Authors' response to reviewers' comments

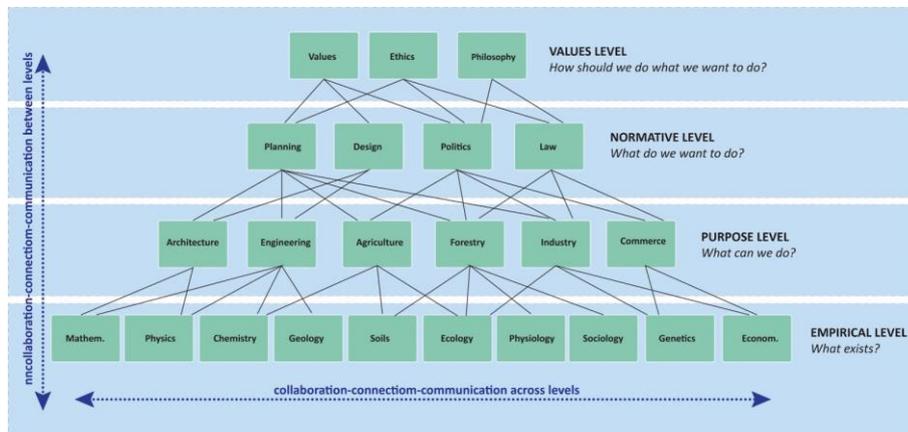
The authors would like to thank the two reviewers for their constructive criticism and comments that have contributed to the improvement of our work. We have considered all comments carefully, revised the manuscript accordingly, and hope to have addressed all issues put forward. Below we provide a step-by-step response (Authors' Response: **AR**) to each of the reviewers' comments (**RC1 and RC2**).

Reviewer #1:

R1C: more clarity in your introduction of key concepts such as transdisciplinarity, interdisciplinarity, and connectivity. It seems, at times, that you are using these terms loosely, if not interchangeably. Please introduce these terms along with agreed (and cited) definitions from the literature, and sharpen your precision in use of them.

AR: Thank you for highlighting this, we made certain additions throughout the text and reworded where necessary for clarification. We also added another short explanation of transdisciplinary into this paragraph: "Transdisciplinarity - being endowed with united knowledge from different fields of science - favours a holistic approach that facilitates a systemic way of addressing challenges across scientific boundaries. Transdisciplinary research therefore, often seeks to engage stakeholders in meaningful ways throughout the research process (Rigolot, 2020). Comprehending the different levels at which ecosystems function, develop, interact, degrade, and are impacted by anthropogenic processes is fundamental to establishing impactful policies and methods to prevent further degradation and promote effective restoration. By adopting a transdisciplinary approach, scientists are better able to understand the multifaceted dynamics of changing ecosystems, in turn allowing the direct and indirect consequences of these changes to be understood and sustainable strategies to protect, conserve, and restore ecosystems to be identified (Naveh, 2005)." Additional references were also added in the revised manuscript version.

R1C: I was also somewhat at a loss with interpreting the figure you adapted from Max-Neef 2005. For me, this flat, 2-D depiction of multidisciplinarity does not capture its richness and potential. I would love to see a different graphical approach to representing this keystone concept in your paper.
AR: Thank you for your criticism of the figure, we tried to alleviate some of your immediate concerns by reworking the figure somewhat, however Max-Neef is only a suggestion. We thought this could be a good starting point to start thinking about the flow of a project at its onset, design and develop it, not necessarily taking it to heart, but using it as a suggestion. There may certainly be more complex diagrams/approaches, however, the simplicity of a 2D depiction of the issue was what caught our eye. Transformative change through trans- and interdisciplinary approaches can often be complex and multi-tiered for many scientists, and our aim was to

introduce these concepts as simply (and as un-threateningly) as possible. We can altogether remove the Figure, but we strongly suggest we keep it in its edited format.

R1C: Another general concern I have with your argument relates to the sometimes huge gap between evidence and decisions. We sometimes talk about the pitfalls of "decision-based evidence making" as opposed to "evidence-based decision making." It often seems that many policy decisions are much more strongly influenced by political concerns than by scientific and technical concerns. How could transdisciplinarity address the situation where decision makers choose to ignore timely and relevant scientific evidence? You mention stakeholder engagement, and this may offer a viable strategy, but please explain how this relates to transdisciplinarity.

AR: To start from your final question, as you know transdisciplinarity, by nature, feeds from different disciplines and methodologies, often allowing a healthy mixture of quantitative and qualitative approaches/assessments/analyses. For example, stakeholders may not necessarily be equipped with quantitative techniques, and integrating qualitative approaches may allow more engagement, and this flexibility in developing/adapting and/or implementing various methodologies for community engagement often requires a transdisciplinary perspective. And yes, your concern over decision-based evidence making vs evidence-based decision making is always a pitfall, however that can only be overcome by the ethical commitment of the scientist or the stakeholder in question, and this is outside the scope of this short commentary, same as in the adverse cases where the decision makers may choose to ignore scientific evidence. We hint at it in here. "It is therefore vital that scientists and their transdisciplinary teams understand the information needs of policymakers and the policy landscape in which they operate (Topp et al., 2018). "). That said, we also think stakeholder engagement may alleviate these risks. But thank you for bringing this concern up, as it is valid, and unfortunately can be a common hurdle in a number of projects which all parties should watch out for.

Reviewer Specific Comments:

R1C: In the abstract, you mention use of the 2022 Kunming-Montreal framework as a foundation for the paper, but it was not clear to me how this framework shows up as a foundation for the discussion in your paper.

AR: The abstract has been updated and this reference has been removed:

"According to a 2019 United Nations' report, of all the known species, up to one million face extinction globally. Despite being considered a pressing global risk with several international efforts to protect and to restore, biodiversity loss and the degradation of ecosystems continue at an alarming rate. In December 2022, COP15 saw the adoption of the Kunming-Montreal Global Biodiversity Framework, where four overarching international goals for biodiversity, and 23 targets were set. While a positive step to addressing the drivers of biodiversity loss, to reach the goals and targets outlined, we will not just need public and political will, but more effective methods to integrate and use scientific information. To facilitate this, scientists and research institutions need to establish alternative and new approaches to transform the way science is conducted, communicated, and integrated into the policymaking process. This will require the scientific community to become proficient at working in inter- and transdisciplinary teams, establishing connectivity across scientific disciplines, and engaging in the policymaking process to ensure that the best available scientific evidence is not only comprehensible to decision-makers, but also timely and relevant. This commentary details how scientists can embrace transformative change within and outside of their own communities to increase the impact of their research and help reach global targets that benefit society."

R1C: Line 64: not sure what is meant by "the bottleneck" -- If you're going to keep that quote, please explain what's implied here about bringing environment and biodiversity through the bottleneck.

AR: Thank you for your comment, in our final edit we had to truncate the text, trying to be parsimonious in the word count. Hopefully it is clearer now: "We understand this radical shift in our scientific approach will bring with it many challenges; however, this may be our last chance, as noted already more than 20 years ago by Edward O. Wilson, "to bring with us as much of the environment and biodiversity through the bottleneck as possible" (2001); Wilson's "bottleneck" acting here as a metaphor for the anthropogenic stressors on biodiversity, fast closing the window of opportunity for us to reverse this trend."

R1C: Lines 65-66: it's not clear to me how "establishing biodiversity benchmarks and baseline data" has a connection to transdisciplinarity and connectivity.

AR: Thank you for picking up on this, we clarified it further: benchmarks and baseline data acting as aids to have scientists and stakeholders from different disciplines to be able to "talk" to each other, the text now reads:

"Thus, we propose meaningful strategic action on biodiversity by establishing biodiversity benchmarks and baseline data, for transparency, replicability, and standardisation of the "research language" to foster connectivity across disciplines and sectors; and encourage the

research community to actively engage in policymaking to ensure that timely and relevant scientific evidence reaches decision makers."

R1C: Line 69: Before going into the benefits of transdisciplinarity, it will be helpful to understand what you mean by this term. Please begin this section by defining transdisciplinarity and explaining the difference between this and inter-disciplinarity.

AR: We changed the sentence to clarify the difference between the terms. The concept of transdisciplinarity was also clarified, please see our first response above.

R1C: Also, you write about addressing challenges "across scientific boundaries", but is transdisciplinarity limited to just scientific boundaries? How about science/non-science boundaries

AR: A valid point. We also touched on this in lines 96-97 and 103-104 in the original text, and hopefully our current revision of this paragraph helps highlight this further (keeping in mind the word limit):

"Connectivity involves multilayered two way interactions across science, society, and policy, where feedback from one component or discipline continuously morphs the results of the ones it feeds into. It is, in essence, a basic version of how nature operates: through an efficient feedback mechanism and information exchange, constantly morphing, changing, and evolving. Where transdisciplinarity in scientific practice encourages advances and provides new perspectives (Knapp et al. 2019), one can think of connectivity as the core, where these perspectives can be further shaped, changed, broken, and rebuilt through continuous feedback. The benefits of connectivity between disciplines and iterative learning processes to scientific practices are further stimulated by transdisciplinarity and interdisciplinary research, and preferably, with the engagement of external stakeholders and community participation (Angelstam et al., 2013). "

R1C: Line 75: you mention the need for "both a theoretical and practical transformation" -- what does such a transformation look like? I'm having difficulty picturing these required transformations, especially the theoretical transformation.

AR: We touch upon it on lines 75 - 78:

"However, conducting transdisciplinary scientific research requires both a theoretical and practical transformation in how we conduct our research as scientists. Scientific communities should not only collaborate in diverse groups that encompass various scientific disciplines and sectors but should also carefully assess how to achieve effective and usable outcomes through such collaborations."

R1C: Line 83: the illustration does not show collaboration-connections-communication across and between all levels, it only shows this between adjacent levels.

AR: Figure was changed to accommodate the missing information

R1C: Line 85: related to my comment 4 above, are you using "inter and transdisciplinary" interchangeably?

AR: No, not at all. But thank you for bringing this concern up, we refined our sentences throughout the manuscript to make the distinction more pronounced.

R1C: Line 87: Please elaborate a bit more about what the "challenges and benefits" are (perhaps in the preceding paragraph) before stating the need for them to be recognized and incorporated. What are these benefits and how can we be confident they will occur for all/most transdisciplinary projects? What are the challenges and how can we anticipate them and identify them when they occur?

AR: We added some in parentheses, we had to trim some of our earlier suggestions due to the word count limitation, hopefully these new short suggestions help clarify:

"However, for transdisciplinarity to become the norm rather than the outlier, both its challenges (i.e. the time, effort and resources necessary to adapt this approach) and benefits (i.e. a multi-tiered approach to scientific analysis from a wider perspective) need to be recognised by institutions and purposefully incorporated into the way in which the organisation functions."

R1C: Figure 1: This is an interesting diagram, but I think you could reconceptualize it, creating something more integrated than the Max-Neef diagram. As mentioned above the lines only connect neighboring levels, which gives the impression there is no direct connection between the values level and the empirical or purpose level, for example. Also, there are no lines between boxes in a given level, but are they really so independent? People may also quibble with specific lines as well -- for example, one might ask why "Law" has no connection to Agriculture, Engineering or Architecture. Finally, I'm not convinced the values-normative-purpose-empirical levels are actually a hierarchy -- could they be zones or enclosed rings in a circular diagram? Perhaps you could generalize the boxes, rather than having specific fields identified? Also, "Values" does not seem to be a field or discipline. Suggestion: search the literature for some commentaries or critiques of the Max-Neef diagram to see if some other alternate diagram could be found to illustrate your point.

AR: Please see our comment to your feedback above. Additionally, we reworded the caption for Figure 1 to further clarify our reference to this diagram:

"Figure 1. The pyramid of transdisciplinarity: continuous coordination/exchange between all hierarchical levels (adapted from Max-Neef, 2005, relations between tiers are suggestive and may change based on the project at hand)."

Also, arrows were defined by Max-Neef. While we hear your criticism that the approach itself may be open to criticism, we propose to keep the figure as a suggestion of an approach that may be adapted/bettered/developed or certainly improved. However, these are not the aim of this commentary.

R1C: Lines 96-97: Are you advocating for the statistician's point of view here? I don't understand the Modeller vs. Statistician comment. What about the rest of us?

AR: The sentence has been reworded to be more inclusive, we included it in our answer to your earlier feedback above.

R1C: Line 105: "engaging stakeholders" is rather vague, what do you (or Diaz) mean when you say this? What does this kind of engagement look like?

AR: The parapraph has been reworded for clarification:

"Engaging stakeholders and society for reversing biodiversity loss has been widely acknowledged by intergovernmental actors (Díaz, 2019) as an integral part of generating change which has enough momentum for transformation and impact." …. "A growing number of studies (Newig et al., 2023; Flanagan et al., 2022; Holifield and Williams, 2019) indicate that considering the needs of the local population, including indigenous communities, through knowledge exchange and assessment provides greater research context, subsequently delivering more relevant and useful outcomes, and for the purposes of this commentary: aids the possibility for transformative change (Fougéres et al. 2022). In the context of the GBF and biodiversity related goals, this is particularly relevant, as the environmental health of lands that are managed by local and indigenous communities are observed to decline more slowly (Díaz, 2019). Conversely, the atrophy in regional heritage and identity and the loss of local and indigenous knowledge has been shown to have significant adverse effects on biodiversity (Wilder et al., 2016)."

R1C: Line 110: You write "Evidence shows" -- which evidence?

AR: We added some specific examples (there are more, but we had to consider the word count) as references, please see our answer to your comment above.

R1C: Line 136: You suggest scientists and their teams "understand the information needs of policymakers and the policy landscape." It seems to be a big ask to expect scientists to do this, but here's a situation when including policy experts within transdisciplinary teams can help meet this need. Maybe you could spell out this kind of scenario.

AR: Very pertinent indeed, and we believe we already have covered this in sections where we mentioned stakeholder involvement.

R1C: Line 144: I would like to know what formats you recommend, which are accessible and useful for policymakers

AR: We provided some suggestions:

"Thus, to participate in and promote transformative change, we encourage the scientific community to not only generate transdisciplinary scientific information, but to institutionalise the integration of this research into formats (i.e. simple infographics, sharable files, plain word summaries, open data) that are accessible and useful for policymakers."

Technical corrections suggested by R1

1. **Lines 33-34: suggest deleting the 1st sentence**

   AR: We changed the order of the sentences to improve the flow.

2. **Line 35: end of sentence after "23 targets" is missing**

   AR: Fixed it.

3. **Lines 37-38: delete "research and"**

AR: Deleted.

4. **Line 50: delete "are"**

   AR: Deleted.

5. **Line 67: change "engaging" to "engage"**

   AR: Changed.

6. **Line 97: change "Bayesian perspective, involving..." to "Bayesian perspective, which involves..."**

   AR: Changed.

7. **Line 99: change "nature should operate" to "nature operates"**

   AR: Changed.

8. **Line 114: change "Furthermore" to "Conversely"**

   AR: Changed.

9. **Line 145: the word "engage" doubled in this sentence; not sure what "both" refers to**

   AR: Sentence reworded:

"This requires the involvement of individual researchers who are willing to engage with policymakers to understand their needs and share relevant and timely information, as well as scientific institutions that create opportunities and activities for science-to-policy interaction. We encourage readers to consider how they can integrate these important aspects into their work and institutions, and become agents of transformative change."

Reviewer #2:

R2C: Transdisciplinarity in science is an important concept that, in my opinion, is crucial to tackle many of today's challenges of humankind and I am happy to see that this publication advocates for it in on the concrete and very important issue of the loss of biodiversity. However, it would be useful to provide a clear definition of transdisciplinarity, connectivity and the relation between the two concepts. Especially a clarification if the authors apply the concept of transdisciplinarity specifically to the research practice (connecting several disciplinary fields to allow a more complete

description/analysis of complex issues such as biodiversity) or if they extend the concept even to non-scientific sectors such as politics or macroeconomics.

 AR: Thank you for highlighting this, we made certain additions throughout the text and reworded where necessary for clarification. We also added another short explanation of transdisciplinary:

"Transdisciplinarity - being endowed with united knowledge from different fields of science - favours a holistic approach that facilitates a systemic way of addressing challenges across scientific boundaries. Transdisciplinary research therefore, often seeks to engage stakeholders in meaningful ways throughout the research process (Rigolot, 2020). Comprehending the different levels at which ecosystems function, develop, interact, degrade, and are impacted by anthropogenic processes is fundamental to establishing impactful policies and methods to prevent further degradation and promote effective restoration. By adopting a transdisciplinary approach, scientists are better able to understand the multifaceted dynamics of changing ecosystems, in turn allowing the direct and indirect consequences of these changes to be understood and sustainable strategies to protect, conserve, and restore ecosystems to be identified (Naveh, 2005)."

Additional references were also added in the revised manuscript version.

R2C: Furthermore, it is not completely clear from the text, how exactly transdisciplinary research can help to bridge the gap between scientific results and policy making or help overcome issues in cross-border collaborations. Most of the issues the authors describe apply to any form of scientific research and are not specific to transdisciplinary research. Nevertheless, I think the publication is very relevant and addresses important issues. I look forward to seeing how the concept will evolve in the future.

AR: We thank you for your constructive feedback. We had to be parsimonious due to the word limit for commentaries, and we did not wish to diverge too much from our main subject at hand.

Specific comments

R2C: Line 54: It would be good to explain the goals and targets and why their pursuit needs transformative change

AR: Thank you for this very pertinent suggestion, however, due to the word limit, and this not really being the aim of this commentary, we will consider your suggestion in another manuscript/platform.

Commented [I1]: PLEASE FEEL FREE TO CHANGE THIS ANSWER :)

R2C: Line 66: You mention benchmarks and baseline data, which are never mentioned again in the publication. Could you explain if and how benchmarks and baseline data relate to the topic of the publication?

AR: Thank you for picking up on this, we clarified it further: benchmarks and baseline data acting as aids to have scientists and stakeholders from different disciplines to be able to "talk" to each other, the text now reads:

"Thus, we propose meaningful strategic action on biodiversity by establishing biodiversity benchmarks and baseline data, for transparency, replicability, and standardisation of the "research language" to foster connectivity across disciplines and sectors; and encourage the research community to actively engage in policymaking to ensure that timely and relevant scientific evidence reaches decision makers."

R2C: Line 69: See my general comment. A definition of transdisciplinarity is needed.

AR: Added

R2C: Line 74: Can you outline what elements need to be transformed?

AR: Keeping in mind the word limit, we explained it in a number of places in the text including here:
"Engaging stakeholders and society for reversing biodiversity loss has been widely acknowledged by intergovernmental actors (Díaz, 2019) as an integral part of generating change which has enough momentum for transformation and impact."
And here,
"The global nature of the biodiversity crisis demands that we transform the way in which we connect and collaborate across political borders to find solutions and achieve the goals and targets set by the GBF (Convention on Biological Diversity, 2023)."

R2C: Line 84: Only to non-academic sectors or also to non-scientific sectors?

AR: Within the context of this commentary.

R2C: Line 87: What are the challenges and benefits of transdisciplinary research?

AR: We provided some suggestion in paragraph (as best we could given the word limit):

"However, for transdisciplinarity to become the norm rather than the outlier, both its challenges (i.e. the time, effort and resources necessary to adapt this approach) and benefits (i.e. a multi-tiered approach to scientific analysis from a wider perspective) need to be recognised by institutions and purposefully incorporated into the way in which the organisation functions."

R2C: Figure 1: The connections drawn in the figure are only happening between the levels and only between adjacent levels. What about the connections between the disciplines or the influences from the values level and normative level on the empirical level?

AR: Figure is edited and additionally we reworded the caption to further clarify our reference to this diagram. Arrows were defined by Max-Neef. Our referral to the figure is an offer for an approach that may be adapted/bettered/developed or certainly improved. We added the new figure into this document above.

R2C: Line 96/97: You describe two points of view for connectivity, the one of modellers and the one of statisticians. Which one is yours? A third one? In that case, why mention the two points of view in the first place?

AR: We reworded this paragraph to be more inclusive:

"Connectivity involves multi-layered two way interactions across science, society, and policy, where feedback from one component or discipline continuously morphs the results of the ones

it feeds into. It is, in essence, a basic version of how nature operates: through an efficient feedback mechanism and information exchange, constantly morphing, changing, and evolving. Where transdisciplinarity in scientific practice encourages advances and provides new perspectives (Knapp et al. 2019), one can think of connectivity as the core, where these perspectives can be further shaped, changed, broken, and rebuilt through continuous feedback." ...

R2C: Line 103: What does "further stimulated by transdisciplinarity" mean? In my understanding of what was written before, connectivity is the core of transdisciplinarity. No transdisciplinarity without connectivity.

AR: We reworded this sentence for clarification: ..."The benefits of connectivity between disciplines and iterative learning processes to scientific practices are further stimulated by transdisciplinarity and interdisciplinary research, and preferably, with the engagement of external stakeholders and community participation (Angelstam et al., 2013)."

R2C: Line 110: Which evidence? Citation missing.

AR: We elaborated on these, and reworded the paragraph (with additional citations):

"A growing number of studies (Newig et al., 2023; Flanagan et al., 2022; Holifield and Williams, 2019) indicate that considering the needs of the local population, including indigenous communities, through knowledge exchange and assessment provides greater research context, subsequently delivering more relevant and useful outcomes, and for the purposes of this commentary: aids the possibility for transformative change (Fougéres et al. 2022)."

R2C: Line 125-128: What is said there is all true but for me the connection to transdisciplinarity and connectivity is missing.

AR: Thank you for your feedback. This section is mainly on connectivity and we remind that transboundary cooperation is a means of connectivity. Here we offer suggestions on how to make it more efficient, and inclusive.

R2C: Line 133: Isn't it true for all science advice? What is special about transdisciplinary science?

AR: Absolutely, thanks for picking this up, we changed it to science advice.

R2C: Line 144: Do you have any suggestions for the mentioned formats?

AR: We provided some suggestions: "Thus, to participate in and promote transformative change, we encourage the scientific community to not only generate transdisciplinary scientific information, but to institutionalise the integration of this research into formats (i.e. simple infographics, sharable files, plain word summaries, open data) that are accessible and useful for policymakers."