CORRESPONDENCE:

Science literacy still matters

To the Editor — Kahan *et al.*[1] find that science literacy is negatively correlated with concern about climate change. This correlation, of questionable practical significance, has been misinterpreted in the media as entirely disproving the relevance of science and climate literacy to the public debate. Not only does this misrepresent the thrust of the research by Kahan and co-workers, but it is also inaccurate and counterproductive to those of us engaged in climate and related literacy efforts.

The study by Kahan *et al.*[1] did not examine people's understanding of climate, focusing instead on general science literacy, numeracy and cultural frames. But the press largely ignored this, pushing headlines such as the *Daily Mail*'s[2] 'Global Warming Sceptics are BETTER-Informed about Science than Believers' and *Mother Jones*'s[3] 'Why Science Education won't Solve our Climate Problems'. *USA Today*[4] summed up with the lead: "Support for climate science doesn't increase with science literacy, a survey suggests."

According to researcher Jon Miller[5], nearly three out of four US adults fail basic civic tests of science literacy skills. This deficit of science literacy in general, and of climate and energy literacy in particular, clearly contributes to the present sense of confusion and our societal inability to have an informed, adult conversation about climate change. Moreover, literacy is generally acquired through effective education, not media messaging or cultural frames.

The Six Americas research[6], conducted at Yale, has shown that those most concerned about climate change do in fact have more knowledge about it than those who are least concerned. Graded on a curve, 97% of those who are alarmed about climate change receive a passing grade, versus 56% of those who are dismissive. Of the alarmed, 87% know that human actions cause climate change, compared with only 6% of the dismissives. Just 7% of the dismissives acknowledge that climate change is happening and humans are responsible, compared with 79% of the alarmed. "Many Americans lack some of the knowledge needed for informed decision-making about these issues," the researchers conclude.

In US schools, climate change is often skipped entirely and, if taught, is presented briefly or as a political controversy. Rarely is it taught across the curriculum, as leading educators recommend[7]. The Six Americas surveys find that fewer than one in five students feel "very well informed" about climate science and solutions, and barely a quarter feel they've learnt "a lot" about climate change in school. Most students rely on their schools for climate change science and — with rare exceptions — they are not getting what they need.

Stern[8] rightly rejects as naive the idea that closing these knowledge deficits alone will resolve our fractious public debate. We concur that strategic framing, including minimizing doom and gloom by integrating science with solutions, is vital, especially in educational settings. But dismissing literacy as unimportant or irrelevant is wrong. Although literacy alone can't solve the climate problem, it provides society with the tools and shared basis for understanding the science and solutions before us. ❐

References

1. Kahan, D. *et al. Nature Clim. Change* http://dx.doi.org/10.1038/nclimate1547 (2012).
2. Waugh, R. Global Warming Sceptics are BETTER-Informed about Science than Believers. *Daily Mail* (30 May 2012); available via http://go.nature.com/uaZlOw
3. Battistoni, A. Why Science Education won't Solve our Climate Problems. *Mother Jones* (30 May 2012); available via http://go.nature.com/iJZhPD
4. Vergano, D. Culture Splits Science Views, not Science Smarts. *USA Today* (29 May 2012); available via http://go.nature.com/AwkN1W
5. Hobson, A. *Phys. Teach.* **46,** 404 (2008).
6. Leiserowitz, A. & Smith, N. *Knowledge of Climate Change Across Global Warming's Six Americas* (Yale Univ., 2010); available via http://go.nature.com/KtWGvG
7. National Research Council *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Academies, 2010).
8. Stern, P. *Nature Clim. Change* **2,** 572–573 (2012).

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CORRESPONDENCE

Uncertainty in thermal tolerances and climatic debt

To the Editor — As modern climate change causes rapid geographical shifts of environmental conditions, there are great concerns that numerous species could be unable to track suitable environments, thereby incurring a 'climatic debt'[1]. Recently, Devictor *et al.*[2] reported that the composition of bird and butterfly communities across Europe has changed at a lower rate than could be expected given the observed increase in temperature. They concluded that communities are accumulating a significant climatic debt. We believe, however, that there are methodological and conceptual issues with their approach that render this conclusion premature.

Devictor *et al.*[2] calculate a temperature index (STI) for each species by averaging the long-term reproductive season temperature across its range (obtained from atlases). Then they compute a community temperature index (CTI) as the average of STI values weighted by species' relative abundances. The authors consider the STI "a proxy for species' dependence on temperature"[2] but omit to evaluate how accurately STIs represent species' actual thermal tolerances. Instead, they treat STIs as a 'perfect' proxy with no associated uncertainty. Here, we show that neglecting the inherent uncertainty in STIs generates a considerable underestimation of CTI uncertainty, ultimately producing overly precise climatic debt estimates.

Many sources of uncertainty can affect STI estimates, such as imprecise knowledge of species' distributions[3] and temperatures[4,5] at the spatial scale of interest. For instance, microclimatic variation not captured by the resolution of the WorldClim database can account for differences of several degrees in average temperatures[5,6]. More fundamentally, STI estimates based on species' current distributions may be biased indicators of their thermal tolerances. The reasons for this have been much debated in the scientific literature on species distribution modelling[7] and include dispersal limitation, truncated niches, biotic interactions, or the fact that other environmental drivers than temperature (for example, precipitation, resource availability) can constrain distribution ranges. Thus, inferring thermal tolerances from species' realized distributions will always produce inherently uncertain (if not biased) estimates, however well-known these distributions are. Furthermore, species' thermal tolerances are not static but vary both in space and time as a result of evolutionary adaptation and phenotypic plasticity[8].

Consequently, rather than considering STIs as well-defined single-point values, their uncertainty needs to be appropriately incorporated in CTI calculations, for example, through sensitivity analyses or Markov chain Monte Carlo techniques. Using a simulated dataset that replicates Devictor *et al.*'s data, we show that increasing levels of uncertainty in STIs propagate into progressively more uncertain CTI values (Fig. 1a) and trends (Fig. 1b). Temporal CTI trends and spatial CTI gradients are similarly affected, ultimately leading to much wider confidence intervals for estimated climatic debts. For instance, incorporating a median 20% deviation in the STIs of our simulated butterfly dataset (which corresponds to 2 °C for a STI = 10 °C) more than tripled uncertainty in CTI northward shifts (95% confidence interval increasing from 43–53 km to 32–65 km). In the bird dataset, the same level of STI uncertainty produced CTI trends that are actually compatible with southward shifts (95% confidence interval changing from 4–23 km to −4–31 km). Note that these simulated levels of STI uncertainty are perfectly realistic given species' broad thermal tolerances (for example, ~15 °C across 74 European bird species[9]) and the many sources of uncertainty affecting STIs. Our analyses underscore that representing species' thermal tolerance as a single-point value constitutes an important step back from prevalent niche-modelling methods[7]. In fact, neglecting intraspecific variation in thermal tolerances leads to overconfident estimates of CTI states and trends, and tends to exacerbate the effects of warming on community reshuffling (Fig. 1c,d).

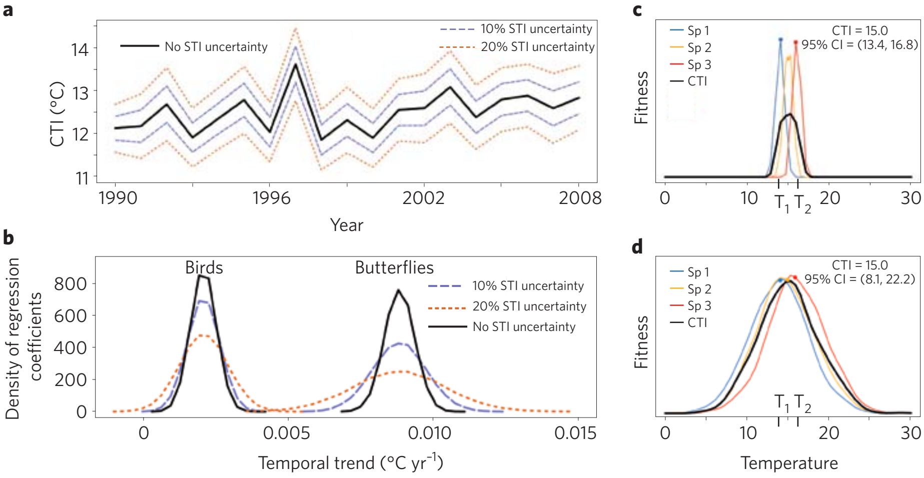

Figure 1 | Uncertainty and variability in species' thermal tolerances affect climatic debt estimates. **a**, Uncertainty in STI values inflates the uncertainty of CTI estimates (dashed lines denote CTI standard errors). Note that, for a species with STI = 10 °C, indicated median deviations of 10% and 20% correspond to temperature differences of 1.0 and 2.0 °C, respectively, which are well within the range of observed microclimatic variation and thermal tolerances[4,5,9]. **b**, Uncertainty in STI does not bias average CTI trends but inflates their uncertainty. **c**,**d**, The importance of considering thermal niche widths: In a community of three species, narrow thermal niches (**c**) produce a much narrower CTI distribution than broader niche widths (**d**). Hence, neglecting species' thermal niche widths produces overconfident estimates of CTI and overestimates the effects of warming on community reshuffling: A temperature increase from T1 to T2 would induce much stronger reshuffling in (**c**) than in (**d**). CI = confidence interval.

Moreover, the exclusive focus on migration as species' response to warming renders Devictor *et al.*'s approach, in our view, equivocal about the actual extent of temperature tracking in biological communities. For instance, small changes in CTI over time could simply indicate that species have broad thermal tolerances (Fig. 1d), high phenotypic plasticity (including changes in behaviour, phenology or habitat choice) or undergo microevolutionary adaptation. Thus, differences between temporal CTI trends among regions or taxa can be challenging to interpret[10]. Using the ratio of temporal and spatial CTI gradients circumvents these problems to some extent, yet this ratio is doubly affected by STI uncertainty (see above).

Taken together, our results indicate that the inherent variability of species' thermal tolerances and the uncertainty in its estimation profoundly affect inferences about climate-driven community reshuffling. As a result, the actual climatic debt of European bird and butterfly communities remains considerably more uncertain than reported[2]. Although we fully share the concerns of Devictor *et al.* regarding the potential threat of modern climate change to extant biodiversity, we also believe that clearly acknowledging the inherent limitations and uncertainties of climate change research is, more than ever, a critical task. ❐

References

1. Menéndez, R. *et al. Proc. R. Soc. B* **273,** 1465–70 (2006).
2. Devictor, V. *et al. Nature Clim. Change* **2,** 121–24 (2012).
3. Rondinini, C., Wilson, K. A., Boitani, L., Grantham, H. & Possingham, H. P. *Ecol. Lett.* **9,** 1136–1145 (2006).
4. Suggitt, A. J. *et al. Oikos* **120,** 1–8 (2011).
5. Dobrowski, S. Z. *Global Change Biol.* **17,** 1022–1035 (2011).
6. Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G. & Jarvis, A. *Int. J. Clim.* **25,** 1965–1978 (2005).
7. Peterson, A. T. *et al. Ecological Niches and Geographic Distributions* (Princeton Univ., 2011).
8. Reed, T. E., Schindler, D. E. & Waples, R. S. *Cons. Biol.* **25,** 56–63 (2011).
9. Barnagaud, J.-Y. *et al. PLoS One* **7,** e32819 (2012).
10. Clavero, M., Villero, D. & Brotons, L. *PLoS One* **6,** e18581 (2011).

Acknowledgements

We thank V. Devictor and colleagues for helpful discussions, and J-Y Barnagaud, D. Coomes, P. Jordano, T. Jucker and R. Petit for reviewing the manuscript. F.R.S. was supported by the European Commission under the Marie Curie Intra-European Fellowship Programme, and P.D.F. held a post-doctoral fellowship from the Research Foundation Flanders (FWO).

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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.

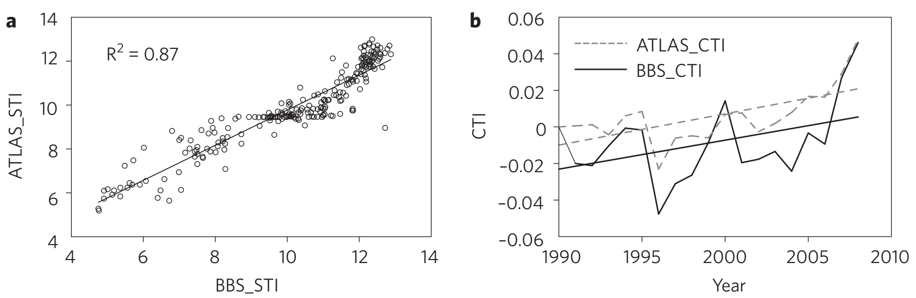

Figure 1 | Estimating STI uncertainty and consequences on the temporal trend in CTI. We calculated two sets of STI values using very different datasets. This was possible for Sweden, where a standardized Breeding Bird Survey (BBS) has been running since 1996, and where the monitored sites (n = 716 fixed 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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References
1. Devictor, V. *et al. Nature Clim. Change.* **2,** 121–124 (2012).
2. Hijmans, R. J. *et al. Int. J. Clim.* **25,** 1965–1978 (2005).
3. Hagemeijer, W. J. M. & Blair, M. J. *The EBCC Atlas of European Breeding Birds: Their Distribution and Abundance* (T. & A. D. Poyser, 1997).
4. Settele, J. *et al. BioRisk* **2,** 33–72 (2009).
5. Albert, C. H. *et al. Persp. Plant Ecol. Evol.* http://dx.doi.org/10.1016/j.ppees.2011.04.003 (in the press).
6. Lindström, Å. *et al. Ecography* http://dx.doi.org/10.1111/j.1600-0587.2012.07799.x (in the press).
7. Loarie, S. R. *et al. Nature* **462,** 24–31 (2009).
8. Godet, L., Jaffré, M. & Devictor, V. *Biol. Lett.* **7,** 714–717 (2011).
9. Kampichler, C. *et al. PLoS One* **7,** e35272 (2012).

Acknowledgements
We thank Cécile Albert for stimulating comments on the importance of intraspecific variability and its consequences. We also thank Francisco Rodríguez-Sánchez and colleagues for initiating this thought-provoking discussion.

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