Review report

Long-term impacts of global temperature stabilization and overshoot on exploited marine species

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Summary of the manuscript

The manuscript uses the GFDL-ESM2M Earth System Model to examine the impact of climate warming scenarios on marine ecosystems based on the Aerobic Growth Index (AGI). They analyze how marine ecosystem habitats are affected under the overshoot vs. stabilization scenarios and quantifies how organisms' adaptation capabilities may mitigate habitat loss due to climate change. They find that under the overshoot scenario, although temperatures peak at 2°C and stabilize at 1.5°C, the maximum habitat loss still occurs over 150 years after the warming peak. Furthermore, they demonstrates that organisms' adaptation strategies will have a measurable impact on capping habitat loss under warming, depending on the adaptation rate.

Major review

The manuscript is generally well-written and structured. The authors outline a clear research question and provide nearly sufficient evidence to support it. I particularly appreciate the attempt to predict adaptability within this approach; although not extensive, it will be a valuable contribution. Adaptation has typically not been quantitatively applied in these types of studies.

That said, there are a couple of limitations inherent to the study's approach that warrant clarification. First, the authors chose to use the relative AGI formulation, which, by definition, removes the species-scale oxygen supply versus demand. Because of the elimination of physiological oxygen dependence, the relative AGI only provides a general “sense” of ecosystem sensitivity to a warming climate, rather than an objective quantitative prediction. While this formulation is mathematically useful and allows for a more flexible analytical framework, it is unclear whether the relative AGI remains instructive for quantifying changes in species abundance. The argument here is that habitat gain or loss with changing environmental conditions depends on organisms' metabolic resource management (the ability to sustain respiration), which varies among species. Thus, vulnerability to stress is also variable among species, which is a key aspect of ecosystem resilience. Namely, not all species are equally important or vulnerable; the loss of some species is more detrimental to the ecosystem than others. Therefore, to appropriately quantify long-term changes in species abundance, it is necessary to assess species' vulnerability to environmental stress. To my understanding, species-vulnerability information is excluded when using the relative AGI, habitability is estimated by a generic count. Thus, it is not clear that the “sense” of habitat changes with warming based on relative AGI is quantitatively meaningful beyond serving as an indicator for potentially hazardous and habitable regions under a warming climate.

For example, during environmental stress events like heat waves or cold spells, it is the extremes of the physiological trait space that matter most for the entire system's ecosystem response and survival. Although the authors mention some of these limitations, they remain quantitative. My main point can be summarized as follows: while relative AGI serves as a meaningful metric for understanding climate change's impact on marine ecosystems by integrating oxygen and temperature changes into a single ecosystem-relevant proxy, it may not be sufficient quantitatively as an indicator of changes in ecosystem abundance. Perhaps I'm missing something; please clarify.

Secondly, the authors repeatedly mention the advantages of AGI over the classical metabolic index proposed by Deutsch et al., citing differences in requirements for lab-based physiological data. However, this difference appears to stem from the application of relative AGI, which removes physiological constraints. I believe the metabolic index can also be applied in a similar manner by simplifying it to yield a relative metabolic index that eliminates physiological parameters. Thus, it is not clear how physiological requirement data differ between classical AGI and the metabolic index; perhaps I am missing something here again; please clarify.

Beyond these two points, the manuscript is well-written and would be an important contribution to the community.

Below are some minor and specific comments

This is a minor point, while I appreciate the application of adaptability in marine organisms, it would be helpful to briefly discuss how robust this adaptation methodology is (or discuss the limitations). While this time-based adaptation may as well reflect how marine species will develop resilience against warming stress, ecosystems often experience tipping points leading to significant habitat loss or gain; such changes can tip systems on short timescale when important species are lost or gained. Moreover, tipping point climate variability and extremes occur over much shorter timescales. I’m curious to how you think about this, it might be worth clarifying.

Line 25: Missing. Howard et al., 2019; Mongwe et al., 2024.

Line 50: This description is unclear and seems incomplete. Perhaps first define what AGI is or move this section to the methods where you can define things more clearly. At this stage, the text assumes the reader knows what AGI is, which is not a reasonable expectation. You only define AGI later in the text.

Line 165: Here you say that relative AGI gives a “sense of the direction and magnitude of habitability.” Maybe only the direction, but not the magnitude; it is not still clear to me that you can quantify change without information on organisms' physiological constraints as stated above. Maybe you can, please clarify.

Line 170: Once again, “AGI can be a poor indicator of which specific species thresholds are needed.” How do you make this distinction when this information is needed or not to make a good prediction? When you don’t include this information, how do you know the magnitudes of change are robust?

Line 219: This description is not clear; the text requires familiarity with Logan et al., 2014. I had to refer to Logan et al., 2014 to understand your point here. Perhaps rephrase and make it a bit clearer

References

Howard, E. M., Penn, J. L., Frenzel, H., Seibel, B. A., Bianchi, D., Renault, L., Kessouri, F., Sutula, M. A., Mcwilliams, J. C., and Deutsch, C.: Climate-driven aerobic habitat loss in the California Current System, Sci. Adv., 6, eaay3188, https://doi.org/10.1126/sciadv.aay3188, 2020.

Mongwe, P., Long, M., Ito, T., Deutsch, C., and Santana-Falcón, Y.: Climatic controls on metabolic constraints in the ocean, Biogeosciences, 21, 3477–3490, https://doi.org/10.5194/bg-21-3477-2024, 2024.