Author's response for comments of referees

*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*

Thank you for your comments.

I added 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) in lines 113-117, 220-223, 240-241, 244-249, 330-332 marked by light blue and green, Table 3 and Figure 3. I added Table 3.

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).

More than 35 % of marine genera and 60 % of marine species loss correlate to > 7 ° C global cooling and > 9 ° C global warming.

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

The ETME correlated with 43 % and 70 % marine genera and species loss and 41 % and 70 % terrestrial tetrapod genera and species loss, respectively, and the KPME correlated with 39–40 % and 68 % marine genera and species loss and 39 % and 67% terrestrial tetrapod genera and species loss, respectively (Figs. 3a, d).

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 167-169, 211-212, 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.

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: duration of climate changes and the others

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*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*

Thank you for your important comments. For your comment 1, I added results of Song et al 2021 (Nature Communications) in the text (lines 33-34, 43-46, 247-249, 261-265 highlighted by green). I used McPherson et al. 2022 in the text (lines 30, 277-279 marked by green). 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 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. I added these in the manuscript (lines 220-223, 245-247, 324-326, marked by light blue and green). The novelty has already been written in Abstract and Conclusions.

*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 59-66, 113-117, 151-152, 233-238, 245-247, 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*

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 43-48, 245-249, 261-265, marked by green).

*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 four 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 59-66, 114-117, 151-152, 222-225, 245-247 marked by green and light blue).

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: duration of climate changes and the others
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 167-169, 211-212, Figures 2, 3, Tables 1, 3).

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03 May 2022

**Associate Editor decision: Reconsider after major revisions**

by Petr Kuneš

**Comments to the author**:

Thank you for your detailed replies to both reviews. They identified serious issues with the scientific significance and novelty of the paper as well as the quality of presentation of the outcomes.

I invite you to undertake a major revision of your manuscript, after which it will be considered again. Please focus especially on the issues raised by reviewer two regarding scientific novelty, presentation of results, statistical evaluation of your data, including sampling bias.

I have revised on them as explained in the above replies.

Kunio Kaiho