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. ❐

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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).

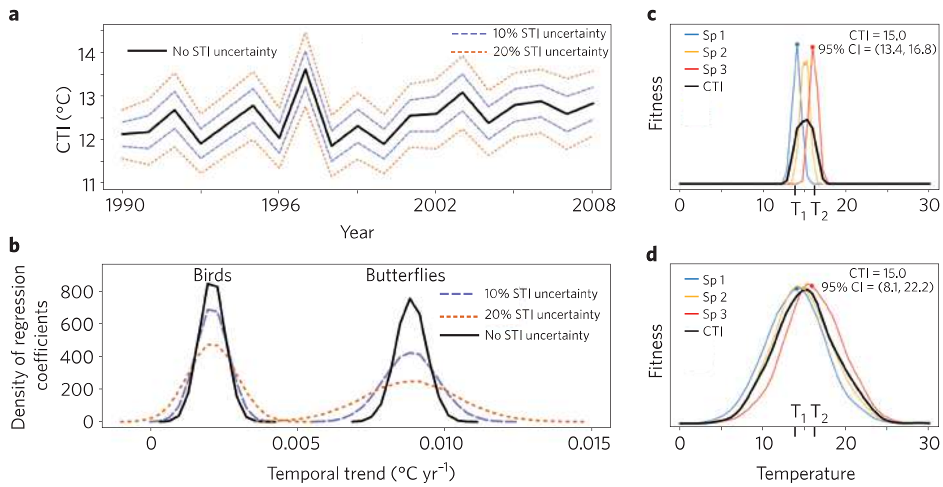

Figure 1 | Uncertainty and variability in species' thermal tolerances affect climatic debt estimates. **a**, Uncertainty in STI values inflates the uncertainty of CTI estimates (dashed lines denote CTI standard errors). Note that, for a species with STI = 10 °C, indicated median deviations of 10% and 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. ❒

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