Author’s response for comments of referees and Associate Editor

Comments of referee #1

Throughout the paper, and especially in Section 3.3, you use the term ‘correlated’, and yet I can see no correlation analysis or test of correlation (e.g. Pearson/ Spearman/ Kendall coefficient of determination). In a sense, such an attempt to fit a straight line would be pointless because the number of points is small, and you are claiming the correlation is with the magnitude of the temperature shift, not its direction, so some are negative, some positive. I guess one could make all temperature shifts positive and then do a line-fit and Pearson r2. But you’d have to factor in reasonable error terms on both estimated temperature anomalies and estimated extinction magnitudes, and these errors might be larger than the 5% you suggest.

But, I’m not sure you should use the word ‘correlated’ if that has not been tested – just refer to a positive relationship…

Author replies for comments of referee #1

Words highlighted by light blue, green, and yellow have been revised in the manuscript marked-up.

Light blue: for referee #1

Green: mainly for referee #2

Yellow: for Associate Editor, duration of climate changes, and the others

Thank you for your comments.

I added Pearson’s correlation coefficient *R* between marine extinction % and absolute SST anomaly (*R* = 0.92–0.95 for genera) and that between terrestrial extinction % and absolute land temperature anomaly (*R* = 0.95 for genera) marked by light blue. I added Table 3 to show Pearson’s correlation coefficient *R*.

I use “correlated” as “corresponding to”. I revised “correlate” to “correspond to” marked by light blue.

I revised “good correlation” to ”significant relationship” marked by light blue.

To show difference of extinction % in cooling and warming cases, I revised the following sentence in Abstract and Conclusions (yellow highlighted parts are revised).

The loss of more than 35 % of marine genera and 60 % of marine species loss corresponding to major mass extinctions so called “big five” correlate with a > 7 °C global cooling and a 7–9 °C global warming for marine animals, and a > 7 °C global cooling and a > ~7 °C global warming for terrestrial tetrapods, accompanied with ± 1 °C error in the temperature anomalies as the global average, although number of terrestrial data is small.

I revised marine genera and species loss % highlighted by yellow in 3.3 because I added Sepkoski data.

I revised the climate change at the F–F crisis from warming to cooling, because warming occurred longer term between the two crises, the Lower Kellwasser and the Upper Kellwasser crises, and shorter-term global cooling episodes separately occurred in the two crises (lines 183-186, 228-231, Figures 2, 3, Tables 1, 3).

Minor changes

Line 142: marking the end of the Paleozoic [not Mesozoic]! Done

Line 163: crises = crisis Done

Line 192: O-S; H-A – add to explanations in caption. I revised "O–S" in Figure 3 to end-O, which is the same as the other figures. In the caption, I added "H–A: Holocene–Anthropocene." in the caption.

Kunio Kaiho

Comments of referee #2

Comment 1

1. The novelty of this study has not been established. The MS says 'relationships between... physical conditions and the magnitude of animal extinctions have not been quantitatively evaluated. My analyses show that the magnitude of major extinctions in marine invertebrates and that of terrestrial tetrapods correlate well with the coincidental anomaly of global and habitat surface temperatures during biotic crises,'. However, it is not accurate that this has not been previously quantitatively evaluated. In particular, Song et al 2021 (Nature Communications) has also published a quantitative analysis of extinction magnitude and temperature change which appears to show, with a larger, statistical analysis, similar conclusions to those stated here (there is also a relevant response paper McPherson et al. 2022 Results in Engineering). E.g. Song et al 2021, which is omitted from the citations of the submitted MS, already concluded, 'The results

show that both the rate and magnitude of temperature change are significantly positively correlated with the extinction rate of marine animals.' There is also a branch of the literature considering specifically the correlations and potential periodicity of extinction and bolide impacts. I believe the author of the current MS needs to explain and adequately justify what it is about their findings that is novel with regard to the recent literature for publication to be considered.

Author replies for Comment 1

Words highlighted by light blue, green, and yellow have been revised in the manuscript.
Light blue: for referee #1
Green: mainly for referee #2
Yellow: for Associate Editor, duration of climate changes, and the others

Thank you for your important comments. For your comment 1, I added results of Song et al 2021 (Nature Communications) and McPherson et al. 2022 in Introduction and Discussion. Song et al 2021 show a good relationship (R = 0.63) between temperature change and marine extinction rate. The novelty of my study is (i) a significant relationship between temperature change and terrestrial tetrapod extinction magnitude (correlation coefficient R = 0.95 for genus and 0.98 for species); (ii) a significant relationship between marine and terrestrial extinction magnitude and the global and habitat [marine or terrestrial realm] surface temperature anomalies; (iii) comparison of marine invertebrate and terrestrial tetrapod response for temperature change and explanation of the different extinction magnitudes; (iv) usage of only data having coincidence of mass extinctions and temperature changes in the same outcrop of marine sedimentary rocks resulting in higher relationship (R = 0.92 and 0.95 for genus and 0.88 and 0.95 for species under comparable data for terrestrial tetrapod extinction magnitude) between temperature change and marine extinction magnitude than that of Song et al 2021 (R = 0.63), as described in the first paragraph of Discussion. Using these findings lead to the other novelty, which is "The Anthropogenic future extinction magnitude will not reach the major mass extinction magnitude, when the Anthropogenic future extinction magnitude will be parallel to global surface temperature anomaly" which has been added in Abstract and Conclusions. This differs from Song et al 2021.

I added "Although Song et al. (2021) claimed that a temperature increase of 5.2 °C above the pre-industrial level at present rates of increase would likely result in mass extinction comparable to that of the major Phanerozoic events, regardless of other, non-climatic anthropogenic changes that negatively affect animal life; the temperature increase is not 5.2 °C, but 9 °C. The 9 °C global warming will not appear in the Anthropocene at least till 2500 under the worst scenario

(*IPCC, 2013*; IUCN 2021; Tebaldi, et al., 2021). Prediction of the Anthropogenic future extinction magnitude using only surface temperature is difficult, because the causes of the anthropogenic extinction differ from causes of mass extinctions in geologic time. However, I can predict that the Anthropogenic future extinction magnitude will not reach the major mass extinction magnitude, when the Anthropogenic future extinction magnitude parallelly changes to global surface temperature anomaly." at the end of Discussion.

Comment 2

2. Table 1 shows that the submitted study is based on secondary data compiled from the references indicated there, covering a small sample of 7 geological boundaries. However, it has not been adequately demonstrated that these secondary data are directly comparable. E.g. There are a range of different methods available for calculating extinction magnitudes and it has not been demonstrated that the compiled data use comparable measures e.g. interval lengths, precise choice of numerator and denominator etc. An analogous point also applies to the temperature proxy data.

Author replies for Comment 2

I use the conventional method (total number of extinction genera for a mass extinction interval / total number of genera in a substage just before the extinction) to calculate genera extinction % of terrestrial tetrapods in all crises studied and marine genera extinction % of the end-Guadalupian crisis, because those data fit to this method but not for a new method of Stanley (2016). Marine genera extinction % data of Sepkoski (1996) and Bambach (2006) correspond to the conventional method. The substage intervals are more similar to those of Bambach (2006). Therefore, I used those extinction % data based on the conventional method to compare marine animal extinction % with terrestrial tetrapod extinction % for the seven biotic crises. I added these in the manuscript (lines 79-81, 168-169, 251-253, 289-292 highlighted by green). I added Table 3.

Comment 3

3. There is apparently no statistical analysis provided to test the presented results or conclusions. Furthermore, there is a small sample size of 7 geological boundaries indicated in Table 1, with only 2 events outside the traditional big 5 extinctions. In contrast, for example Song et al 2021 and Fan et al 2020 (Science) have published large statistical analyses, of consistent datasets covering complete series of extinction

magnitudes (not hand-selected examples), to test correlations between extinction and environmental proxies.

Author replies for Comment 3

I added Pearson's correlation coefficient *R* between marine extinction % and absolute SST anomaly ($R = 0.92–0.95$ for genera) and that between terrestrial extinction % and absolute land temperature anomaly ($R = 0.95$ for genera) marked by light blue. I added Table 3 to show Pearson's correlation coefficient *R*. These results are shown in Abstract, Results, Discussion, and Conclusions marked by light blue.

Although Song et al. (2021) analyzed all data of extinctions and sea surface temperature (SST) changes, there are no confirmation of exact coincidence between extinction rate and temperature change for minor extinctions. I use only data showing coincidence of marine extinction horizons and temperature changes in the same outcrop of marine sedimentary rocks to reach the truth on relationships between extinction magnitude and surface temperature change in each biotic crisis. Therefore, I analyze the six mass extinctions and the modern extinction, which coincided with global climate changes. Explanation on statistical analysis is the same as the reply for comment 2. I added these in the manuscript (lines 36-38, 43-44, 292-297 marked by green and yellow).

Comment 4

4. There is currently inadequate consideration of potential effects of sampling bias on measures such as % extinction. This issue does not appear to be discussed at all despite its considerable importance in this research area. See for example, Alroy (2014 Paleobiology).

Author replies for Comment 4

For consideration of potential effects of sampling bias, I separated data of marine taxa extinction % into three data sets; one is a data group calculated by Sepkoski (1996) with low extinction values (0–5 %) of G–L and H–A, second one is Bambach (2016) with the low extinction values, and the third one is Stanley (2016) based on a new method with the low extinction values, because low extinction values do not change largely based on different methods (marked by three types of blue circles in Figure 3). I compared the data based on the conventional methods [Sepkoski (1996) and Bambach (2016) for marine animals, data calculated from Benton (2013) and Sahney and Benton (2017) for terrestrial tetrapods] for both marine and terrestrial to get the conclusions.

Even when I use the other data set based on the new method of marine animals (incomparable data sets for terrestrial data), the figure shows the same conclusions. This confirms the conclusions. I added these in the manuscript (lines 79-83, 131-134, 168-169, 239-242, 289-295 marked by green and light blue).

I revised the climate change at the F–F crisis from warming to cooling, because warming occurred longer term between the two crises, the Lower Kellwasser and the Upper Kellwasser crises, and shorter-term global cooling episodes separately occurred in the two crises (lines 183-186, 228-231, Figures 2, 3, Tables 1, 3).

Kunio Kaiho

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25 May 2022

Associate Editor decision: Reconsider after major revisions

by Petr Kuneš

Comments to the author:

Thank you for performing the major revision and following the reviewers' comments. After evaluating your revision, I am not entirely satisfied with addressing all the issues.

In particular, I believe that the introduction needs more clarification and justification as to why your work would bring novel insights into the climate-extinction relationship.

Author reply:

Words highlighted by light blue, green, and yellow have been revised in the manuscript.

Light blue: for referee #1

Green: mainly for referee #2

Yellow: for Associate Editor, duration of climate changes, and the others

Thank you for your comments. I agree with your comments and added some words and sentences. The novel insights are clarifying of similarity and difference in response of terrestrial tetrapods and marine animals for global surface temperature and habitat (land and sea) temperature changes using only biotic crises having coincidental abrupt surface temperature anomaly (major five mass extinctions and end-Guadalupian). I added "--- using only biotic crises coinciding with abrupt climate changes, to access similarity and difference in response of terrestrial and marine animals for global and habitat (land and sea) temperature anomalies and coincidental environmental changes.

Song et al. (2021) claimed that a temperature increase of 5.2 °C above the pre-industrial level at present rates of increase would likely result in mass extinction comparable to that of the major Phanerozoic events, regardless of other, non-climatic anthropogenic changes that negatively affect animal life. The 5.2 °C is not a global surface temperature anomaly but a sea surface temperature (SST) anomaly. The global surface temperature anomaly is much higher than 5.2 °C. Fig. 1d shows the conversion between the global surface temperature anomaly, land-surface temperature anomaly (global mean), and SST anomaly (global mean) to access global and habitat (land and sea) temperature anomalies in each biotic crisis. I reached different conclusions on the surface temperature anomaly and the prediction for the future extinction magnitude for the conclusions of Song et al. (2021)." in the final part of Introduction. I revised a conclusion of Song et al. (2021) at the end of the sections 4.1 and 4.2 (lines 397-302, 347-355). I added "The Anthropogenic future extinction magnitude will not reach the major mass extinction magnitude, when the extinction magnitude parallelly changes with global surface temperature anomaly." at the end of Abstract and Conclusions.

It requires a more extended overview of previous studies and their finding, not just mentioning in one sentence (such as Song et al. 2021), and their fitting into a more general context, which would be better understandable for the reader (perhaps by using some of the text you added to the next chapter).

Author reply: I added the following sentences in Introduction.

On the modern Earth, an ongoing species extinction occurred mainly on land rather than the sea (Barnosky et al., 2011). A study on thermal tolerance of modern animals shows a higher sensitivity of marine animals to warming than terrestrial animals (Pinsky et al., 2019). However, whether this relationship holds true for ancient animals has not yet clarified. ------ Song et al. (2021) claimed that a temperature increase of 5.2 °C above the pre-industrial level at present rates of increase would likely result in mass extinction comparable to that of the major Phanerozoic events, regardless of other, non-climatic anthropogenic changes that negatively affect animal life. The 5.2 °C is not a global surface temperature anomaly but a sea surface temperature (SST) anomaly. The global surface temperature anomaly is much higher than 5.2 °C. Fig. 1d shows the conversion between the global surface temperature anomaly, land-surface temperature anomaly (global mean), and SST anomaly (global mean) to access global and habitat (land and sea) temperature anomalies in each biotic crisis. I reached different conclusions on the surface temperature anomaly and the prediction for the future extinction magnitude for the conclusions of Song et al. (2021)."

Please explain better why you aimed to clarify the relationship and why it is so important to repeat that! Moreover, the last sentence in the introduction should be better explained concerning the previous content.

Author reply: I moved the last sentence to the above paragraph, and added new sentences in the introduction to show why I aimed to clarify the relationship (lines 45-51). “On the modern Earth, an ongoing species extinction occurred mainly on land rather than the sea (Barnosky et al., 2011). A study on thermal tolerance of modern animals shows a higher sensitivity of marine animals to warming than terrestrial animals (Pinsky et al., 2019). However, whether this relationship holds true for ancient animals has not yet clarified. I aimed to clarify the relationship between the magnitude of biotic crises in not only marine invertebrates but also terrestrial vertebrates (tetrapods) and the global and habitat [marine or terrestrial realm] surface temperature anomalies using only biotic crises coinciding with abrupt climate changes, to access similarity and difference in response of terrestrial and marine animals for global and habitat (land and sea) temperature anomalies and coincidental environmental changes.”

I added “The Anthropogenic future extinction magnitude will not reach the major mass extinction magnitude, when the extinction magnitude parallelly changes with global surface temperature anomaly.” in Abstract and Conclusions; “However, I can predict that the Anthropogenic future extinction magnitude will not reach the major mass extinction magnitude, when the Anthropogenic future extinction magnitude parallelly changes to global surface temperature anomaly.” at the end of Discussion.

Please, do not mix methods with discussion. I think that all the arguments to support your results should be moved to discussion, e.g., line 63-66.

Author reply: I moved the sentences to the second paragraph of discussion 4.1.

Chapter 2.3 - please provide in more detail what kind of analysis did you use to calculate the correlation? Is it Pearson or something else? How did you text the significance? And change it throughout the text.

Author reply: I used Pearson (the results are same as those by Correl). I wrote it in Methods 2.3 and Table 3. The significance of the correlation is very high correlation (0.92-0.95 in marine genera compared with 0.63 in marine genera of Song et al.) between temperature and extinction magnitude in land and sea. I wrote this in abstract, discussion 4.1, and conclusions.

In the first paragraph of the discussion, you should better highlight the novelty of your results.

Author reply: I exchange the first and second paragraph of 4.1, and revised the sentences to show novelty of my results [(I)–(IV)] in 4.1.

The other novelty is the additional sentences "Although Song et al. (2021) claimed that a temperature increase of 5.2 °C above the pre-industrial level at present rates of increase would likely result in mass extinction comparable to that of the major Phanerozoic events, regardless of other, non-climatic anthropogenic changes that negatively affect animal life; the temperature increase is not 5.2 °C, but 9 °C. The 9 °C global warming will not appear in the Anthropocene at least till 2500 under the worst scenario (IPCC, 2013; IUCN 2021; Tebaldi, et al., 2021). Prediction of the Anthropogenic future extinction magnitude using only surface temperature is difficult, because the causes of the anthropogenic extinction differ from causes of mass extinctions in geologic time. However, I can predict that the Anthropogenic future extinction magnitude will not reach the major mass extinction magnitude, when the Anthropogenic future extinction magnitude parallelly changes to global surface temperature anomaly." at the end of Discussion.

The last sentence reads like a speculation, do you have any better explanation for that supported by your or other data?

Author reply: I revised it to "The correlation coefficient of Song et al. (2021) is much lower (R = 0.63 for genus), which is likely due to the low correlation in low extinction rates. It is likely due to the lack of sensitivity of marine animals for small temperature change or the usage of an uncertain coincidence with global climate changes." (lines 295–397).

Kunio Kaiho