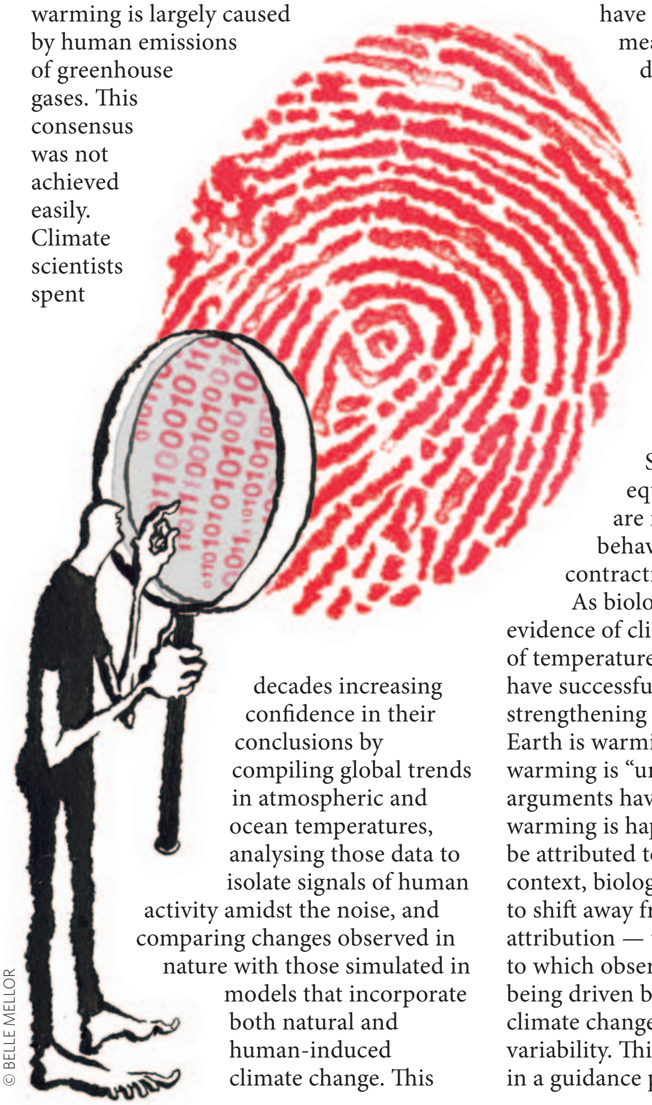
COMMENTARY:

Overstretching attribution

Camille Parmesan, Carlos Duarte, Elvira Poloczanska, Anthony J. Richardson and Michael C. Singer

The biological world is responding rapidly to a changing climate, but attempts to attribute individual impacts to rising greenhouse gases are ill-advised.



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Richard Lindzen of the Massachusetts Institute of Technology was once quoted in *NewsMax* magazine saying: "Climate change is the norm. If you want something to worry about, it would be if the climate were static. It would be like a person being dead." Lindzen is that rare but conspicuous animal: a *bona fide* climate scientist who rejects the scientific consensus that current climate warming is largely caused by human emissions of greenhouse gases. This consensus was not achieved easily. Climate scientists spent decades increasing confidence in their conclusions by compiling global trends in atmospheric and ocean temperatures, analysing those data to isolate signals of human activity amidst the noise, and comparing changes observed in nature with those simulated in models that incorporate both natural and human-induced climate change. This protracted process is known as 'detection and attribution', because climatic trends are detected and partitioned among various causes or 'drivers' of change[1].

For more than a decade, detection of climate change impacts has extended beyond the physical environment to biological systems. Spring events have been advancing by an average 2.8–3.2 days per decade[2,3]. Species' range boundaries have shifted polewards with a mean velocity of 6 km per decade, as well as upward in elevation[4]. Confidence in attributing such shifts to climate change has been strengthened by fingerprints, such as 'sign-switching', that defy alternate explanations. For example, poleward range boundaries expanded during warming periods of the twentieth century and contracted in cooling periods[4]. Similarly, poleward and equatorial range boundaries are now showing opposite behaviour, expanding and contracting respectively[4].

As biological impacts provide evidence of climate change independently of temperature measurements, they have successfully bolstered 'detection', strengthening the scientific consensus that Earth is warming[4–7]. However, now that warming is "unequivocal"[8], contrarian arguments have shifted from whether warming is happening to whether it can be attributed to human activity. In this context, biologists are now expected to shift away from detection towards attribution — that is, assessing the extent to which observed biological changes are being driven by greenhouse-gas-induced climate change versus natural climate variability. This expectation is formalized in a guidance paper for scientists taking part in the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC)[1].

In theory, this is a scientifically sound approach. In practice, we argue that these expectations are misguided when applied to most biological data. It is rarely possible to attribute specific responses of individual wild species to human-induced climate change. This is partly because human forcing of the climate is only detectable on large spatial scales, yet organisms experience local climate. Moreover, in any given region, species' responses to climate change are idiosyncratic, owing to basic differences in their biology. A further complication is that responses to climate are inextricably intertwined with reactions to other human modifications of the environment. Even where climate is a clear driver of change, little insight is gained by asking what proportion of the overall trend is due to greenhouse gases versus solar activity. From the perspective of a wild plant or animal, a changing climate is a changing climate, irrespective of its cause.

Biological complexities

The IPCC guidance paper states that attribution seeks to determine whether a specified set of drivers are the cause of an observed change in a specific system[1]. However, the probability of successfully attributing climatic trends to greenhouse gases declines sharply at spatial scales smaller than 10^6 km^2 and at temporal scales shorter than 50 years[9,10]. Therefore, studies linking biological changes to anthropogenic climate change are likewise most robust at continental to global scales[4,6] (Fig. 1). A corollary of this limitation is that it is inappropriate to attribute single events to anthropogenic climate change. For example, extinction of the mountaintop golden toad (*Bufo periglenes*) is linked to an extremely warm and dry year[11], but this single climatic event cannot be attributed with high confidence to human-induced climate change.

Another challenge for biological attribution is that global average trends in impacts camouflage a striking diversity of responses, even among species living in the same area and subject to the same climatic changes. In a 2003 study, 57% of wild species showed strong responses to regional climate change, whereas 32% showed no significant change and 11% behaved in ways opposite to anticipated responses to climate change[4]. Even among climate 'responders', the strength of response can vary by an order of magnitude, as evidenced by studies of birds and flowers in Great Britain, butterflies across Europe and intertidal invertebrates off California[7].

Some of this diversity stems from basic differences in species' sensitivity to climate. However, there is also a complex interplay among habitat destruction, land-use change, exploitation and pollution, in addition to climate change. The emerging view is that interactions among drivers of change are the norm[12]. For example, after a warming event, corals in overfished areas recovered more poorly from bleaching than those with intact food webs[13]. Effects of habitat fragmentation also interact with those of climate change. Northwards expansion of the speckled wood butterfly *(Pararge aegeria)* in Great Britain progressed rapidly where barriers were minimal, but was hampered in regions where agriculture had rendered woodland habitat patches too scattered for individuals to find[14].

Land-use change can lead to more subtle synergisms, either enhancing or masking responses to climate change. For the map butterfly (*Araschnia levana*) it does both. In recent decades this insect has expanded its northern range limit in Estonia and Finland, as expected from warming, but its southern limit in Catalonia has also expanded, contrary to expectations[15]. Both phenomena are partly explained by land-use change: by mowing road verges, humans improved the quality and accessibility of the butterfly's host plant (nettles) throughout Europe, allowing an overall range increase. Expansion occurred faster at the northern boundary than the southern, accelerated by two additional factors: summer warming causing new habitats to become climatically suitable, and evolution of greater flight capacity, driven by selection accompanying colonization of these new habitats[16].

Anthropogenic attribution

Global meta-analyses have documented systematic biological changes consistent with climate change across many species, ecosystems and geographic regions. As global climate change over the same time period has been unequivocally linked to the rise of greenhouse gases[8], such global coherence of biological responses is, by inference, due in part to anthropogenic climate change[2,4,6,7,17–19].

Modelling studies have attempted to separate the relative contributions of human-induced and natural climate trends to observed biological impacts. A 2005 study by Root and co-authors[2] showed that observed changes in timing of biological events (such as breeding or flowering dates) only correlated well with simulated changes of climate when the models factored in anthropogenic climate change as well as natural climate variability. In a separate study, Rosenzweig *et al.*[18] showed that global-scale spatial patterns of biological changes since 1970 have corresponded better with observed temperature changes than with simulated changes from models lacking the human-induced climate component. These studies, then, support earlier analyses showing coherence of biological impacts, and further point to anthropogenic climate change as a likely driver. Is it fruitful, then, to continue to pursue deconstruction of biological responses into those due to natural or anthropogenic climate change?

The IPCC[1] believes that it is, and advocates an ever-more-detailed approach to attribution. We disagree. We argue that 'chained-attribution' assessments from greenhouse gases to climate change to biological change, as called for by the IPCC[1,19], are largely inappropriate, principally because our understanding of the biological impacts of climate change cannot aspire to the level achieved in physical climate science. This is not simply a matter of further research, for there is no common biological response to a single climate driver, and no simple biological metric analogous to global temperature rise. Each ecosystem, species, or even population can respond differently to climate change, and there are an estimated 30–100 million species. Thus, we are far from being able to achieve realistic coupled climate–biological models, and in an attempt to reach this goal, we risk taking research effort away from the critical issue of adaptation.

A way forward

What, then, are the most productive avenues for biological attribution research? We propose concentrating on assessment of the interacting roles of climate and other environmental factors, regardless of the causes of the climate events or trends. Such 'attribution' assessment would involve synthesizing multiple lines of evidence linking climate drivers with species' responses, such as empirical studies on physiological thresholds and preferences for thermal environment, precipitation or ocean pH. It would also include palaeontological evidence for correlations between species' changes

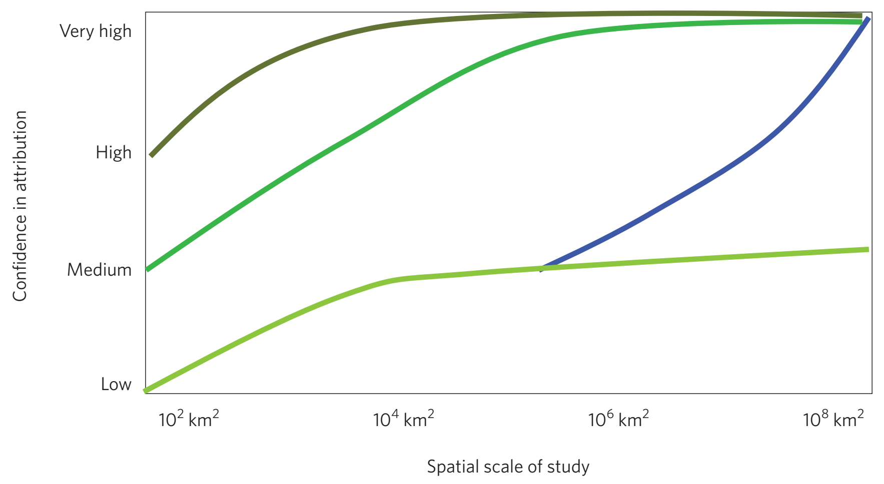

Figure 1 | Attribution and scale. The *x* axis shows the spatial scale of study or set of studies: <10^2 km^2 = individual field site; 10^4 km^2 = local (most single species studies); 10^5 km^2 = regional (some single species, mostly multi-species); 10^6 km^2 = continents and ocean basins; 10^8 km^2 = global (meta-analyses of many independent studies). The *y* axis shows the level of confidence in attributing a hypothetical observed biological change to either natural climate change (green lines) or anthropogenic climate change (blue line). Green shading shows the length of time series: light green = <10 years; medium green = 20–50 years; dark green = >70 years. Attribution to anthropogenic climate change (blue line) only appropriate at >10^5 km^2; published studies all of time series of >20 years, and hundreds to thousands of species, so never falls below 'medium' confidence.

and climate drivers in the past, and tools such as species niche models that can link observed changes in distributions to particular environmental drivers. Although this approach has been advocated in earlier IPCC reports, the importance of multi-faceted empirical assessment has been recently de-emphasized in favour of model-based approaches[1,2,10,18].

Species' extinctions have already been linked to recent climate change; the golden toad is iconic, but the white lemuroid possum is a likely successor[11]. In this context, the most important information for biodiversity preservation centres around achieving better estimates of future biological impacts to begin constructing adaptation programmes. Understanding the roles of different climate drivers can be crucial, but it is likely that the true climate drivers of biological systems are metrics for which we do not have good future projections at present, such as complex patterns of extreme weather events and seasonal variability[20].

By over-emphasizing the need for rigorous assessment of the specific role of greenhouse-gas forcing in driving observed biological changes, the IPCC effectively yields to the contrarians' inexhaustible demands for more 'proof', rather than advancing the most pressing and practical scientific questions. This focus diverts energies and research funds away from developing crucial adaptation and conservation measures. To improve estimates of future biological impacts we need research focused on how other human stressors exacerbate impacts of climate change. Most importantly from a conservation standpoint, these other stressors are more easily managed on local scales than climate itself, and thus, paradoxically, are crucial to constructing adaptation programmes to cope with anthropogenic climate change.

We advocate striving for a richer understanding of interactions between multiple drivers of change through doing empirical research, emphasizing tractable questions and using model-based attribution approaches more as a tool for improving projections of biodiversity impacts than as an end in itself. To do so should clarify the dialogue between climate scientists, biologists and policymakers, and generate much-needed assessments of the current and future impacts of anthropogenic climate change on biota. ❐

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COMMENTARY:

Time to try carbon labelling

Michael P. Vandenbergh, Thomas Dietz and Paul C. Stern

A global private carbon-labelling scheme for consumer products could fill the climate-policy gap by influencing the behaviour of consumers and corporate supply chains.

Most analysts agree that the economically efficient way to reduce greenhouse-gas (GHG) emissions is by pricing them. However, such prices will not be in place globally or in the largest emitting nations in the near term. The climate system has substantial inertia. Difficult-to-identify nonlinearities and tipping points are also likely. Thus waiting for a 'best' policy may increase the likelihood of severe impacts[1]. The policy challenge is to develop near-term strategies that can bend the global carbon-growth curve to buy time, reduce costs and build support for more efficient approaches.

Bottom-up approaches are proliferating as many subnational jurisdictions adopt renewable portfolio standards, promote energy efficiency and develop climate-adaptation plans[2]. A private carbon-labelling programme for consumer products could help fill the policy gap by influencing both corporate supply chains and consumer behaviour. Through supply chains, a labelling programme can have cross-border effects, influencing incentives around the world.

The household sector generates a third or more of total greenhouse-gas emissions through direct use of energy in heating and cooling dwellings and water, lighting, appliance use and transportation (in the US it