Devictor *et al.* reply — In their comment, Rodríguez-Sánchez *et al.* claim that our conclusions on the climatic debt of birds and butterflies[1] are premature because introducing statistical and biological uncertainties in species-specific thermal tolerance (species temperature index, STI) would blur the temporal trend in the community temperature index CTI). Here, we show why our results are not affected by this uncertainty and further assess the STI uncertainty and its consequences.

An increase in CTI reflects the rate of replacement of individuals belonging to species with low STI by those with higher STI. The actual value of STI for a given species is not what determines the trends in CTI. What really matters is the relative value of the STI among a set of species. The uncertainty of the relative STIs is in fact remarkably low. It is linked to the uncertainty of the spatial distribution of average temperatures over 30 years in Europe, and to the uncertainty of the spatial distribution of common birds and butterflies. The resolution and accuracy of the spatial distribution of temperature in Europe is very high: the difference in long-term average temperature between any two points in space in Europe is known to the nearest 0.1 °C (ref. 2). Similarly, distribution atlases of European birds and butterflies are among the most accurate data available on animal distribution today. The European atlas of birds integrates 25 years of effort by thousands of skilled field ornithologists and data analysts in more than 40 countries[3]. The butterfly atlas also results from a considerable amount of work and knowledge on species' distributions[4]. Therefore, although several sources of uncertainty may affect the exact boundaries of each species' distribution, the variation in the relative STIs obtained with these data is very robust to these uncertainties. These uncertainties are also constant through time and similar for most species. The rate of change in CTI should therefore not be affected. Although we agree with Rodríguez-Sánchez *et al.* that accounting for intraspecific trait variation is crucial, we think that estimating the distribution and magnitude of this variation is even more important[5] and cannot be generated at random.

To illustrate this issue with empirical data, Lindström *et al.* recently showed that the relative STI is indeed very robust to the change in the data source, the extent of the climatic niche, as well as the time-window considered[6]. They calculated different STI values with different ranges of temperature, extents of species distribution and with very different sources of data with different sampling efforts, resolutions or detection probabilities. All these STI values, albeit yielding different uncertainties, were highly correlated and led to similar trends in CTI. We further estimated STI uncertainty from two different datasets documenting species distributions. We found that this uncertainty is very low (Fig. 1a) and does not change the temporal slope in CTI (Fig. 1b). This uncertainty is far from that simulated by Rodríguez-Sánchez *et al.*, who proposed to vary STIs at random by increasing their value by 10% to 20% (Note that percentage is meaningless for temperature. Our estimate of STI uncertainty would correspond to 0.068%). The level of uncertainty they simulated makes no ecological sense: this would shift the distribution of species several hundred kilometres at random, which clearly does not correspond to what we know for the species considered. We conclude that such simulations actually do not reflect a relevant aspect of the data used in our study.

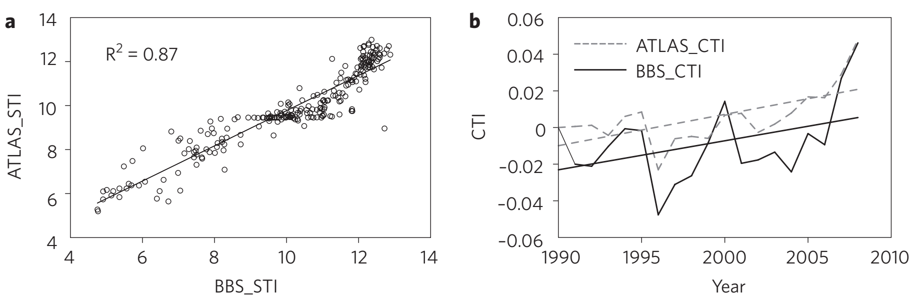

Figure 1 | Estimating STI uncertainty and consequences on the temporal trend in CTI. We calculated two sets of STI values using very different datasets. This was possible for Sweden, where a standardized Breeding Bird Survey (BBS) has been running since 1996, and where the monitored sites (n = 716 fixed sites) are regularly distributed in the country from south to north. From these data, we estimated for each species the 'BBS STI' as the average of each temperature of the monitored site where the species was detected at least once during the period 1996–2008. We compared this BBS STI with the STI calculated using the Swedish subset of the European Atlas using the method we describe in ref. 1. These two estimates of STIs are highly correlated. **a**, On average, the uncertainty of STI values is 0.068% (absolute value of the mean of the ratio (Atlas_STI – BBS_STI)/ Atlas_STI). **b**, The trend in Swedish CTI (calculated using data from another independent scheme[6] running from 1990) is consequently robust to the change in the STI considered.

Moreover, we acknowledge that the relationship between species fitness and temperature cannot be accounted for by STI only. Most species occur over a range of several degrees Celsius, and changes in temperature within this range are not expected to substantially affect their fate. This is even an underlying assumption of the climatic niche. This is precisely why temporal changes in CTI cannot be directly compared to temporal changes in temperature. The climatic debt calculated in our paper instead uses the ratio between the temporal trend in CTI and the spatial trend in CTI, which accounts for local adaptations, dispersal limitations, species interactions and other factors determining the realized species distributions. This approach has the great advantage of using a ratio between two values estimated with the same basic data and was also proposed to estimate the spatial shift in temperature[7]. The spatial and the temporal slopes of CTI are therefore similarly affected by any bias or uncertainty affecting STIs and can be safely compared. Unfortunately, the authors only briefly mention this crucial step of our reasoning.

Overall, as already discussed in our original paper[1], we acknowledge that the CTI approach has several limitations, including the inability to separate evolutionary adaptation from phenotypic plasticity or true decrease in individual fitness. It is however very different from distribution-based niche modelling methods as it reflects the realized observed changes in local composition of species assemblages in response to climate change very well. Besides, it was recently used successfully with several independent datasets to measure various aspects of biodiversity responses to climate changes for different groups[8], habitats[9] and scales[6]. Also, when applied to species with low dispersal constraint, CTI responded as expected[8]. We therefore think that STI and CTI are indeed very good proxies for assessing community responses to climate change. All sources of uncertainty can and should be accounted for when calculating trends in CTI, but although STI values can be refined with even better ecological data in the future, we think that published results on CTI available with current data are unlikely to be flawed by major problems due to STI uncertainty. ❒

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COMMENTARY:

A new paradigm for climate change

Kevin Anderson and Alice Bows

How climate change science is conducted, communicated and translated into policy must be radically transformed if 'dangerous' climate change is to be averted.

With the Rio+20 conference on sustainable development now over, it remains unclear how much attention policymakers, businesses and the public paid to scientific analyses of climate change. A question also remains as to how impartial, objective and direct scientists were in presenting their evidence; politicians may well have left Rio without understanding the viability and implications of proposed low-carbon pathways.

We urgently need to acknowledge that the development needs of many countries leave the rich western nations with little choice but to immediately and severely curb their greenhouse gas emissions[1,2]. But academics may again have contributed to a misguided belief that commitments to avoid warming of 2 °C can still be realized with incremental adjustments to economic incentives. A carbon tax here, a little emissions trading there and the odd voluntary agreement thrown in for good measure will not be sufficient.

Scientists may argue that it is not our responsibility anyway and that it is politicians who are really to blame. The scientific community can meet next year to communicate its latest model results and reiterate how climate change commitments and economic growth go hand in hand. Many policymakers (and some scientists) believe that yet another year will not matter in the grand scheme of things, but this overlooks the fundamental tenet of climate science: emissions are cumulative.

Long-term and end-point targets (for example, 80% by 2050) have no scientific basis. What governs future global temperatures and other adverse climate impacts are the emissions from yesterday, today and those released in the next few years. Delaying an agreement on meaningful cuts to emissions increases the risk of exposing many already vulnerable communities to higher temperatures and worsening climate-related impacts. Yet, behind the cosy rhetoric of naively optimistic science and policy, there is little to suggest that existing mitigation proposals will deliver anything but rising emissions over the coming decade or two.

Hope and judgement

There are many reasons why climate science has become intertwined with politics, to the extent that providing impartial scientific analysis is increasingly challenging and challenged. On a personal level, scientists are human too. Many have chosen to research climate change because they believe there is value in applying scientific rigour to an important global issue. It is not surprising then that they also hope that it is still possible to avoid dangerous