

RC1: 'Comment on [bg-2023-5](#)', Anonymous Referee #1, 24 Feb 2023

We would like to thank the reviewer for the constructive and valuable comments and suggestions to improve the manuscript. Below we go through point-by-point our answers to the comments. The comment is always in black and our response in blue.

General comments

The introduction is not tailored to the research question but rather puts in various issues about urban trees, which are unfortunately sometimes wrongly cited (see also specific comments). The ways how cooling and shading might be affected by heat and drought (stomata, leaf senescence, hydraulic failure) are not properly described, nor are direct (heat and drought) and indirect impacts (nutrition, air pollution impacts) or impacts that may mitigate damaging influences (CO₂, irrigation) properly differentiated.

We have improved the readability of the introduction towards the set research question. The last one of those, we revised to be more logical outcome of the introduction. Now it states,

L82: "What are the main environmental drivers affecting transpiration rates during heatwave and drought in urban green areas?"

We added information about tree cooling and shading role in urban trees and the tree responses to heat and dry with respect to the study research questions. We have also corrected and updated the references accordingly.

Also, hypotheses are not clearly specified and H1 and H3 seem to be the same anyway. Transpiration will be increased (vpd) or decreased (stomatal control), or both (in which cases)? Drought decreases stomatal conductance (old news) or photosynthetic capacity (and then impacts stomata)?

We have removed the original hypothesis H3 as it truly seemed to overlap with H1 as pointed out by the reviewer. We improved and specified only the H1 in the revised manuscript.

The methodology is problematic, trees were of different species at each site, so neither species differences nor site differences can be evaluated. Furthermore, trees varied considerable in height and age, and measurements were taken at different heights and also the stratification within the crown was not homogeneously done. In addition, some sites were irrigated while others were not.

We agree that the methodology had some limitations. Thus, we have removed the parts where there are unnecessary comparisons between sites and tree species in the study. Nevertheless, especially the trees in the park, the street and the forest are roughly equal in age (30-40 years) and soil type (sandy loam) and on the other hand, they represent typical species in their environment i.e., these specific green area types. For example, it is uncommon to have birch as a street tree whereas *Tilia × europaea* is clearly the most common street tree in Helsinki due to its capacity to bear compaction, salt, and pollution. At the same time, it is incredible to have an urban forest consisting of these non-native species in Helsinki. Therefore, we did not totally remove all text considering the site comparisons but revised the text throughout the manuscript in such a way, that is clear to the reader that these results arise not only from the site nor the species but a mixture of effects typical for them. In addition, we acknowledged that in the orchard, trees are older and the site. In any case, we focus mostly on the responses to heat and drought in the revised manuscript.

It is not clear, how the 'normalization' by vpd is actually done and if this is in accordance with theoretical considerations regarding the vpd response. In addition, it is not clear, how much drought stress was actually present at the different sites since only percentages of water are given without indication of how much water is available in absolute or relative (absolute in relation to total water holding capacity) terms.

We normalized the sap flux density using VPD by simply dividing the halfhourly J_s by corresponding halfhourly VPD data. Please see our response to the comment below.

Overall, since vpd is not the only influence, which is necessary to consider in order to compare the different site and species responses, a more complex approach seems to be necessary in order to differentiate between site and species impacts. Perhaps, this means using a model that describes gas exchange based on climatic as well as soil conditions.

We agree that a more complex model describing both immediate and slow responses to environmental factors including phenological events such as growth stages of different organs could bring more insights into the observed effects. For example, the size of the reaction to a drought or a heatwave during the leaf-developing period most probably differs from the reaction seen later in the season. Such models could also be useful in an analysis differentiating the effect of site conditions and species, apart from VPD. However, including such modelling at this stage in this study is an enormous task requiring specific knowledge and skills. In this study, we included automatic sap flow data over four sites accompanied by manual leaf-level measurements of CO₂ and H₂O gas exchange at different heights of the canopy, which we found to be a giant effort alone. Even though there are clear limitations in our study, such as missing process-based modelling, we find it valuable to share the unique data in a Nordic city experiencing extreme conditions and report that even

then, there were no clear indicators that trees in the different green spaces would notably decrease their ability to function and cool the environment. Therefore, as indicated already earlier, we decreased the focus on species-specific comparisons and physiological speculation and focused on the observed responses in transpiration and gas exchange. In addition, we included in the revised conclusions that there is a need for process-based modelling in order to validate the responses and omit the role of other driving environmental or e.g., phenological factors.

Despite the very different boundary conditions and species and the few samples for each condition, the discussion tries to differentiate between heat and drought effects although both influences were simultaneously occurring and can hardly be distinguished. This leads to counter-intuitive results (such as a restricting (significant?) role of soil moisture for forest gas exchange in the wet period) and very disputable conclusions (e.g. "severe weather events did not alter the stomatal action").

Thanks for the comment. We agree that the heat and drought are occurring simultaneously during a certain period. Although their effects can be hardly distinguished, we added new analysis and separate these stressful days into period of only heat, only dry and both heat-dry by the intersection of the heatwave days and dry period days which was derived as described in section 2.5. We analysed the response of sap flux density during only heat, only dry and both heat-dry periods at the four sites and found that the response during only heat was relatively higher than the other period at Park, Forest and Orchard; but at the Street site, there are no differences in the response of sap flux density during these periods (Appendix A6) and added the text accordingly in the manuscript (see below response)

The potential benefit of this study, which is the different response of species that a) do not close stomata, b) close stomata, c) are damaged by non-stomatal effects, could not be addressed due to the various degree of stress and different boundary conditions. Therefore, the conclusion is that species and site differences are causing the variation – which is probably true but could not really be shown given that neither species could be compared on different sites nor site influences could be evaluated using the same species. Accordingly, also the impacts that different species might have on their environment under heatwave conditions are highly speculative and are more based on literature than on measurements presented here.

We do acknowledge the worry about the solidness of our conclusions and therefore, we modified those according to the suggestion and removed the part where there is a comparison between sites and species. In addition, as stated already above, we focused there on the key message (just a minor decline if anything even though there were extreme conditions from the local perspective). We find that the revised discussion reflects the strength of this particular study without over-speculation and conclusions arising elsewhere.

Specific comments (and some technical corrections)

L1: I guess the role in offsetting CO2 emission is actually not important. If anything, consider pollution deposition effects. (see also L27)

Thank you for the comment! The offset by urban vegetation is found to be 6-14% of cities' anthropogenic emissions so even the value is low and they do not capture all emissions, we argue that their role is still significant (Hardiman et al. 2017, Vaccari et al. 2016, Havu et al. 2022). It is true that vegetation absorbs pollutants but at the same time, they emit BVOCs and particularly street trees can block the natural ventilation of street areas making the air quality worse. In any case, we added a comment amount the pollutant deposition to the sentence and removed the word important:

L1: *"Urban vegetation plays a role in offsetting urban CO2 emissions, mitigating heat through tree transpiration and shading, and acting as deposition surface for pollutants."*

L5: how many trees?

Three trees per site were selected. Information was now added to the abstract:

L5: *"We conducted sap flux density (J_s) and leaf gas exchange measurements of three trees per species"*

L10ff: Do you say that street trees reduced their transpiration during a heatwave (relative to other sites) but not during dry periods? Can you actually differentiate between the two kinds of stress?

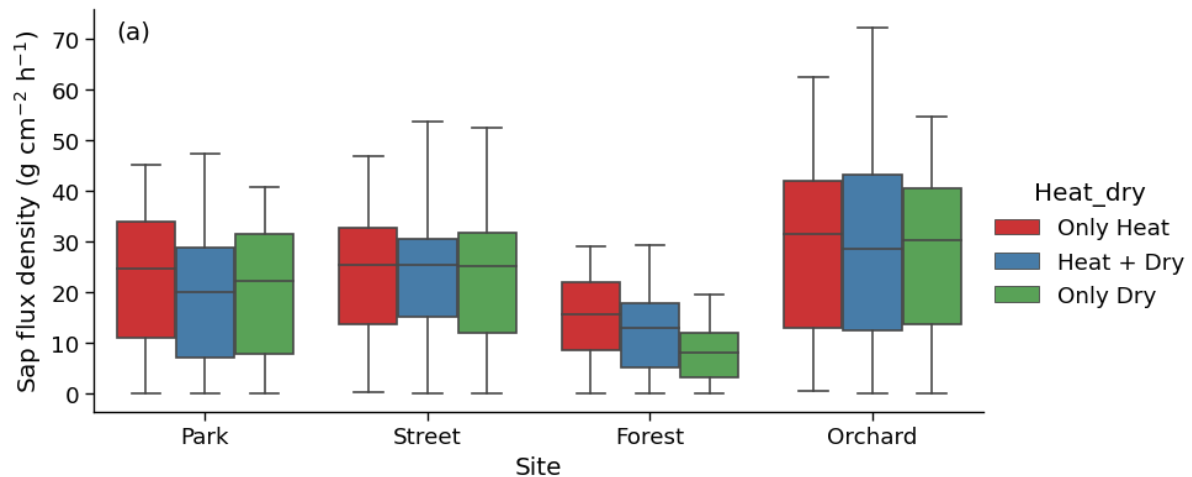
Thank you for the comment! We did not compare or differentiate the effect between heat and dry stress. In the results, we showed that there was no change or difference (same) in transpiration at the Street site during heatwave as compared to other heat periods, but the transpiration increased during dry period as compared to wet period.

However, as indicated in the general comments, we added new analysis to compare the effect of heat and dry separately by separating the period into three periods: Only heat, Only dry and both heat-dry by intersection of the heatwave and dry days which were defined earlier (as describe in section 2.5) and found that the effect of heat and dry periods did not change at the Street site but at the other three sites, the effect of heat stress on sap flux density was relatively higher than the effect of dry stress.

For clear understanding, we have reworded and added the sentences accordingly in the text. Also, an appendix figure was added as Appendix A6.

L13: *"but similar J_s was observed at the Street site during the heatwave as compared to the non-heatwave period."*

L278: *"We separate the period into three periods: only heat, only dry and both heat-dry by intersection of the heatwave and dry days which were defined earlier (as describe in section 2.5) and analysed the effect of only heat, only dry and both heat-dry on sap flux density and found out that the effect of heat was relatively higher than the effect of dry and both heat and dry at Park, Forest and Orchard while at the Street site, the effect of heat, dry and both are similar (Appendix A6)."*



L15ff: Here you say that there is no effect on stomata during heatwaves - also for street trees. How does this fit to the indication of street trees having reduced their transpiration?

Thank you for this comment! There might have been a misunderstanding. In our result, we did not find any changes in the stomatal regulation during heatwave and dry period, thus indicating no significant effect on stomatal activities during these periods. Also, there was no change in sap flux density at the Street site during heatwave period. For more clarification, we have modified the sentence as shown in previous response.

L13: *"but similar J_s was observed at the Street site during the heatwave as compared to the non-heatwave period."*

L17-20: In one sentence you say that drought limited transpiration in forests and in the following it is stated that drought was so mild that it could not affect stomata control. What did I miss here??

Thank you for the comment. Here in these lines, we want to describe the control of VPD over the sap flux density and at the Forest site, J_s increases with the rise in VPD but saturates after certain level of VPD, and we think that it might be due to the low water availability at Forest site. We reworded the sentence as follow:

L19: “while at the Forest site, the increase of J_s with the rise in VPD saturates after certain level of VPD, which might be evident due to low soil water availability at the Forest site during these hot and dry periods.”

L28/29: regulating energy balance and cooling the surrounding is actually the same.

As suggested, energy balance is removed, and the sentence has been reworded as

L33: “they have the potential for carbon sequestration and storage, and regulation of water for cooling the surroundings”

L29: pollution deposition, not ‘infiltration’

Infiltration changed to deposition, as suggested.

L32/33: Sorry, but none of the indicated references are saying that urban trees are important to mitigate the global GHG. In the contrary!

We are sorry for the confusion! We changed “mitigate the global GHG” to “cities’ GHG emission” in the revised text. New references were updated and cited accordingly.

L34: “Urban trees also provide other ecosystem services such as cooling effect through shading, pollutant deposition and infiltration, aesthetics and recreation, buffer for noise and wind, and soil conservation (Brack, 2002; Jo, 2002; Jim and Chen, 2009; Pataki et al., 2009; Hardiman et al. 2017).”

L35: human disturbances? Do you mean damages due to traffic or pruning by urban managers?

We have reworded the sentence to make it clear and added a reference (Czaja et al., 2020).

L45: “In urban condition, trees are subjected to human disturbances such as construction activities, dense building, and vandalism (Czaja et al., 2020)”

Czaja, M., Kołton, A., and Muras, P.: The Complex Issue of Urban Trees—Stress Factor Accumulation and Ecological Service Possibilities, *Forests*, 11, 932, <https://doi.org/10.3390/f11090932>, number: 9 Publisher: Multidisciplinary Digital Publishing Institute, 2020

L43-45: I cannot derive this conclusion from Bussotti et al.. Did I miss something?

Apologies for the misunderstanding. We have reworded the lines for better clarification.

L54: *"In urban areas, tree reactions to heatwaves are rarely studied, but trees in natural forests can adapt to the rising temperature by enhancing growth and utilized water more efficiently, provided enough moisture in the soil (Winbourne et al., 2020). The foliar temperatures of urban trees are often higher, which limits photosynthesis and transpirations through enzyme activity and stomatal regulation (Bussotti et al., 2014), hence such acclimation may not be apparent in urban settings."*

L65: What's the difference between research question 3 and 1/2? Do you want to address the impacts in combination?

Thank you for the comment. We would like to address the response or effect of heatwave and drought in urban trees transpiration and leaf gas exchange in research questions 1 and 2, while in research question 3, we would like to address the main environmental driver affecting the transpiration separately in heatwave and drought periods. For better clarification, we have reworded the 3rd research question as follow:

L82: *"What are the main environmental drivers affecting transpiration rates during heatwave and drought in urban green areas?"*

L60ff: Since the research capacity is limited, I think it is logical to assume that not all urban trees but a selection based of the most representative species is targeted. Please elaborate the text to make it more specific.

True, we are not measuring all trees. We modified the first sentence of that paragraph (original lines 59-60) where we state that we measured a set of typical urban trees as suggested.

L75: *"In this study, we measured the functions of a set of typical urban tree species, particularly their transpiration and leaf gas exchanges, during heatwave and drought periods in a boreal urban environment in Helsinki, Finland."*

L71-75: Shift to site description.

This line has been moved to site description as per reviewer's suggestion.

L104: *"The summer of 2021 was hot and dry as the mean air temperature in July 2021 was 21.6°C, being 21% higher than in July 2020 (16.7°C) and 19% higher than the average mean temperature in July (18.1 °C) during a climatic reference period (1991 to 2020). The total precipitation for the months of June and July 2021 (86 mm) was 51% lower than during June and July in 2020 (177 mm) and 27% lower than the average total precipitation in June and July during the climatic reference period (117 mm)."*

L80: sparse tree cover! Roadside single trees (not a plantation)!

Thank you for the correction. Roadside plantation has been changed to single line roadside trees accordingly.

L118: do you mean damages by pedestrians?

It has been reworded to "damage or disturbances by pedestrians" for more clarification.

L134: 'normalizing' flux density by dividing by vpd seems strange to me since velocity will likely have an S-shape response of vpd. Is this a common strategy (please cite) or may it be that you first would need to derive the dependency between both and then normalize by applying the respective function? Or did you do that as it seems later on that you fitted curves to this relationship?

Thank you for the comment! We did not normalize with any functions or with min-max normalization techniques. Here, we have only divided the half hourly J_s data with their corresponding half hourly VPD in order to check the effect of VPD during these different periods and also to examine any dependency of J_s on other environmental variables during these different periods. For better clarification, we have reworded the sentence as follows:

L157: "In addition, we normalized the sap flux density using VPD by simply dividing the halfhourly J_s by corresponding halfhourly VPD data. This is done in order to assess the effect of VPD and also to examine the dependency of J_s on other environmental variables during these heatwave and drought periods"

L175ff: I don't understand this. What is the control period to define heatwaves? The long-term (30year) average for the respective season/month/specific days? The heatwave duration was more than one month? Can you provide explicit temperatures?

Thank you for your comment. Here, we have considered the control period as an average of daily maximum temperature for the last 30 years and added new sentence for more clarification and mean temperature values during the different heatwave periods have been provided accordingly.

L205: "Here, we have considered the control period as an average of daily maximum temperature for the last 30 years. Accordingly, our study period was categorized into heatwave (21.9 °C; 17 June 2021 to 18 July 2021), pre-heatwave (16.8 °C; 1 June 2021 to 16 June 2021), post-heatwave (16.8 °C; 19 July 2021 to 31 August 2021) and no heatwave (17.5 °C; 1 July 2020 to 31 July 2020) periods."

L183: What do you mean with a 'further' separation of periods ... based on soil moisture? What is this give an absolute value that you indicate here – an arbitrary value between field capacity and wilting point? What is the water content relative to field capacity at this point?

Thank you for the comment. Here, we have removed the word "further" to avoid confusion. We meant to say that the period has been separated into dry and wet period based on no precipitation days and low threshold soil moisture data after considering the monthly SPEI value. Now, we have calculated the field capacity and wilting point based on soil texture type according to Hagemann & Stacke (2015) for the four sites and estimate the relative extractable soil water (REW) using soil moisture data, field capacity and wilting point. We considered REW threshold of 0.45 to determine the drought days along with the daily precipitation values. For better clarification, we added an estimation of wilting points at each site, and we reworded the sentences as follows:

L210: "To determine the drought period, monthly Standardised Precipitation-Evapotranspiration Index (SPEI, Vicente-Serrano et al., 2010) was calculated and found out that June (SPEI = -0.7) and July (SPEI = -0.3) 2021 had mild drought conditions. According to the particle size distribution, all other sites were determined as sandy loams except for the Orchard which was clay. According to Hagemann, S Stacke T (2015), the wilting point and field capacity of sandy loam is 10 % and 22.9 %, respectively and of clay is 25 % and 38.4 %, respectively. We calculated the relative extractable soil water (REW) from soil moisture data, field capacity and wilting point of the site according to Granier et al., (1999). We considered days with precipitation less than 1 mm and mean REW in the depth of 10cm less than 0.45 as a dry period for all sites. As a result, the dry period was (22 June 2021 to 27 July 2021) and wet period (28 July 2021 to 31 August 2021)."

L185: Are the hypotheses (if better defined) not better evaluated with transpiration than with sapflux density? Or by Water use efficiency?

Thank you for your comment which is correct! We have changed the transpiration into sap flux density in the hypothesis as per your suggestion.

L202: I would rather say site climate instead of microclimate (which is normally used for microsites such as canopy layers).

Thank you for the comment! We have changed microclimate to climatic conditions in the text as suggested.

L206: Soil moisture at what time of the year? Or do you mean maximum water content?

It is the average of soil moisture content during the summer months (June, July and August) of 2021. To make it clearer, below sentences have been added

"L240 The mean of the meteorological variables (air temperature, VPD, soil temperature and soil moisture) during the summer months (June, July, August) of 2021 were considered for comparison."

"L246 Mean soil moisture content varied largely as the Orchard site had the highest (0.37 m³ m⁻³) and the Forest site the lowest (0.09 m³ m⁻³) whereas Park and Street sites had 0.13 and 0.22 m³ m⁻³ respectively."

L211: Do you mean sapflow rate instead water use? (Water use would be expressed per m² ground area).

Yes true, it is sap flow rate. Thanks for the correction and now it has been changed to sap flow rate accordingly.

Figure 3: Strange that there is no increase in soil moisture at the 1st of July despite considerable rainfall. Any explanation for this?

Thank you for your comment! Actually, it does increase, particularly at the topsoil (10 cm depth) but at 30 cm depth soil, there is no sign of change as it seems the water didn't infiltrate well to the bottom soil and likely more of runoff or flash short rain on 1st July. I hope this explanation give more understanding on it.

Table 2: Do you mean average soil moisture within the indicated period. Please use average (relative) available soil moisture instead.

Thank you! We have changed the caption accordingly.

Table 2: "Monthly mean air temperature (Air T, °C), mean vapor pressure deficit (VPD, kPa), mean soil temperature (Soil T, °C) and mean soil moisture content (m³ m⁻³) for the four study sites in 2021."

L236: Still unclear how a normalization was done (see also comment to L134).

We only divided the half hourly J_s data with their corresponding half hourly VPD in order to check the effect of VPD and also to examine any dependency of J_s on other environmental variables during these different periods. Hope you will find this to be cleared now in the revised manuscript!

L282: vpd is due to impervious cover? Do you mean it is due to the increased temperatures that are caused by the impervious cover? Or are you assuming that vpd could be lower because of soil evaporation?

Thank you for the comment. Here, we observed that the VPD was higher at the Street site as compared to other site and we assumed that the high VPD was mainly due to larger impervious cover at the street site (fig 1c), which exacerbates the surface/ air temperature. For more clarification, the sentence has been reworded as follow:

L324: "At the Street site, VPD was clearly higher as compared to the other three sites and this is likely due to the larger cover of impervious surface at the Street site where the air temperature is marginally increased"

L289ff: Again, it is difficult to comprehend, what 'water use' means. If it is defined on the sapwood area, stem size indeed plays a major role (as indicated), but is this also the case if the water consumption/transpiration on a ground area basis would be calculated? I guess the latter is more important in the context of comparing site conditions.

Thanks for clarification! Here, we have changed the tree water use to sap flow rate or sap flux density accordingly, since we didn't really calculate with either sapwood area or crown area due to lack of these information and the literature derived sapwood area are not accurate to scale up to the tree level water use. We will not consider water use throughout the text to avoid confusion.

L291ff: Similarly, water availability is only meaningful if it is the water storage capacity minus the water bound by the wilting point. The definition is however, not clear.

Thank for the correction! True, water availability is meaningful in this context. However, we considered soil moisture content data due to lack of field capacity and wilting point data. Now, it has been changed to "soil moisture content".

L298ff: needs references. For *Betula* isohydry, I would recommend to consider Zapater et al. 2013. *Tilia*, however, seems also to be fairly isohydric (Leuschner et al. 2019), so I am not sure about the logic of the reasoning here.

Thank you for the suggestion. Now, we have added the suggested references accordingly in the text.

L301ff: What do you want to tell here? That *Tilia* may use more or less water than other trees? Or that site conditions might influence the transpiration rate of *Tilia*? But this is generally true for any species.

Thank you for the question! Here, we want to tell that in other studies in the street site of Munich and Helsinki, variability in tree water use have been observed and are likely due to differences in tree species type. For better clarification, we have reworded the sentences as follows:

L351: *"Other studies in the streets of Munich and Helsinki have reported variability of transpiration rates, mainly due to the differences tree species. In Munich, the transpiration of Tilia cordata Mill. were three times higher than water use of Robinia pseudoacacia L. tree in the (Rahman et al., 2019) and in the street trees of Helsinki, Alnus glutinosa have four times higher tree water use than Tilia x vulgaris (Riikonen et al., 2016)"*

L323: replace 'cover' by 'represent' or similar (of course, one day does not cover the whole period)

As per the suggestion, 'cover' has been changed to 'represent' in the text.

L324ff: This is a conclusion that is contrary to the statement that J_s/VPD declined during drought. Please provide an explanation for your conclusion. I can also not see where you see a similarity to Gillner et al. despite the very general fact that transpiration is mostly higher in summer. If this is about species comparison, the whole paragraph needs to be directed towards this.

Thank for this interesting comment! I think we have misinterpreted the results with the ratio between J_s and VPD. The ratio value reduced during drought in all sites (fig 6b), which indicates the significant role of VPD during drought; however, while looking further into the relative importance of VPD in explaining the observed variation in sap flow during heatwave and dry conditions (Table 5), the influence of VPD varied at the four sites. We have also removed the reference Gillner et al 2015 as it is not relevant to the context.

For better clarification, we have reworded the sentences as follows:

L371: *"The ratio between J_s and VPD was significantly reduced during all periods and at all sites, which indicates the substantial role of VPD; however, the relative importance of VPD over daily sap flow variation differed at the four sites and during different periods of heatwave and drought. The response of sap flow with VPD was less sensitive during heatwave and drought periods as compared to other heatwave periods and wet period (Table 4)."*

L333ff: You are probably indicating that the drought was not sufficient to cause damages to photosynthesis (non-stomatal effects, see e.g. Gourlez de la Motte et al. 2020), since you already discussed that a stomatal effect should have taken place. In addition, the stomatal control may be differently strong, depending on the isohydry or anisohydry of the species. The literature references should support your respective message and not only indicate similar results under possibly similar conditions.

Thank you for this interesting comment and the provided reference. We have added the below sentence with the suggested reference as per the suggestion.

L391: "Interestingly, it was previously reported that the non-stomatal origin limitation was responsible for reductions of photosynthesis in temperate forest during European drought 2018 (Gourlez de la Motte et al. 2020) but these non-stomatal effects might play some role in our urban site but yet to study, and it may be also due to tree species behaviours (isohydril or anisohydril) towards drought response."

L351: delete ', suggesting that ... at these sites' (redundant)

As suggested by reviewer, the words have been removed from the sentence accordingly.

L389-391: not shown in this paper

We have removed the sentences.

L391-393: this cannot be derived from this study

We have changed the sentences accordingly

L393/4: wishful thinking, not a conclusion

Thank you. We have changed it accordingly.

Mentioned references

Gourlez de la Motte L, Beauclair Q, Heinesch B, Cuntz M, Foltýnová L, Sigut L, Manca G, Ballarin I, Vincke C, Roland M, et al. 2020. Non-stomatal processes reduce gross primary productivity in temperate forest ecosystems during severe edaphic drought. *Philosophical Transactions of The Royal Society B Biological Sciences* 375(1810): 20190527.

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Added references:

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