have tended to increase. As discussed above, this potentially outlines the importance of non-climatic factors in influencing population trends of southern butterfly populations, but may also reflect the impact of recent cold weather. BICCO-Net indicator trends for aphids and moths were positive, but not statistically significant due to strong inter-annual fluctuations. Thus, although large-scale moth population declines and aphid population increases may be related to climate change (Appendix 3), there is less consistency in the response of individual species within each group to that expected from warming.

These contrasting results highlight the challenges associated with the production of indicators of climate change impacts on biodiversity. Whilst some indicators appear to work well and produce the expected result (Gregory *et al.* 2009, Devictor *et al.* 2008, 2012, Pearce-Higgins *et al.* 2011), in other circumstances, they may not (e.g. Kampichler *et al.* 2012, this appendix). Here, it appears that the observed changes for birds most closely match that expected from temperature, whilst those for aphids and moths are weakly consistent with expectation and butterfly indicator trends are not. However, in both Catalonia (Clavero *et al.* 2011) and the Netherlands (Kampichler *et al.* 2012), there are some avian CTI trends which appear driven by non-climatic factors. Across all taxa, there appears to be significant variation in the performance of these climate change indicators, and it is difficult to *a priori* identify the taxa where such an indicator may be appropriate. An alternative interpretation may be that these indicators are actually providing a true measure of the impact of climate change on these groups relative to other drivers, and that for the taxa studied, apart from birds, climate change has had only a relatively weak effect upon species-specific variation in population trends within groups.

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Table 1. Parameter estimates, standard error and significance of models of index over time.

Indicator type	Taxon	Year	Slope estimate	Std. Error	t value	P value
Devictor	birds	1966:2011	0.032	0.002	20.04136	0.0000***
Devictor	birds	1991:2011	0.028	0.002	11.01516	0.0000***
Devictor	butterflies	1976:2011	-0.005	0.003	-1.88606	0.0679 .
Devictor	butterflies	1991:2011	-0.007	0.005	-1.485	0.154
BICCO-Net	aphids	1970:2010	-0.553	0.714	-0.775	0.4431
BICCO-Net	aphids	1991:2010	0.468	1.839	0.254	0.8022
BICCO-Net	birds	1966:2011	-0.661	0.138	-4.792	0.0000***
BICCO-Net	birds	1991:2011	0.555	0.189	2.939	0.0088**
BICCO-Net	butterflies	1976:2011	-0.243	0.078	-3.12	0.0037**
BICCO-Net	butterflies	1991:2011	-0.502	0.142	-3.53	0.0022**
BICCO-Net	moths	1975:2010	0.345	0.370	0.932	0.3581
BICCO-Net	moths	1991:2010	0.537	0.423	1.270	0.2203

Table 2. Summary of results across all indicators. Non-significant trends are in parentheses. The expectation is based on warming trends.

	Pre 1990 trend	**Post 1990 trend**
Expectation	**(+)**	**+**
Birds (CTI)	+	+
Birds (BICCO-Net)	-	+
Butterflies (CTI)	(-)	(-)
Butterflies (BICCO-Net)	-	-
Aphids (BICCO-Net)	(-)	(+)
Moths (BICCO-Net)	(+)	(+)

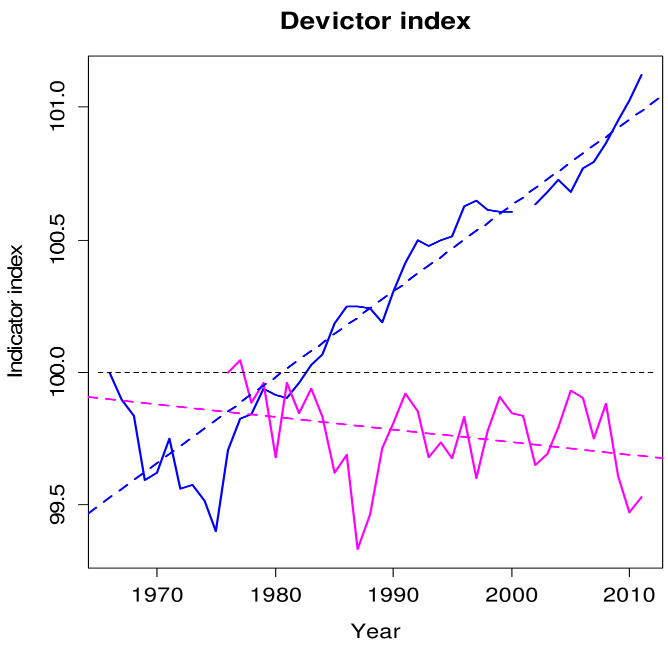

Figure 1 Devictor index based on the community temperature index for English birds (blue) and butterflies (magenta) from 1966 – 2011.

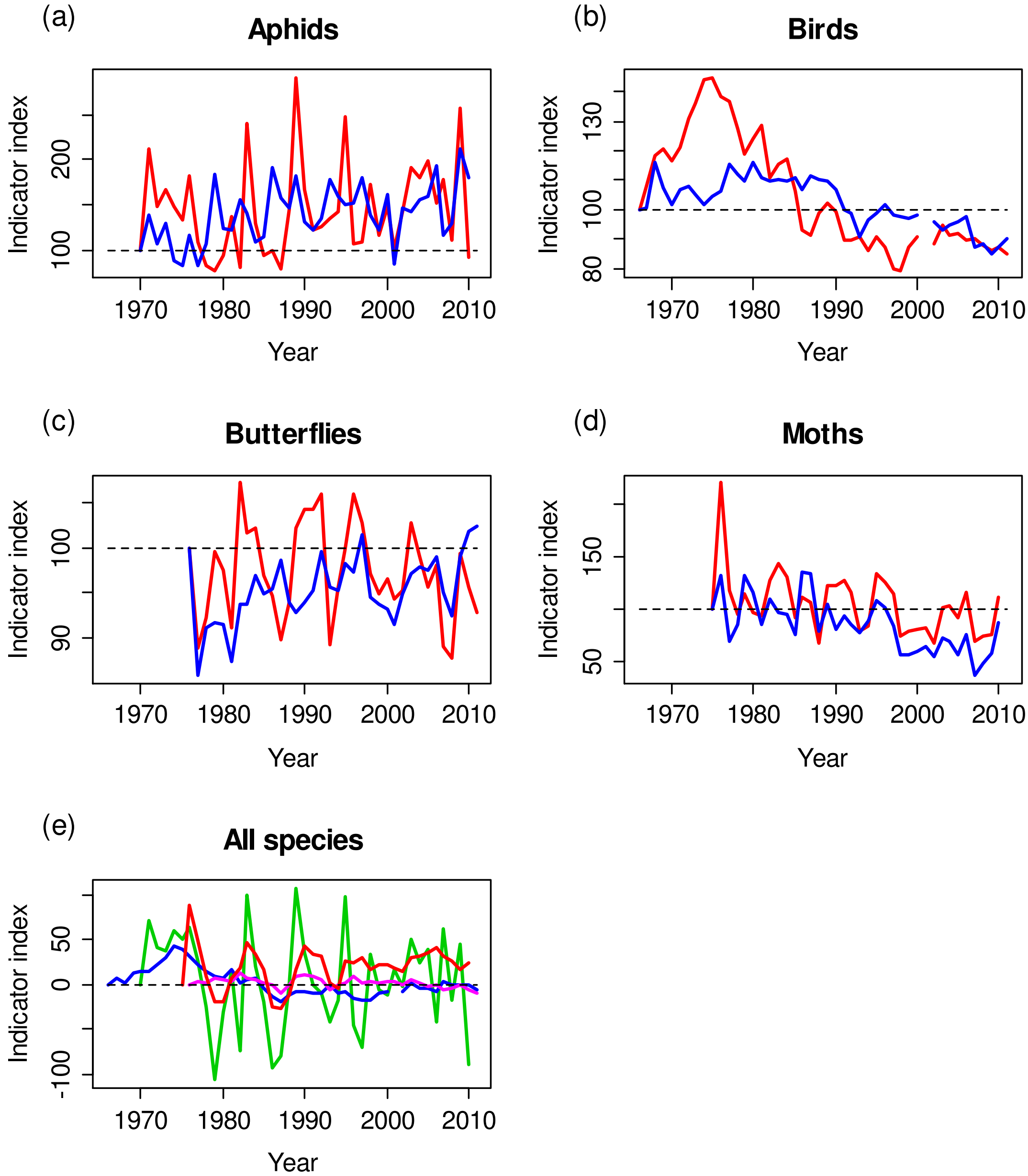

Figure 2 (a) – (d) Geometric means of species population indices of (a) aphid, (b) bird, (c) butterfly and (d) moth species predicted to increase (red) and decline (blue) in rising temperatures. (e) BICCO-Net index based on the index of species predicted to increase minus the index of species predicted to decline.

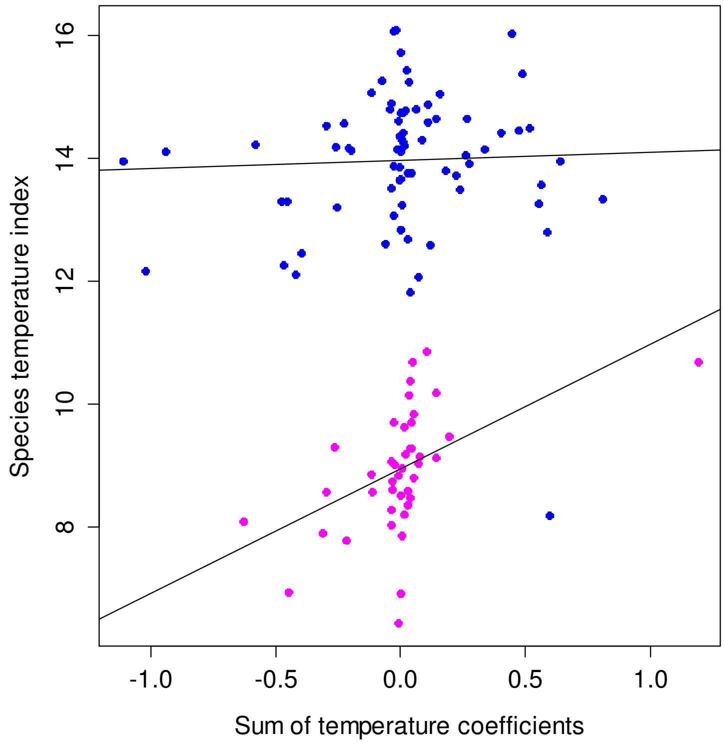

Figure 3 Species temperature index and the sum of temperature coefficients for birds (blue) and butterflies (magenta).

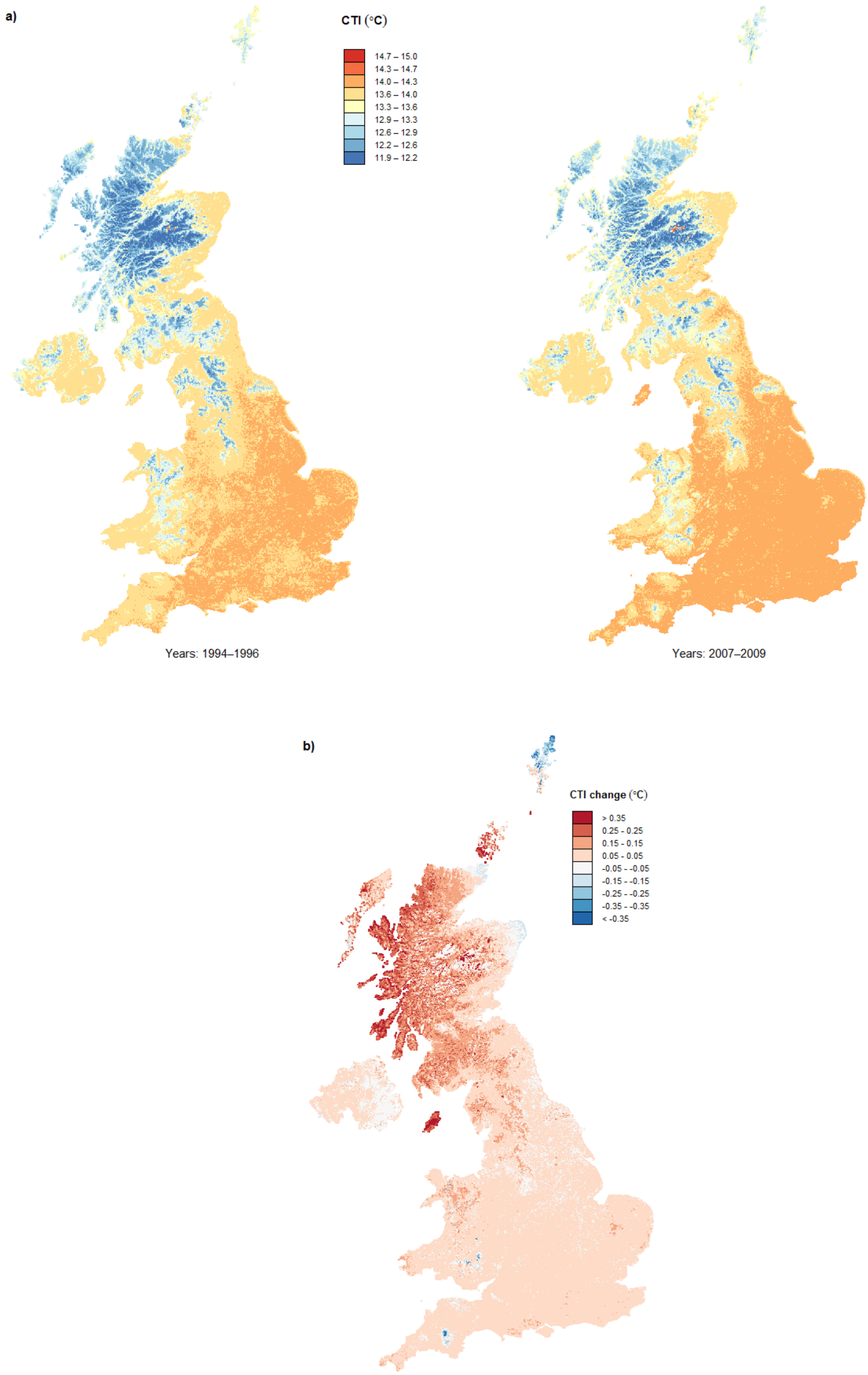

Figure 4. Maps of spatial variation in the Devictor index (CTI) across the UK for 1994-1996 and 2007-2009 (a), and of its change between the first and second time period (b).