Author response to reviewer comments for https://doi.org/10.5194/esd-2023-35 "Assessment of warm-water coral reef tipping point thresholds"

We welcome the attention already received for this manuscript in terms of website views and social media posts. We hope that this positive attention demonstrates the value of this review.

Reviewer 1 comments:

COMMENT 1: The paper is a comprehensive and reasonable review article focused on coral reefs under local as well as global environmental changes, which would be valuable for researchers and managers in this field.

Author response: We thank the reviewer for this positive assessment.

COMMENT 2: However, While the paper describes the concept as a threshold characterized by non-linear hysteresis or cascading effects resulting from positive and negative feedback loops, it falls short in offering a systemic elucidation of why the outcome becomes synergistic rather than merely additional from the point of system science. To rectify this critical shortcoming, urgent measures should be taken to enhance the originality and academic contribution of this paper. Strongly recommended actions include incorporating more quantitative analyses or empirical evidence supporting the discussed concepts and delving deeper into the systemic dynamics driving the observed phenomena.

It was our intention to create a review article that summarises our current knowledge of tipping points thresholds and dynamics for warm-water coral reefs. We feel this is beyond the scope of this paper, would change the nature of the article and move it away from a focussed review. We have changed the title to emphasise that this is a review article.

Our primary intention is to convey the diversity of contributing stressors and the need to consider their impact significance in threat assessments, rather than the interaction directions and strengths. We have included a large amount of high level references that provide insight into the kind of interactive dynamics and outcome information the reviewer's referring to.

Our intention is not to labour the synergistic elements of interactions, rather to demonstrate there are many stressors that require investigation/consideration to provide any comprehensive assessment of coral reef futures. We do clearly state in the manuscript that robust interactive stressor considerations have yet to be sufficiently included in tipping point assessments. A key aim of our manuscript is to highlight important stressor considerations and to encourage their robust inclusion in assessment initiatives.

COMMENT 3: In conclusion, the lack of an effective explanation due to the absence of original data significantly undermines the academic value of this paper. Consequently, the paper, in its current state, is more suitable for publication in a general introduction book rather than an academic journal.

The catalyst and main reference base for this manuscript is the global tipping points report (Lenton 2003) and seeks to be a review informed by expert opinion. We leave it in the hands of the editors to decide on the merit of this work as a review article and its value in helping to advance this vitally important assessment area. We hope that the extensive revision of this manuscript that we are working on will largely address these comments.

COMMENT 4: Other specific comments:

- **Lines 111-116 are mostly repeated in lines 124-129.**

We have revised the manuscript to remove repetition and improve clarity.

- **Chapters 8. Pollution, 9. Disruption, and 10. Disease should have their threshold values shown.**

We have added threshold values for these and other stressors in the revised table, where there is information available. We have now included threshold values for all stressors except invasive / problem species.

- **Chapter 11. Crown-of-thorns seastar is not an invasive species; it is common in coral reefs, but its problem lies in its outbreak.**

We did not intend to suggest it was an invasive and the native predator context is made in the text but we will amend the section title (and Table 1 text) to better convey that both invasive and native 'problem' species are included in this section and ensure named species are correctly ascribed.

Reviewer 2 comments:

COMMENT 1

The paper reviews climate impacts on coral reefs to consider adjusting the tipping points for coral reefs. It is not clear until the conclusions that they are suggesting a further reduction in temperature thresholds from the original 1.5 estimates. There are many problems with this assessment that are briefly outlined below. Perhaps, the greatest is that it is a poor review of the literature in that it is out of date and selective citation of the literature. I only give a small number of papers that should be considered in a thorough and up-to-date review. The authors needs to do a systematic review of the recent literature and write a current status review that is more balanced, quantitative, and explains the decisions better.

We thank the reviewer for the suggestion of new articles. This is such an active area of research with new information coming out all the time, certainly since we submitted this manuscript. We are in the process of a substantial revision, including many new supporting references.

There is also the problem of the tipping point definition and how it is measured and if they are rates or states, what is the time scale of the change, what are the specific irreversible changes, and what are the confidence intervals around estimates. There are two recent reviews that summarises these problems well and would cause a reconsideration of the confidence in this new lower threshold.

We clearly state the IPCC tipping point definition and are using published values described by other authors as tipping points rather than creating new ones. In terms of timings, these values are in the context of ongoing climate change and the timescales of observed and predicted changes. We have chosen to include both rate and state related issues and have tried to clarify the text accordingly. All supportive references are provided to point the reader to their sources if further detail is required.

Klein, S. G., C. Roch, and C. M. Duarte. 2024. Systematic review of the uncertainty of coral reef futures under climate change. Nature Communications 15:2224.

McClanahan , T. R. 2022. Coral responses to climate change exposure. Environmental Research Letters 17:073001.

These references have been added to the revised manuscript.

Table 1 is the core finding of the paper but it still reads as poorly articulated draft. I would suggest the authors review the current literature, summarize it and present table 1 as a key element. Then, most of the text can focus on the evidence or lack of evidence for the conclusions in this table. The authors could conclude with what are the key unknowns required to better estimate the tipping points. Otherwise, the current draft is an uncritical, out of date, and selective citation review of a much richer, data intensive, and nuanced coral reef literature that should be used to make these important conclusions.

We have substantially revised Table 1 removing the interactions to another section of the manuscript to make this a clearer summary of published tipping points. We have updated references to try to bring this manuscript as up to date as is practically possible in line with the scope and intent of the manuscript.

Abstract

The abstract is diffciult to distinguish from similar conclusions of past work. It is not that clear or adding much to past work from my reading as the context of the works is missing.

The abstract has been revised (along with all the manuscript).

What a tipping point threshold is should be defined early, otherwise the text is mysterious. I assume this is an irreversible change but that often depends on the time scale of observation and what is being measured. Readers will want to know.

In addition to the tipping point threshold definition in the introduction section, we have now included a brief description in the abstract. These definitions are drawn from IPCC and the recent tipping points review.

Usually, a sentences on methods for assessing tipping points is required to understand the results. It should be stated that this is a review.

As stated above this is not presenting new analysis, we have amended the title, abstract and main text to make it clear that this is a review. Including methodologies for every stressor is beyond the scope of this work, but supporting references are provided in the table if readers wish to delve deeper into methods. We also highlight the importance of robust inclusion of stressor interactions and their combined significance in future assessments. Doing so will better enable individual and interacting stressor influences to be determined/constrained. We consider this to be an urgent message/communication remit of the manuscript.

The suggested tipping points seems similar to previous work, is it different and by how much? What would cause it to change.

This review will necessarily tread ground that others have already covered, our objective here is to bring a wide range of information into a single document. We believe this is a useful exercise that may be of value for future assessment efforts. The outcome of the global tipping points review

indicated that assessments of tipping points need further consideration so they could change in the light of ongoing & further robust analysis. In particular we highlight the importance of including the wider range of stressor considerations detailed in the manuscript.

What are the uncertainties. How were they addressed?

The revised text delves further into uncertainties around the published thresholds and stressor interactions and it is part of the purpose of this work to encourage others to explore these uncertainties further and in the meantime apply precautionary principles to their approach.

Introduction

It is important to distinguish states from rates. Rates determine states but this is not clear and confused as written. The states are also vague, is is coral cover, calcification, ecological state and integrity, biodiversity, etc?

The text has been significantly re-written to convey the significance of both rates (of change) and states (i.e. currently observed values) and provide more information on each to help draw out the relevancy of both.

There is a much larger literature than is being cited here and the introduction seems to out of date given the many recent meta-analyses and reviews. I would suggest the authors look closer at the literature in the past 5 years and mostly cite these large data compilation studies. Much is being learned and it is not always in line with the general consensus that is being expressed in this paper. These are just a few examples that come to mind.

We have substantially revised the text to incorporate more references (see comments above), including those kindly provided by the reviewer.

It is worth remembering that permanent reversal and large scale changes is not just due to climate but also overfishing on large scales. These have been shown to have tipping points and large scale changes. Here is a recent meta-analysis paper.

McClanahan, T. R., A. M. Friedlander, L. Wantiez, N. A. J. Graham, J. H. Bruggemann, P. Chabanet, and R. M. Oddenyo. 2022. Best-practice fisheries management associated with reduced stocks and changes in life histories. Fish and Fisheries 23:422 - 444.

We highlight the importance of non-climate change stressor impacts and thank the reviewer for the reference, we note that this paper does not include any explicit definition of tipping point or threshold values. We include a section on "disruption" that includes fishing impacts and will include this reference therein.

P103 – this threshold is not being well supported by recent studies. There are many large studies that do not find this to be very useful. Here is just one.

DeCarlo, T. M. 2020. Treating coral bleaching as weather: A framework to validate and optimize prediction skill. PeerJ 8:e9449.

While we recognise there is some conflicting opinion over the significance of ocean warming and heatwaves, we believe the statement that global heating is a main driver of coral declines is well supported by current research (independent of any particular threshold).

If you are going to cite papers that use these threshold models, perhaps other approaches and findings should be cited as well. Low oxygen has been shown to be associated with higher coral cover, so the theory here is not supported empiricallly.

Vercammen, A., J. McGowan, A. T. Knight, S. Pardede, E. Muttaqin, J. Harris, G. Ahmadia, Estradivari., T. Dallison, E. Selig, and M. Beger. 2019. Evaluating the impact of accounting for coral cover in large-scale marine conservation prioritizations. Diversity and Distributions 25:1564-1574.

McClanahan, T. R., and M. K. Azali. 2021. Environmental variability and threshold model's predictions for coral reefs. Frontiers in Marine Science 8:1774.

We agree that dissolved oxygen is a critical factor for coral reefs, and the Vercammen et al. 2019 and McClanahan & Azali 2021 papers confirmed that with their analysis of the Bio-ORACLE database. We maintain that (1) oxygen can become limiting for corals, (2) that oxygen limitation can affect diversity and cover, and (3) that oxygen limitation will be observed below a threshold or critical value where corals are no longer able to maintain metabolic homeostasis (commonly <1-2 ml/l) (e.g., Altieri et al. 2017, Johnson et al. 2021).

The range of dissolved oxygen values observed in McClanahan & Azali 2021 are ~4.35-4.85 ml/l (figure 2) which are concentrations well above levels found to be limiting in experimental trials and field observations with corals. The information available in the Vercammen et al. 2019 paper and online supporting information were not adequate to determine the values included in their analysis, but based on the WOD09 data availability and their interpolation across available data points, they are likely to have integrated spatially and temporally in such a way that would miss the extreme values (i.e., below critical thresholds) associated with deoxygenation events that can be detrimental to coral cover and diversity.

The relationship between dissolved oxygen and hard coral is both positive and negative in McClanahan & Azali 2021 depending on the interval of oxygen values within the relatively narrow range presented in fig 2. There is insufficient information presented in Vercammen et al. 2019 to determine whether the relationship is negative, positive, or both – only that there is a significant relationship.

So there does not appear to be sufficient evidence that low oxygen (<1-2 ml/l) is associated with high coral cover. Further, it should be noted that oxygen CAN be a limiting factor for corals below certain thresholds, but that at higher ranges it could likely be serving as a proxy for other factors related to ecosystem metabolism (e.g., carbon dioxide, pH, photosynthesis), or could be limiting for other organisms that interact with corals (e.g., corallivores) even though it is not limiting for the corals, or a product of the abundance of primary producers that influence coral abundance and health. And so the relationship between oxygen concentration and coral abundance and diversity likely requires additional ecological and scale-dependent information for proper interpretation.

Altieri, A.H., Harrison, S.B., Seemann, J., Collin, R., Diaz, R.J. and Knowlton, N., 2017. Tropical dead zones and mass mortalities on coral reefs. Proceedings of the National Academy of Sciences, 114(14), pp.3660-3665.

Johnson, M.D., Swaminathan, S.D., Nixon, E.N., Paul, V.J. and Altieri, A.H., 2021. Differential susceptibility of reef-building corals to deoxygenation reveals remarkable hypoxia tolerance. Scientific Reports, 11(1), p.23168.

There is a view that sea level rise will increase calcification but this was largely developed before the views of coral mortality.

We thank the reviewer for this comment. We believe this relates to the potential increase in habitat availability in certain circumstances, which we reference in the current manuscript where we consider the antagonistic and other interactions of sea level rise with other factors. We will keep these comments in mind as we revise the section on sea level rise.

There are also the sediments and seabird studies that show increased nutrients improve reef condition and resilience.

Graham, N. A., S. K. Wilson, P. Carr, A. S. Hoey, S. Jennings, and M. A. MacNeil. 2018. Seabirds enhance coral reef productivity and functioning in the absence of invasive rats. Nature 559:250.

MacNeil, M. A., C. Mellin, S. Matthews, N. H. Wolff, T. R. McClanahan, M. Devlin, C. Drovandi, K. Mengersen, and N. A. J. Graham. 2019. Water quality mediates resilience on the Great Barrier Reef. Nature Ecology & Evolution 3:620.

We thank the reviewer and will investigate this further and ensure it is captured in the appropriate section. We note here that the current biodiversity crisis extends beyond corals to include seabird declines that may negatively impact coral reefs.

L353 – the authors should give the reasoning for lowering the thresholds not just cite papers. The recent review by Klein et al 2024 indicate that lack of confidence intervals around thresholds.

We provide verbatim reasoning for the thermal and CO_2 thresholds derived from the conclusions of the global tipping point revision (Lenton et al 2023). We also provide ranges for thresholds where these are available. We also address confidence considerations, including the rationale for better inclusion of interacting stressors in the assessment process and the need to adopt a precautionary approach when considering confidence uncertainties. We consider these to be important messages of the manuscript.

Much of table 1 is out of date. However, they do cite Veron et al. 2029 to compensate for this problem. I look forward to reading it in 5 years. Authors should know the literature and how to organize and write a review and subsequently submit a more polished paper.

We have updated our references and have corrected typographic errors. Please also refer to our table related replies above.

□