

Multi-fold increase in rainforests tipping risk beyond 1.5-2°C warming

Response to Reviewer #2

Overall, I think the reviewers did a great job of addressing the previous comments. In particular, the authors have greatly improved the clarity of their methods explanations. They have also elaborated more fully on the limitations and assumptions of their work, which has strengthened the ability of a reader to contextualize the authors' findings.

Response: We appreciate the reviewer's feedback and are glad that the revisions have appropriately addressed their previous concerns.

Methods restructuring:

The authors add full descriptions of their transition categories as well as an updated appendix with further details on the methods. The changes to the methods and appendix greatly improved my ability to understand the analyses that have been done. I have just two suggestions:

- First, in section 2.3.2, it would help to more clearly delineate what information under the headings of “Lowly water-limited forest”, “moderately..”, “etc..” (sections i, ii, iii, iv) comes from this study vs what comes from the previous Singh study or is “common knowledge” (maybe requiring citations?). For example, Line 218 mentions ecosystem “maximum rooting depths typically between 15-20m.” Where does this number come from? Similarly, see line 238, which states “this also suggests that, for savanna, deeper roots don't always necessitate a high Sr”. This seems more like a result or from a previous paper also?

Response: All qualifications of tree cover, root zone storage capacity, and maximum rooting depth for different forest-savanna classifications are based on a previous study. We have now appropriately cited Singh et al. (2020) where necessary, with references to potential mechanisms taken from other studies cited separately. [Pg 7-8, Ln 195-235]

- Second, I find that the Appendix was incredibly helpful. Section A2 clarifies the calculation and interpretation of Sr and greatly enhances the manuscript. Figure A1 is great too! However, I wonder if section A3 (or even both appendices...) could be incorporated into the main text?

Response: We kindly request that the reviewer allow us to retain the Appendices in their current form. In our previous revision, we attempted to incorporate them into the main methods text, but this disrupted the flow of the methodology and made the text unnecessarily dense/complex, potentially leading to confusion. This complexity may have been evident in our original submission, where we didn't use appendices.

Presently, the only way to include the appendices' information in the main text of Methods section without disrupting the flow would be to significantly condense it. However, this would sacrifice the level of detail in our discussion (e.g., the technicalities of root zone storage calculation, subsoil interactions within the scope of this study, how previous studies have projected tipping points and the rationale behind our methodology for analysing such transitions).

Moreover, we believe that retaining the discussion in the appendices is beneficial because, in ESD, the appendices are considered an integral part of the main paper and are appropriately highlighted for readers.

My biggest hesitation with the methodology originally was exactly what you state here - that Sr cannot actually distinguish between forest and savanna ecosystems on its own. I think your argument here that

you can use future climate to calculate Sr, and therefore forest and savanna transitions, by assuming equilibrium between future climate and landcover is valid and provides interesting results. However, I wonder if the manuscript would benefit from having this assumption laid out very clearly (as you do here in the appendix) in the methods section. Perhaps somewhere around section 2.3.3, which begins “A recent study..demonstrated that Sr effectively represents an ecosystem’s above-ground state..” and seems to directly contradict the appendix note about Sr not being able to fully achieve this. Specifying that in the present, we can relate Sr to observed forest vs savanna patterns and then use assumptions to project those into the future would be helpful.

Response: We agree with the reviewer and have now added the following sentences to the beginning of Section 2.3.3:

“Due to the lack of appropriate metrics for vegetation structure (e.g., tree cover density, tree height, floristic patterns) and the reliance on assumptions about future land-use change (i.e., prescribed rather than biophysically simulated) in ESMs (Hurtt et al., 2020), we use hydroclimate from ESMs as a proxy to project forest transitions under future climate conditions. Using this proxy, we assume that the hydroclimate projected for the end of the 21st century and the ecosystem are in equilibrium (Staal et al., 2020).” [Pg 8, Ln 248-252]

Small comments:

- In this new revision, there are quite a few grammatical and spelling errors. I have pointed out a few below, but I suspect there are more that I didn’t catch.

Response: Thank you for your thorough review of our work and your careful attention to detail in identifying grammatical and spelling errors. We have now carefully reviewed the entire manuscript to address any such mistakes.

- Line 30, “Meanwhile, recovering to a less water-limited state gradually diminishes.” This sentence doesn’t make sense to me in the flow of the abstract. Could it possibly be deleted?

Response: We agree with the reviewer and have removed the sentence from the abstract as suggested.

- Line 33: “their immediate” should just be “the immediate”?

Response: Thank you. Changes have been made to the revised manuscript. [Pg 1, Ln 31]

- Line 42: Grammatical fix: “...decrease in precipitation and an increase in seasonality and atmospheric water demand.”

Response: Thank you for your suggestion. However, we have now revised the whole sentence for clarity: *“However, these forests are under severe pressure from climate and land-use changes (Davidson et al., 2012; Lewis et al., 2015; Malhi et al., 2008). These changes result **in decreased precipitation, increased seasonality, and higher atmospheric water demand** (Malhi et al., 2014), leading to soil moisture deficits that inhibit plant growth (Singh et al., 2020; Wang-Erlandsson et al., 2022)”*. [Pg 2, Ln 39-40]

- Line 53: Shedding leaves, or shredding leaves (as written)?

Response: Thank you for pointing that out. The correct term is "shedding leaves," and we have made this correction in the revised manuscript. [Pg 2, Ln 50]

- Line 56: I really liked this sentence - good summary of the goal!

Response: Thank you.

- Line 61: Capacity should be plural? The sentence might be clearer if written “This limits the capacity of ESMs to...”
Response: Thank you. We have made this correction in the revised manuscript. [Pg 2, Ln 58]

- Line 82: “Yet, forest resilience is often assessed based on changes in forest carbon stocks (Huntingford et al., 2013; Parry et al., 2022) or precipitation (Hirota et al., 2011; Staal et al., 2020; Zemp et al., 2017); and rarely on the subsoil moisture availability of the ecosystem (Singh et al., 2022). “ This is a super important point and great motivator for your study.
Response: Thank you.

- Line 198-99: Slightly weird grammar here with the “and the potential of them approaching the threshold..” This full sentence could possibly be broken up into multiple, or else everything after the “hydroclimatic conditions on forest ecosystems” could be deleted.
Response: Indeed, this part does seem somewhat repetitive, so, following the reviewer's suggestion, we have removed the aforementioned sentences. [Pg 6-7, Ln189-194]

- Line 199-201: Is this sentence “According to Singh...benefits available to ecosystem” necessary? I wonder if it is a bit tangential to the argument of this paragraph which is that S_r can be used to diagnose ecosystem state? Bringing in the (true) fact that plants can also change their S_r might also confuse readers as to what part of this puzzle you are primarily addressing here.
Response: Thank you for your observation. We agree that this may have led to confusion about the paragraph's primary focus. To improve clarity, we have revised this paragraph as:
“A recent study by Singh et al. (2020) demonstrated that S_r can effectively represent an ecosystem's above-ground state (i.e., whether it is a forest or savanna) and its level of water–stress, based on root-zone moisture availability. In this study, we refine their terminology from 'water-stressed state' to 'water-limited state' to more precisely describe the effects of changes in hydroclimatic conditions on forest and savanna ecosystems. They classified these terrestrial ecosystem responses into four distinct categories based on the relationship between tree cover density and root zone storage capacity (S_r) (for a more detailed description, see Singh et al., 2020):...”. [Pg 6-7, Ln189-194]

- Line 238: “Completive”? Do you mean complementary? Or complete?
Response: Thank you for pointing that out. The correct term is "competitive", and we have made this correction in the revised manuscript. [Pg 8, Ln 233]

- Line 456-460: Suggest breaking into two sentences to lose the semicolon and improve readability.
Response: Yes. We have now divided these into two sentences:
“These climate change-induced shifts in ITCZ can potentially both mitigate and exacerbate the effects of (accumulated) water-deficit on the forest ecosystem, especially critical for highly water-limited forests, even without considering the changes to atmospheric moisture flow caused by localised deforestation (Leite-Filho et al., 2021; Schumacher et al., 2022; Staal et al., 2018; Wunderling et al., 2022). This underscores the importance of including changes in atmospheric circulation in studies that analyse the impact of future climate on the resilience of forest ecosystems (Staal et al., 2020; Zemp et al., 2017).” [Pg 15, Ln 453-458]

- Line 529: Typo, should be “rely” instead of “reply”?
Response: Thank you. Changes have been made to the revised manuscript. [Pg 18, Ln 527]

- Line 539 and 541: Might be clearer to say “projected climate” instead of just climate?

Response: Thank you. Changes have been made to the revised manuscript. [Pg 18, Ln 537 and Ln 539]

- Line 571: Remove first word of the sentence “although” or add in second half of sentence if it is missing?

Response: Thank you. Changes have been made to the revised manuscript. [Pg 19, Ln 569]

- Line 665: Missing . at end of sentence

Response: Thank you. Changes have been made to the revised manuscript. [Pg 24, Ln 663]