Climate warming effects on stream-fish size spectra are modulated by other perturbations

Across taxa, increased temperature has been reported to generally reduce individual body size and change the body size structure of wild communities. Our research reveals that the effects of climate warming on the body size structure of stream fishes are also dependent on the intensity of other human pressures.

This is a summary of:
Arranz, I, Grenouillet, G. & Cucherousset, J. Human pressures modulate climate-warming-induced changes in size spectra of stream fish communities. *Nat. Ecol. Evol.* https://doi.org/10.1038/s41559-023-02083-z (2023).

Published online: 1 June 2023

The problem

Climate warming can lead to a decrease in individual body size owing to the accelerated metabolism of organisms in response to increased temperature[1]. However, recent evidence suggests that these effects can be modulated by the environmental context. Investigating how the effects of climate warming on community body-size structure interact with other human pressures is therefore needed[2]. The community size spectrum, which quantifies the relationship between the abundance (or biomass) of organisms and their body size[3], represents an integrative approach to identifying the mechanisms of community responses to global environmental changes. This approach has also been used as a key indicator of community responses to human pressures[4]. In our study, we quantified the temporal trends in body size spectra for stream fish in wild communities and assessed the interaction effects of climate warming and other human pressures on these temporal dynamics.

The observation

We conducted an empirical study using an extensive biomonitoring dataset that comprises individual body-size measurements for nearly 5 million fish, collected during 9,748 fish surveys over more than 20 years in 583 stream locations across France[5]. First, we calculated the slope of the body size spectrum for each community and each sampling year in all stream locations and explored the temporal changes in the slope (Fig. 1a). Then, we identified the environmental drivers of these changes using databases of measurements of the environmental conditions around each stream location. We hypothesized that the annual trends of size spectra would be more negative (that is, increased numerical abundance of small-bodied individuals over time) with increasing temperature over the past 20 years. However, we also expected that this effect would be modulated by other human perturbations acting on streams[2].

Our analyses show that, as predicted, climate warming (Fig. 1b) had a negative effect on the community size spectra for streams with low levels of human pressures, and this effect was associated with an increased abundance of small-bodied individuals and a decreased abundance of large-bodied individuals. However, climate warming had the opposite effect in streams with high levels of human pressures (Fig. 1c), which had an increased number of large-bodied and reduced numbers of small-bodied individuals. Our findings reveal a re-configuration of the body size structure of stream fish communities over a long temporal scale, driven by the interaction between climate warming and other human pressures (Fig. 1c), suggesting that the general assumption that climate warming results in a decreased individual body size does not always hold true when other human-induced pressures are at play.

The interpretation

Our findings have important implications for ecosystem functioning because several ecosystem processes, including trophic transfer efficiency and energy fluxes, are linked with body-size spectrum theory[3]. In streams with low levels of human pressures, the decline in the number of large-bodied fish may be attributed to shifts in consumer–resource dynamics and a decrease in food chain length, as large-bodied individuals tend to have higher trophic positions than smaller-bodied individuals.

Although we found an interaction effect between climate warming and other human pressures, it was challenging to identify the specific determinant of these interaction effects because we quantified human pressures using an integrative index that consolidates multiple types of human activities. Fish stocking and biological invasions might be responsible for disrupting the negative effects of climate warming on fish size spectra, as non-native individuals and legally stocked individuals tend to be larger in body size than individuals in native populations in streams across France. However, fish stocking is not monitored in France (and in other countries), which makes it particularly difficult to assess the ecological effects of this common management practice.

An important research avenue would be to understand the direct link between the body size spectrum and ecosystem functioning, as body size is commonly measured in biomonitoring programmes and should continue to be part of biodiversity monitoring, as it provides unique insights into the complex response of wild communities and ecological processes to global environmental changes.

Ignasi Arranz & Julien Cucherousset
UMR 5174 EDB, Université Toulouse III - Paul Sabatier, CNRS, Toulouse, France.

EXPERT OPINION

"The study covers both a large geographical region (countrywide; France), an extensive time period (two decades) and multiple taxa (65 fish species). I am unaware of any empirical studies of this scale for inland stream size spectra. The interactions between climate warming and other human pressures are really interesting, and future studies should take care when interpreting these drivers individually in size spectrum analyses." **Freddie Heather, University of Tasmania, Hobart, Tasmania, Australia.**

FIGURE

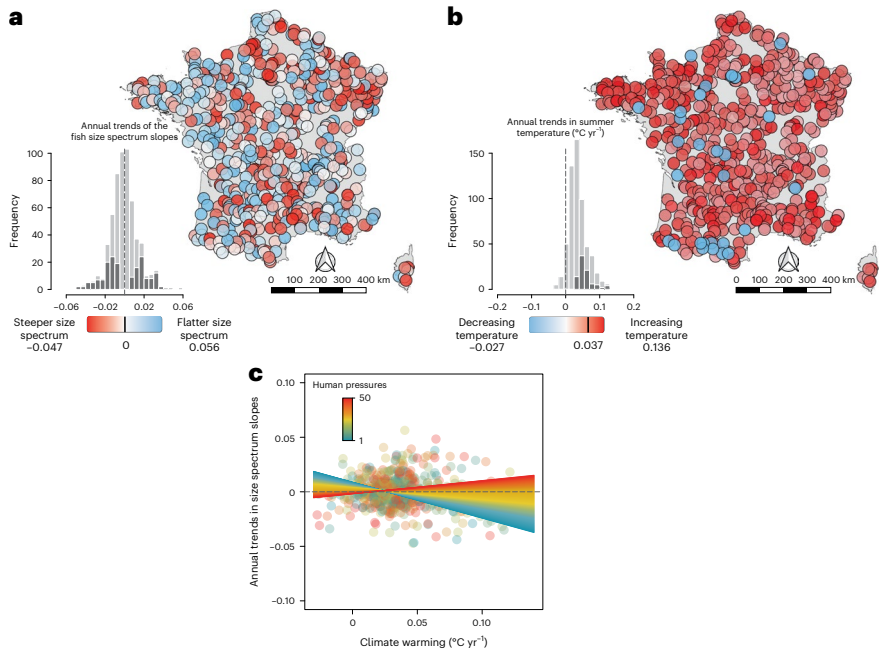

Fig. 1 | Annual trends in fish size spectra and climate warming, and interactions with human pressures. **a**,**b**, Annual trends in size spectrum slopes (**a**) and summer water temperature (**b**) across streams in France for the period 1994–2018. Histograms show the frequency distribution for each variable; significant ($P < 0.05$) and nonsignificant ($P > 0.05$) trends are depicted by dark grey and light grey bars, respectively; dashed line indicates no temporal change; black lines in legend are the average for each variable. **c**, Interaction effect of climate warming and human pressures on annual trends in fish size spectra. Colour lines indicate increasing levels (blue to red) of human pressures. Circles correspond to individual stream locations.

BEHIND THE PAPER

This work is part of a project that aims to quantify the importance of measuring individual body size in biomonitoring surveys and, more generally, of investigations aiming to understand the responses of fish communities to global environmental changes and the relationship between biodiversity and ecosystem functioning in fresh waters. The start of the project was challenging owing to the COVID-19 pandemic, which made it difficult for all of the scientists involved to make progress. Overall, these findings and those from companion studies highlight the importance of continuing to monitor organism body size to fully comprehend the effect of global environmental changes on biodiversity. This work would not have been possible without the contribution of our colleague and coauthor Gaël Grenouillet. **I.A. & J.C.**

REFERENCES

1. Daufresne, M., Lengfellner, K. & Sommer, U. Global warming benefits the small in aquatic ecosystems. *Proc. Natl Acad. Sci. USA* **106**, 12788–12793 (2009).
   This paper reports that increased temperature can negatively affect the average body size of organisms at multiple levels of biological organization.
2. Morris, O. F. et al. Local stressors mask the effects of warming in freshwater ecosystems. *Ecol. Lett.* **25**, 2540–2551 (2022).
   This paper reports that local stressors can override the effects of climate warming on community structure.
3. Kerr, S. R. & Dickie, L. M. *The Biomass Spectrum: A Predator–Prey Theory of Aquatic Production* (Columbia Univ. Press, 2001).
   A book that introduces the theory of organism size spectrum in aquatic food webs.
4. Petchey, O. L. & Belgrano, A. Body-size distributions and size-spectra: universal indicators of ecological status? *Biol. Lett.* **6**, 434–437 (2010).
   A commentary that highlights the use of body size approaches as indicators for ecosystem status.
5. Irz, P. et al. A long-term monitoring database on fish and crayfish species in French rivers. *Knowl. Manag. Aquat. Ecosyst.* **423**, 25 (2022).
   A data paper that reports the fish body-size data used in our study.

FROM THE EDITOR

"Although we know from mostly marine studies that climate change will affect fish body size, these changes are not straightforward, and we also have very little idea of how freshwater fish will be affected. This paper fills that gap, with over 20 years' worth of data on freshwater fish in France, to show that the complicating factor is human pressures, which interact with climate warming to modulate size spectrum slopes." **Editorial Team, *Nature Ecology & Evolution*.**