Kaiho “Future diversity and lifespan of metazoans under global warming and oxygen depletion”

General comments

This manuscript presents a novel and comprehensive model that predicts the lifespan of metazoans on Earth over the next 1.5 billion years. It combines a wide range of geological, climate, and biological data to create a compelling narrative about the long-term future of complex life. The main conclusion—that metazoans will go extinct in approximately 700 million years, much earlier than previous estimates—is a significant and provocative contribution. However, given the immense timescale and the complexity of the integrated model, it is essential to carefully present assumptions, uncertainties, and limitations to address skeptical readers convincingly.

This is a potentially high-impact manuscript that aligns well with the scope of this journal. Its bold projections are its main strength. To maximize its impact and increase the chances of publication, the authors need to strengthen the presentation regarding the treatment of uncertainty and provide more robust justifications for the key parameters that drive the model. By doing so, they can turn a compelling thought experiment into a foundational and highly cited piece of future Earth system science. I put specific comments about each section below.

Specific comments

[introduction]

While the author currently identifies several individual gaps, such as cyclical rhythms “ (L. 40), have not yet been fully incorporated, and abrupt events “ (L. 46) have not yet been factored in,” this can feel somewhat fragmented; they could be woven together to create a single, compelling argument for why your study is necessary. The author can reframe the problem to highlight the interaction of multi-timescale forcings as the central, unexplored challenge. I recommend adding a concise, overarching problem statement just before your final thesis paragraph (L. 48). Moreover, the final paragraph should then directly answer this problem statement. The list of seven critical factors is comprehensive, but the paragraph's impact will be greater if it highlights the integrative model itself as the core novelty.

The transitions between the main ideas, such as long-term trends, cycles, and abrupt events, can be made smoother, and the link between physical forcings and biological impacts can be clarified. A key conceptual point is the difference between predictable cycles and unpredictable events. Strengthen this transition by adding a sentence that clearly contrasts their timescales. For example, at the end of the cycles paragraph: “...have not yet been fully incorporated into projections of future surface temperatures. Beyond these predictable, multi-million-year cycles, Earth's climate is also punctuated by unpredictable, abrupt events...” Then, the author briefly explains how physical drivers influence biological outcomes modeled in the system. Regarding Tectonic Cycles, the author adds a phrase on how these cycles might influence plant crises or metazoan survival (e.g., through changes in continental configuration that affect weathering rates or create or eliminate refugia). Additionally, regarding abrupt events, the author can include a sentence explaining that these events are modeled as drivers of "step-changes" in biodiversity, which can reset recovery trajectories.

The author can enhance clarity and scientific rigor by refining specific sentences. The sentence "Global warming will accelerate terrestrial weathering..." serves as a key link. The author should add a few words to clarify how the mechanism works, which would add depth. In the final paragraph, the sentence "Projections are based on temperature modeling, thermal tolerance limits..." appears to preview the Methods section. Therefore, the author can rephrase it as, “Our model projections combine future scenarios of temperature and oxygen levels with established data on metazoan thermal tolerance and diversity trends.”

The final two paragraphs contain some repetitive information and could be merged to create a more powerful and concise conclusion to the introduction. The author can integrate the description of metazoan evolution and thermal tolerance into the core thesis paragraph. This creates a single, strong paragraph that states what you did, what you based it on, and the scope of your analysis.

[**Methods: 2.1**]

The statement "Assuming that the icehouse-greenhouse cycle and major mass extinctions continue at the same pace as in the past" (L. 66) is a significant assumption that is central to your model. This requires a brief justification. Is there a reference supporting the consistency of these cycles over billion-year timescales? A sentence citing relevant geological timescale studies would greatly strengthen this.

The method assumes that the relationships between temperature/O_2 and biodiversity observed in the deep past will also apply to the entire future of complex life. This core assumption should be clearly acknowledged as a potential limitation or justified with a solid rationale.

Although the author mentions specific groups later, the term "metazoan extinction" (L. 72) in point 3 is quite broad. It would be helpful to clarify early on that your study focuses on the specific groups listed —marine metazoans, terrestrial tetrapods, and insects —as proxies for overall metazoan diversity.

The nature of these abrupt large-scale future climate events (Events 1-16; L. 81 and 83) remains unclear. Are they modeled as analogues to the Big Five? Are they stochastic events? A brief explanation of how these were defined and selected would be very helpful.

The phrase "framework that includes temperature trends, oxygen levels, and C_3-C_4 plant crises" (L. 78-79) is too general. The author needs to describe the actual model. Is it a statistical correlation? A dynamic system model? A set of conditional rules? Then, C_3-C_4 plant crises (L. 79) are mentioned but are not introduced earlier. The author should briefly explain what this crisis involves and why it is a factor in your model.

Regarding methodological precision, the author used "compiled records (L. 63)" and "analyzed the relationship (L. 64)," but should specify the particular statistical methods, such as correlation analysis and regression modeling. At point 3 (L. 69~), the transition from "local extinction temperature" to "global average surface temperature" at which extinction occurs is a crucial scaling step. This process should be clearly explained in the detailed methods (2.6), and the summary should hint at its complexity (e.g., "...was scaled to a global average surface temperature using latitudinal gradients"). Finally, in the last paragraph (L. 85~), the sentences about gradual extinctions (orange curve) and the estimated durations (0 Gyr and 0.05 Gyr) seem somewhat out of place in the method summary. They are better suited for the Results section or a dedicated part of the detailed methods. The "0 Gyr" duration for temperature anomalies is confusing and needs clarification.

Revised first paragraph:

To project the future lifespan of metazoans on Earth, we developed a multi-step model that integrates relationships derived from past climate and biodiversity dynamics. Our core assumption is that the pacing of icehouse-greenhouse cycles (~0.3 Gyr) and major mass extinctions (~0.094 Gyr), along with the physiological constraints on metazoans, will remain consistent in the future [references, if possible]. The analysis proceeded as follows:

1. Past Climate and Diversity Baselines: -- correspond to subsection 2.2
2. Future Temperature Projections: -- correspond to subsection 2.3
3. Metazoan Thermal Tolerance Limits: -- correspond to subsection 2.4
4. Oxygen-Biodiversity Relationship: -- corresponds to subsection 2.5
5. Integrated Future Diversity Model: -- corresponds to subsection 2.6

The paragraph about five past events, 16 events, and gradual extinctions (L. 81-88) could be moved or integrated into points 2 and 5 above for better flow.

To maintain consistency across subsections, the author should verify that the titles of subsections 2.2 through 2.6 directly correspond to points 1 through 5 in the Method summary and expand on them. For example, 2.2 should include a detailed methodology for point 1, “Past Records.” Therefore, if possible, the author should either revise the outline based on your Method summary or revise the Method summary itself.

The subsections (2.2 to 2.6 (or 2.7)) must flesh out the details summarized in 2.1. For each step, the author needs to specify: About data sources, the author mentions specific databases or publications, and provides tables (e.g., Tables A1 and A2). About analytical techniques, how did the author analyze the relationship? Was it a linear regression? A non-linear model? Specify the statistical tests and the software/tools used. About Quantitative Definitions, what are the numerical thresholds for "low, mid, and high latitudes"? What defines a "C_3-C_4 plant crisis" in your model? Define these operationally. Model Parameters: The values "0.3 Gyr" and "0.094 Gyr" are key model inputs. Justify these choices with references beyond the general (Erwin et al., 1987). How sensitive are your results to these specific values?

[**Methods: 2.2**]

The issue with this section is the jump from describing the data to stating the objective. The sentence “To estimate future abrupt climate changes and biotic crises, we selected the five largest mass extinctions...” (L. 91-92) is an objective, not a method. Thus, the author should restructure the text to first present the data and then explain the analytical step.

The author also needs to provide a more detailed explanation of how they selected and used these “five major mass extinctions.” This clarifies the reason for choosing specific events and helps ensure the methodology can be reproduced.

The author mentions two different types of data: 1) long-term climate cycles (icehouse-greenhouse) and 2) short-term temperature anomalies during extinction events, but the connection between them is not explained. Please briefly explain the role of each dataset in your overall model.

The final sentence (L. 95), “These data are applied in section 2.2,” is redundant as it is already within section 2.2.

[**Methods: 2.3**]

The paragraph (L. 97-L. 104) states that “marine metazoan diversity rates” were “derived from past records,” but it does not provide a source for these diversity rates, only for the oxygen levels. This creates a notable gap in reproducibility. The author must provide the reference(s) for your biodiversity data.

What does a "diversity rate" of 0.04 or 1.0 actually mean? Is it a count of families or genera normalized to a maximum value? Is it an estimated measure of richness? Without a clear operational definition, the metric remains ambiguous. Please provide a brief explanation of how the calculation is performed.

The second paragraph (L. 105-108) is mostly interpretative. Phrases such as “suggests that there is a positive relationship,” “significant declines,” and “appear to require higher oxygen levels” are conclusions based on the data. Remove the entire second paragraph from the Methods section. These should be moved to your Results section (to show the relationship) and the Discussion section (to discuss the possible reasons).

The final sentence (L.108), “These interpretations are further applied in Section 2.4,” should be rephrased to emphasize the data and relationship, not the interpretation. The author should rephrase it to something like, “The quantitative relationship between O_2 and biodiversity established here (Figure 3) is used in Section 2.4 to describe the specific action, such as constraining future diversity projections based on predicted oxygen levels.”

[**Methods: 2.4**]

Averaging percentages from different extinction events, which had vastly different causes and selective pressures, into a single "future diversity loss" value is a highly simplified modeling choice. The author should justify why this is a valid approach for long-term projection. Please add a sentence or two explaining the rationale. The author should also acknowledge the limitations of this approach.

The author lists five events for marine metazoans but only three for tetrapods and insects. Why is there a discrepancy? Is the author averaging five events for the marine group and three for the terrestrial group? This needs to be clarified.

The subsection is titled “Past and future extinction percentages and the interval,” but the content does not mention any time interval. The 0.094 Gyr extinction cycle from your initial summary is a crucial parameter. This is where to define it. The author includes the methodology for the interval here.

[**Methods: 2.5**]

The first paragraph (L. 120-123) doesn’t serve well as an introduction to this section because the framework for temperature estimation is unclear. Additionally, the section reads more like a collection of individual sub-models rather than a coherent methodology. The most significant gap is clarifying how the mass extinction events are timed and situated within the 2.5 Gyr timeline. Are they periodic, random, or triggered by a specific threshold? This is a key factor affecting the results and remains undefined.

Several critical numbers and equations in this Section are presented without explanation, making it impossible for a reader to evaluate or reproduce your work:

1) Why is there an 8°C temperature difference between the icehouse and greenhouse periods? (L. 129) Bond and Grasby (2017) are probably insufficient because their study focuses on specific events. Using a single value over 2.5 Gyr is a big oversimplification that needs strong justification. Therefore, the author should provide a brief context.

2) These equations (L.156-161) are the core of your event-based temperature calculation, but they are presented as a “black box.” Where do the constants, such as -8.9, 9.9, 2/3, 9.9, 0.00108 …, originate from? The author cites Kaiho et al. (2022), but it is unclear whether these are empirically derived relationships from that paper or if the author has manipulated their data. This is the most critical part of the section to expand on.

3) “A 50% reduction in CO_2 and a 67% reduction in SO_2 emissions” (L. 167) are striking figures. How were they calculated? Are these the results of your model or the inputs into the model?

4) The author mentions the basis for applying “the 0.3 Gyr climate cycle to the next billion years” (L. 126-127), but further explanation is needed. What is the physical mechanism? Additionally, why do its period and amplitude remain constant over billions of years, despite geological changes such as increased solar activity and/or mantle cooling?

5) The decision to model the impact of declining mantle temperatures only for the next 1.5 Gyr (L. 168) seems arbitrary. Why not consider the entire 2.5 Gyr?

6) The term "sill" (Ts, Ti) is used without being defined for a non-geology specialist. A brief explanation is necessary.

7) The formulation of Equation (10), Er = SD + Er(ΔTc), is problematic. It defines the total error, Er, in terms of itself, creating circular logic. Furthermore, it adds a standard deviation (SD), a statistical measure of dispersion, to an error term, Er(ΔTc), which likely represents a potential range. The description implies these components are being combined, but the equation's additive form is not logically justified. Clarification is required on the functional form of Er(ΔTc)—is it a root-sum-square, a linear addition, or another method?

8) Finally, the claim that the error is "within 0.1 Gyr" is ambiguous; it needs clarification on whether this refers to an uncertainty in age or temperature.

9) Concerning Equation 8, the derivation from the Arrhenius equation should be briefly explained or referenced.

[**Methods: 2.6**]

The section outlines a logical and organized approach to determining critical thermal thresholds for metazoans, which is a key and valuable contribution. The method of converting physiological limits into the global average surface temperature required for extinction (GATE) is ambitious and clearly segmented by habitat. However, the description currently needs significant clarification and justification to meet the standards of reproducibility:

- Regarding the 5°C adjustment from the Local Monthly Maximum Temperature (LMMT) to the Local Daily Maximum Temperature (LDMT) in Section 2.6.1, point 3, why 5°C? Is this a global average? Is it based on the Weather Spark data cited? This needs a clear justification.
- Regarding the 1°C and 5°C Local Annual Temperature (LAT) adjustments in Section 2.6.1, point 4, the cited reference (Upchurch et al., 1998) is somewhat outdated. Is this still the most relevant source? Please briefly explain the climatic reasons behind this latitudinal gradient in temperature differences.
- The selection of 37° latitude for determining GATE in Section 2.6.1, point 5, appears arbitrary as stated. Why 37°? Is this based on a global average temperature weighting? This step is crucial in determining your final GATE value and must be clearly explained.
- The assumed future burrowing depth of 2.5 meters in Section 2.6.2 is a significant biological assumption. Why choose 2.5 m instead of 1 m or 5 m? Is there evidence that metazoans can or will burrow to this depth for thermoregulation? This requires ecological justification.

The step-by-step process in Section 2.6.1 can be confusing because it mixes the description of what is shown in the figure with the actual methodological steps. It would be clearer to organize it as a standalone explanation. If possible, the author should rewrite 2.6.1 as a numbered or bulleted list that is independent of the figure: 1) Define the upper thermal tolerance (46°C) as the average maximum daily temperature (...) at key latitudes (0°, 30°, 60°, 90°). 2) Establish the warm Earth latitudinal temperature gradient (15°C from 0° to 90°). 3) Adjust this gradient for LMMT by applying a -5°C correction. 4) Adjust LMMT to LAT using a latitudinally variable correction (ΔLT). 5) Calculate the GATE from the LAT at a representative latitude (37°N/S).

The text in Section 2.6.1, point 5 states, "The GATE values for St and Sw metazoans are the same as described in Section 2.3.3." However, since your structure indicates that 2.3 is about oxygen levels, this likely refers to a different part of your manuscript, which could cause confusion. All necessary information for understanding the calculation should be in this section or clearly cross-referenced.

The frequent and inconsistent use of acronyms makes the text very difficult to understand. Readers must constantly refer back to remember what they stand for. Therefore, if possible, please consider adding a table: a summary that lists each metazoan group, its defined upper thermal limit, all applied corrections, and the final derived GATE value would greatly enhance clarity and reproducibility.

[**Methods: 2.7**]

The three main equations of the core model are shown, but their logic and connections are not clearly explained. Equation (13) presents a problem in this recovery model. Dt-2 refers to diversity two time steps earlier, implying that recovery aims to reach a diversity level similar to what was before the last extinction event, which may not be ecologically realistic. A more common approach would be to target a recovery toward a carrying capacity or a pre-event level. The reasoning behind this needs further clarification. Equation (14) appears to apply to gradual diversity loss preceding an event. It's unclear why this is a separate equation from equation (12) and how the "Survival Rate for gradual changes" (SR) differs from SRC in practice. The model's flow between these equations is not described.

This is a critical issue that significantly hampers readability. The text uses over 20 different acronyms (SRC, SRO, RR, SR, SAR, SARS, SARU, SARD, SRCT, SRCM, StR, SwR, UR, DR, FS, GATE, etc.). Many are non-intuitive, and some are confusingly similar (e.g., SR vs. SRC vs. SRO; SARS as "Survival Area Rate" is an unfortunate choice). The author should create a nomenclature table before Section 2.7, including a list of all acronyms, their full names, and brief definitions. Otherwise, please avoid creating an acronym for every term. Use them sparingly for the most frequently used concepts.

Many of the numerical values used in the model seem arbitrary or lack a clear, reproducible source. This presents the biggest risk to the model's credibility.

- Regarding SRC for Event 0 (Anthropocene), the values of 0.95, 0.70, and 0.90 for a "full-scale nuclear war" are very precise. What is the basis for these exact numbers? The citation (Kaiho, 2023) must specifically provide these values or the model that produced them.
- Regarding Food Scarcity (FS)**,** a reduction of "0.1–0.5" is a very broad range. How is a specific value selected for a particular calculation? This requires a clear rationale.
- Concerning "Underground Rate (UR=0.05) and Deep-water Rate (DR=0.33)**,"** the logic for converting modern lineage proportions (e.g., 15 out of 315 mammalian families) into a future survival rate is not clearly explained. This is a major assumption that requires a strong ecological justification.
- For "Recovery Rates (RR)," many RR values (e.g., 0.01-0.3 for events 8-10) are given without a clear, quantitative link to environmental conditions. The justification is qualitative ("reduced capacity," "adaptation challenges"), but the output is a precise number. There needs to be a transparent method for converting the severity of an event into a recovery rate.

Regarding the "C_4 Plant Crisis" (L. 287), the timeline is set to "coincide approximately with event 11," and the extinction of metazoans is then "set at 0.97 Gyr." This appears to be a circular argument where the model is adjusted to fit a pre-selected outcome rather than the outcome emerging naturally from the model's mechanics. Is it true?

The Methods section should describe how you calculated diversity, not what the results are. This section often overlaps with presenting results and speculative explanations, such as … expected to decline (L. 276), … are expected to evolve (L. 280), and … are expected to include (L. 290). The author should rephrase these statements to describe the model's rules.

[**Results: 3.1**]

The most significant issue is the lack of a methodological link between your methods and your primary result. The "Results" section should present findings derived from the previously described methodology; however, the description of the temperature curve reads more like an input scenario than a calculated outcome. The core problem is that the reader is told *what* the temperature curve is, but not *how* it was generated. While Section 2.6 details a model for calculating extinction thresholds, it does not explain the foundational climate model that produced the temperature projection itself. The author must explicitly state the model or data source used to generate the orange curve in Figure 1. Is it an output from a climate model run under specific CO_2 scenarios? An extrapolation from past climate data? Or is it derived from astronomical solutions, such as Milankovitch cycles? Crucially, you must identify the primary forcing driver (e.g., increasing solar luminosity, greenhouse gas concentrations) to provide the necessary context.

The same time periods and temperature ranges are described multiple times in slightly different ways (e.g., 0.65-0.95 Gyr vs. 0.7-1.0 Gyr). This repetition is redundant and causes confusion. Paragraph 2 (L. 352-355) describes the trend with specific future time points (0.35, 0.65, 0.95 Gyr), while Paragraph 4 (L. 359-363) restates the trend by re-binning the timeline into Phases A-E. Therefore, the author should combine these into a single, clear description, using the climate phases as the main structural framework and avoiding disconnected time points.

The nature of the abrupt climate changes described in Events 5, 8, 11, and 14 in paragraph 3 (L. 356-358) remains unclear. What physical process causes these "temperature surges" of more than 10°C in "<0.1 million years"? Are they inputs to the model (prescribed forcing) or results (emergent behavior)? The text currently treats them are given. We need to determine whether these are hypothetical events, representations of volcanic or tectonic activity, or outcomes from climate tipping points.

The use of "expected" and "projected" is inconsistent. Since this is a model result, "projected" is more appropriate.

The final paragraph states that Phases B-E are "triggered by" abrupt events (L. 364). This creates a causality dilemma. Is the long-term trend the primary driver, or are the abrupt events the triggers for new phases? The current description makes it seem like both, which is confusing. The author must clarify the relationship between the gradual trend and the abrupt events.

[**Results: 3.2**]

The first paragraph states diversity is "estimated using" (L. 368) several factors but provides no explanation of how this estimation is performed. What is the model? Is it a statistical correlation, a dynamic ecosystem model, or a set of threshold rules? What are the "survival thresholds" (mentioned in 3.2.1) and how are they determined? The reader cannot assess the results without understanding the fundamental rules of the model.

Several claims are presented as facts without justification, moving from scientific projection to pure speculation. "Large volcanic eruptions and asteroid impacts are expected to trigger…" (L. 382-383) The timing and occurrence of these specific events cannot be projected. This must be framed as a scenario or sensitivity test like "In scenarios where large volcanic eruptions occur...".

The line between results and interpretation is often unclear. A Results section should present the data (or model outputs), while the Discussion should explain what they mean. In this section, phrases like "This high-temperature environment will also impact..." or "will drive the complete collapse..." are interpretive. The text often states what will happen as if it is certain, based on the model, rather than just presenting the model's output. Therefore, the author should reframe to simply present the model's findings.

The author provides us with specific numbers (e.g., insect families dropping from 610 to 74–103), but does not inform us how these numbers were generated. This breaks the chain of reproducibility. Therefore, when presenting a key result, briefly link it back to the methodological framework.

The text in this section mentions ranges (e.g., 74–103 insect families) and different scenarios (Figs. 5 and 6), but it doesn't explain the *causes* of these ranges. For a projection of this magnitude, a thorough exploration of uncertainty is crucial. The author needs to state which parameters are responsible for the ranges explicitly.

Given the highly speculative nature of billion-year projections, using definitive language like "will," "are expected to," or "lead to" is too strong for a Results section. The author should adopt more tentative and precise phrasing that reflects the model-dependent nature of the findings. For example, the author can use phrases such as: “The model projects...”, “Under the defined scenarios...”, “Simulation results indicate...”, and “Our findings suggest...”.

The “Aftermath” section (L. 415-428) extends beyond metazoan diversity to explore the fate of all life and the planet. While a compelling conclusion, it exceeds the stated scope of "metazoan diversity change." The author should consider whether some of this material, especially the comparison to Venus, might be better suited for the Discussion.

[**Discussion: 4.**]

This section currently reads more like a summary and extension of the results than a critical discussion. To meet the journal's standards, the work needs to be more thoroughly addressed, including the limitations, uncertainties, and broader implications, shifting from "what we found" to "what it means and how reliable it is."

Section 4.1 (L. 430-460) mainly defends the assumptions rather than thoroughly examining their uncertainties. A robust discussion must openly acknowledge and analyze the weaknesses. Some specific gaps include: 1) The model incorporates highly uncertain components (billion-year climate, biodiversity, oxygen, plant evolution). The combined effect of these uncertainties is not addressed. How reliable is the 0.7 Gyr extinction date, considering this? 2) The model assumes fixed thermal tolerances. The discussion should explicitly consider the possibility of evolutionary adaptation over millions of years, even if the conclusion suggests it might be limited due to fundamental physiological reasons. 3) The survival and recovery rates are key but poorly constrained. A discussion on how sensitive the main conclusion (extinction at ~0.7 Gyr) is to these parameters is essential. Is the outcome unavoidable across a wide range of plausible values? The author can integrate a dedicated subsection, like “4.5 Model Limitations and Uncertainties,” that systematically addresses these points. This demonstrates scholarly rigor and strengthens the paper.

The author often restates results (e.g., "The combined effects... will drive a substantial decline") and ventures into highly speculative territory (e.g., Section 4.3 on intelligent life strategies and Mars) without a clear framing. For example, Section 4.3, while interesting, is tangential to the core scientific findings about metazoan diversity. It risks detracting from the paper's focus and lacks the scientific support found in other sections. Thus, the author reframes result restatements as a setup for interpretation. For speculative sections, clearly label them as such and connect them directly to the model's projections.

While citations are used, the discussion often *uses* them to support the model's assumptions rather than to contrast *or* synthesize the model's findings with other published work. Therefore, the author should actively engage with alternative viewpoints or models, positioning their work within the ongoing scientific conversation.

The central message that metazoans will decline after 0.4 Gyr and go extinct at 0.7 Gyr due to combined temperature, O_2, and plant crises is repeated multiple times (e.g., in 4.1, 4.1.2, 4.2, 4.4). This repetition reduces its impact. The author should simplify the main narrative, state the key conclusion clearly once, and then use the following sections to discuss different aspects of it (limitations, mechanisms, implications) without restating the conclusion verbatim.

There is a clear copy-paste error in Section 4.4 (L. 566-574), where a whole paragraph is duplicated ("Rising Global Temperatures at Events 8–10...").

[**Conclusion: 5.**]

The second half of the conclusion goes far beyond the paper's scientific findings into policy, ethics, and futurology. The author's statements, such as "To mitigate biodiversity loss, advanced species may need to implement strategies..." and "emphasizing the urgency of proactive measures," are not conclusions derived from your model. While interesting, the author should phrase it more neutrally. The author should focus the conclusion on the scientific findings. The speculative strategies (aerosol shielding, space colonization) can be mentioned as potential consequences of the findings, but not as prescriptive "needs." Avoid language that tells the reader what is "urgent."

The entire study relies on a model with significant uncertainties (as noted in comments for the discussion). The conclusion states the 0.7 Gyr timeline as a definitive result without any qualification. The author should consider adding a sentence that acknowledges these inherent uncertainties.

The phrase "this study is the first to reveal that humanity exists at the midpoint of metazoan lifespan" makes a very strong claim in the conclusion. While it might be true, it sounds self-promoting. The most suitable place to highlight this novelty is in the Introduction and Discussion sections. The author could rephrase this to emphasize the finding itself. For example, "An interesting corollary of this timeline is that humanity appears near the midpoint of Earth's metazoan history."

The main point, extinction at 0.7 Gyr, is repeated three times in a very brief text. While repetition can emphasize a point, here it limits the development of a more nuanced final message. The author can condense the key finding into one strong statement at the beginning and use the remaining space to discuss its causes and implications.