Dear Authors

Congratulations, you are almost there!

I have now received the report of the one nominated referee on your first revision and it was suggested to accept for publication, after consideration of a number of points. The evaluation does not require new calculations and interpretations, but mainly tries to harmonise the presentation in the text with the actual results found. Mentioning of heat wave and drought responses has become less relevant after the clarifications made in discussion and the revision.

A number of additional suggestions on the presentation are made, which I ask you to consider or to clarify case by case.

With kind regards,
Andreas

Dear Editor,

We would like to thank you for your report and support throughout the reviewing process. We have considered the points suggested by the reviewer in the revised manuscript accordingly. However, when it comes to using the heatwave and drought concepts, we pursue to use them also in the revised manuscript. We use standard and widely used methods for classifying the heatwave (definition by Fischer & Schar, 2010) and drought (SPEI values). Based on these, the local heatwave and drought were indeed experienced in the Helsinki region. The maximum temperature during the heatwave may not be as high as compared to southern regions but for Helsinki and its vegetation, the temperatures are clearly elevated reaching 30 °C and the daily temperatures are higher than 6 °C during the heat period when compared to the long term (1990 to 2020) reference data. Thus, the definition of Wikipedia for heatwave is also reached. In the revised manuscript, we clarified the definition of heatwave and emphasised the local nature of both heatwave and dry conditions. We added a new subsection in the revised manuscript for this and further motivate this in the detailed point-by-point responses below. The original comment is always in black and our response in blue.

With regards,

Joyson and co-authors

General comments

I acknowledge that more information about the boundary and driving conditions have been provided in the new version. In particular the results section has also much improved and looks mostly good now.

We would like to thank the reviewer for acknowledging the revised manuscript.

However, based on the knowledge provided and also consistent with the discussion as it is now, it seems necessary removing the indication of drought and heatwave from the manuscript throughout the text and concentrate on the potential of Finland's urban trees to provide the ecosystem service of heat mitigation under somewhat higher temperatures (such as expected in the future?).

As mentioned, we somewhat disagree with the suggestion to remove the indication of drought and heatwave. Our definition of heatwave is based on Fischer and Schär (2010) with over 1000 citations (in Google Scholar, see later). Moderate drought on the other hand is based on a commonly used drought indicator Standardized Precipitation Evapotranspiration Index (SPEI, Vicente-Serrano et al., 2010) calculated using local precipitation and potential evapotranspiration (PET). Thus, based on these two commonly used metrics we can quantify a local heatwave and drought. We have now sharpened the definitions in the manuscript (L205-220) and added a new section 2.5.

Also, we added text in the manuscript about the potential of urban trees in providing heat mitigation under higher temperatures in the Introduction and Discussion sections as per the suggestion.

L43-44: "Particularly, under extremely high temperatures, the potential of urban trees in heat mitigation has been shown to be significant (Gillner et al., 2015; Schwaab et al., 2021)"

L458-460: "The elevated levels of transpiration (represented by high J_s) observed in the studied green areas during the heatwave indicate the presence of transpirational cooling. This phenomenon could hold substantial promise for alleviating extreme heat conditions caused by exceedingly high temperatures."

Added reference:

Fischer, E. M. and Schär, C.: Consistent geographical patterns of changes in high-impact European heatwaves, Nature Geoscience, 3, 398–403, https://doi.org/10.1038/ngeo866, number: 6 Publisher: Nature Publishing Group, 2010.

Gillner, S., Vogt, J., Tharang, A., Dettmann, S., and Roloff, A.: Role of street trees in mitigating effects of heat and drought at highly sealed urban sites, Landscape and Urban Planning, 143, 33–42, https://doi.org/10.1016/j.landurbplan.2015.06.005, 2015

Schwaab, J., Meier, R., Mussetti, G., Seneviratne, S., Bürgi, C., and Davin, E. L.: The role of urban trees in reducing land surface temperatures in European cities, Nature Communications, 12, 6763, https://doi.org/10.1038/s41467-021-26768-w, number: 1 Publisher: Nature Publishing Group, 2021.

> As it is, the manuscript states that heatwave and drought conditions were observed but impacts indicated that neither heat nor drought stress occurred – which is irritating at the least. I can corroborate my opinion by the authors definition of a heatwave as just 'exceeding the daily maximum air temperature of the control period'. The general definition of heatwave, however, is a 5 oC difference (see e.g. Wikipedia). The July 2021 seemed to be 3.5 oC warmer than the average from the 30 years before but the actual difference of the period defined as 'heatwave' (17.06-18.07.) is not given in the manuscript. If the weather doesn't meet the general definition, I strongly recommend to avoid the term 'heatwave' in this manuscript.

The 3.5 °C difference is based on the mean monthly temperature difference between July 2021 and July of the control period. When we look daily level, larger differences between the summer 2021 heatwave and the control period are seen (see below). We apologise for the misleading presentation. We have now added the actual temperature difference during the heatwave in the revised manuscript (L213).

We followed the Fischer and Schär (2010) definition of heatwave where heatwave is defined as the spell of at least six consecutive days with maximum temperatures exceeding the local 90th percentile of the control period. In our study, a heatwave was defined as a period of consecutive of at least 6 days when the local daily maximum air temperature of the year (2021) exceeds the daily maximum (100^{th} percentile) air temperature of the control period (1991-2020).

Based on this definition, the daily maximum temperature for the period (17 June 2021 to 18 July 2021) exceeded the daily maximum air temperature of the control period (1991-2020) and stayed continuous at least for 6 days. The daily maximum air temperature during this heat period ranged from 20.5 to 30.2 °C, with a mean daily difference of 6 °C (ranging from 1.8 to 10.8 °C) with the control period. Accordingly, the period was categorized into heatwave (26.4 °C; 17 June 2021 to 18 July 2021), pre-heatwave (21.5 °C; 1 June 2021 to 16 June 2021), post-heatwave (20.4 °C; 19 July 2021 to 31 August 2021) and no heatwave (19.6 °C; 1 July 2020 to 31 July 2020) periods for comparison. The difference is also visualized in the figure below (Fig. C1).

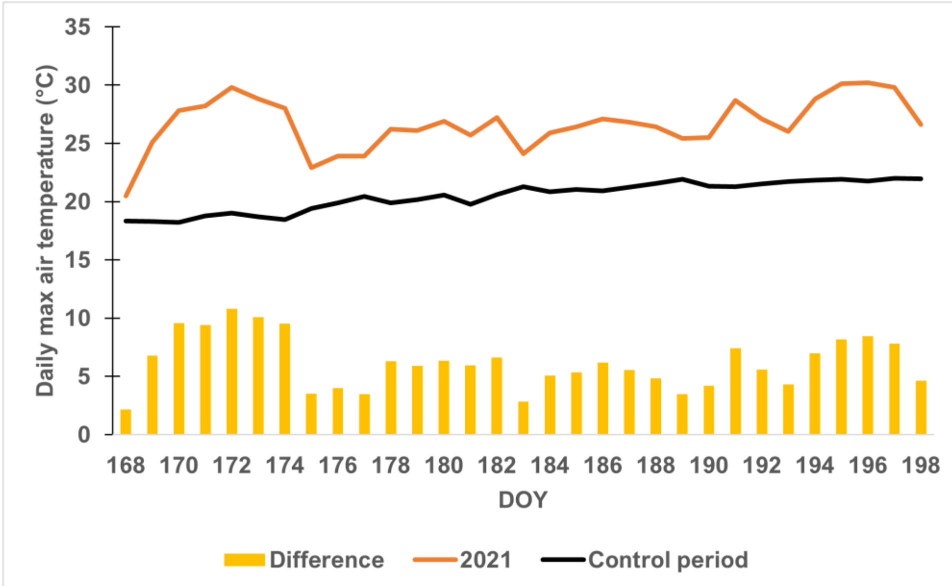

Figure C1: The daily maximum air temperature from 17 June to 18 July in 1991-2020 (black), in 2020 (red) and their difference (yellow bar). DOY indicates the Day of Year.

Thus, looking at the daily level, also the Wikipedia definition for heatwave is met as the average difference of daily maximum temperature exceeds more than 5 °C the control period during the local heatwave period.

In the revised manuscript, we have separated the description of heatwave and drought into a new subsection for a clear definition of Heatwave detection.

L230 -236: "According to Fischer and Schär (2010), a heatwave is defined as a spell of at least six consecutive days with maximum temperatures exceeding the local 90th percentile of the control period. Accordingly, in our study, heatwave (Appendix A1) as defined against a control period spanning from 1991 to 2020. Further, our study period was categorized into four periods: heatwave (17 June 2021 to 18 July 2021), pre-heatwave (1 June 2021 to 16 June 2021), post-heatwave (19 July 2021 to 31 August 2021) and no heatwave (1 July 2020 to 31 July 2020) periods with mean daily maximum air temperatures of 26.4 °C, 21.5 °C, 20.4 °C and 19.6 °C respectively. The daily maximum air temperature during the heat period ranged from 20.5 to 30.2 °C, with a mean daily difference of 6 °C (ranging from 1.8 to 10.8 °C) above the average temperature in the control period."

I also recommend also to be careful with term 'drought'. The respective 2-month period is characterized to have 86mm rainfall (instead of usually 117). The estimated soil water availability hardly decreased below 45 % relative available water. Thus, the results basically show that any increase in sap flux is due to a higher vpd resulting from higher temperatures.

Thank you for your comment! It is correct that the respective 2-month period experienced 86 mm rainfall during 2021 as compared to 117 mm for the climatic reference. We agree that the difference between these values is not dramatic. Monthly precipitation is, however, complicated indicator for drought as precipitation might not be evenly distributed throughout the period. For example, if the rain events take place at the beginning of the first month and late in the second month, there is a great change that the vegetation suffers from drought in between, especially if it takes place in the middle of the growing season with high evaporative demand. Here, Standardised Precipitation-Evapotranspiration Index (SPEI) calculated based on precipitation and potential evapotranspiration (Thornthwaite, 1948) indicated moderate drought during June and July 2021. We calculated the monthly SPEI based on the difference between daily precipitation and potential evapotranspiration (PET). PET was calculated using daily average temperature based on Thornthwaite (1948) equation. SPEI values in our study site fell into the moderate drought category, with SPEI = -1.4 in June and SPEI = -0.8 in July 2021.

We further used the relative extractable soil water threshold and no precipitation days to detect the days of dry or drought periods during these 2 months (June and July 2021).

We added the description of drought detection in the revised manuscript, in a similar manner as the heatwave (see the comment above).

L237-243: "To determine the drought period, a monthly Standardised Precipitation-Evapotranspiration Index (SPEI, (Vicente-Serrano et al., 2010) was calculated, indicating that June (SPEI = -1.4) and July (SPEI = -0.8) 2021 had moderate drought conditions. Here, we considered days with precipitation less than 1 mm and mean relative extractable soil water (REW) at the depth of 10 cm less than 0.45 as a dry period for all sites. As a result, the dry period was from 22 June 2021 to 27 July 2021 and wet period from 28 July 2021 to 31 August 2021. We calculated the REW from the soil moisture data, field capacity and wilting point of the site according to Granier et al. (1999), where the wilting point and field capacity of sandy loam (Park, Street and Forest) are 10 % and 22.9 %, respectively and those of clay (Orchard) are 25 % and 38.4 %, respectively based on Hagemann and Stacke (2015)."

The relatively small decrease of stomatal conductance in park and orchard trees is a bit irritating and might indicate a beginning soil water influence or a stronger isohydricity of Tilia cordata and Malus compared to the other two species. The impact, however, is obviously too weak to characterize this as drought stress.

We agree with the reviewer that the relatively small decrease in stomatal conductance in park and orchard might be due to isohydricity of the tree species of *Tilia cordata* and *Malus sp*. However, the influence of soil moisture during the dry period seemed to impact less the stomatal conductance and thus no visible impact of the stress. We reworded the sentences in the revised manuscript.

L420-422: "At the Park site, the relative decrease in gs during the dry period might be due to the influence of soil moisture reduction during the dry period and also due to the isohydric behaviour typical for Tilia cordata growing in the Park.".

Specific comments:

According to the general comments, wording needs to change in all parts of the manuscript, and it is too tedious to make specific suggestions basically for each sentence. Therefore, I only indicate what I feel sounds particularly strange in every section.

Thank you for the comment. We have now carefully checked the language and improved it accordingly throughout the manuscript.

Abstract

- Imprecise problem definition (L4, 5)

We reworded the sentences as below:

L2-4: "The frequent occurrence of heatwaves and concurrent drought conditions significantly disrupts the processes of urban trees, particularly their photosynthesis and transpiration rates. Despite the pivotal role of tree functioning in delivering essential ecosystem services, the precise nature of their response remains uncertain."

- To detailed methodology (three trees)

We reworded accordingly

L7-10: "We conducted sap flux density (Js) and leaf gas exchange measurements of four trees species (Tilia cordata, Tilia × europaea, Betula pendula, Malus spp.) located in different urban green areas (Park, Street, Forest, Orchard) in Helsinki, Finland. Measurements were made, over two contrasting summers 2020 and 2021."

- Exaggerated boundary conditions (heatwave, drought)

We have added local heatwave and also please see the above comments for heatwave and drought description.

- It is irritating to see the results obtained for the street trees highlighted here.

Here, we have highlighted the results for all the sites and reworded the sentence for better clarification.

L14-16: "When comparing the heatwave and non-heatwave periods, a 35-67% increase in Js was observed at the Park, Forest, and Orchard locations, while the Street site exhibited comparable values."

Introduction

- I still think that the 'vital role in compensating urban CO2 emissions is exaggerated (e.g., Ariluoma et al. indicates 0.1 % for Helsinki residential greening, Street trees compensate for 0.08% of the transport sector in Bolzano). Don't mix up carbon stocks with net sequestration rates. It is also not important to dive on this because the current study only investigates the water balance.

The contribution from urban vegetation in offsetting anthropogenic emissions of cities ranges between 6-14% (Hardiman et al. 2017, Vaccari et al. 2016, Havu et al. 2022). Despite the modest magnitude and incomplete coverage of all emissions, we contend that their role remains noteworthy. We have reworded the sentence.

L34-36: "Urban green spaces have a role in offsetting urban CO2 emissions and alleviating the urban heat island (UHI) effect, given their potential for carbon sequestration, storage, and the regulation of water to cool their surroundings (Lindén et al., 2016; Bowler et al., 2010, Hardiman et al. 2017, Havu et al. 2022)."

Added references:

Hardiman, B. S., Wang, J. A., Hutyra, L. R., Gately, C. K., Getson, J. M., and Friedl, M. A.: Accounting for urban biogenic fluxes in regional carbon budgets, Science of The Total Environment, 592, 366–372, https://doi.org/10.1016/j.scitotenv.2017.03.028, 2017.

Havu, M., Kulmala, L., Kolari, P., Vesala, T., Riikonen, A., and Järvi, L.: Carbon sequestration potential of street tree plantings in Helsinki, Biogeosciences, 19, 2121–2143, https://doi.org/10.5194/bg-19-2121-2022, 2022.

Vaccari, F. P., Gioli, B., Toscano, P., and Perrone, C.: Carbon dioxide balance assessment of the city of Florence (Italy), and implications for urban planning, Landscape and Urban Planning, 120, 138–146, https://doi.org/10.1016/j.landurbplan.2013.08.004, 2013.

- Too much emphasize on damages and extreme conditions that may cause uncertainty, which is not addressed in this article. Concentrate on conditions that may be on the verge of limitation such as water supply (due to pervious soils) and surface overheating (due to already increased temperatures and less options for transpiration cooling).

We have removed and reworded accordingly

L51-55: "In urban conditions, trees are subjected to harsh environmental conditions, such as elevated air temperature, lower air humidity, limited soil water and nutrient availability, compared with surrounding areas (Nielsen et al., 2007). Climate extremes such as heatwaves and drought affect the physiology of urban trees and thus also their potential to mitigate the effect of and to adapt to climate change. Hence, it is important to understand the response of the physiological processes regulating urban trees' functioning during extreme climate events."

- Shortening and more precision is needed (e.g., L60-68). Also, gas exchange (including transpiration) is still not a function but a process (that might serve a function).

We have reworded the sentence as per the suggestions.

L99-100: "*In this study, we measured a set of typical processes regulating the functions of urban trees, specifically transpiration and leaf gas exchange, during local heatwave and drought in the boreal urban environment of Helsinki, Finland"*

- The setting is not suitable to address the research questions (see above).

We clarified in the revised text that the heatwave was local in the revised manuscript. Please see the above comments for heatwave and drought description.

- Stomatal closure decreases photosynthesis, not photosynthetic potential (or better: capacity). And sapflux isn't the driver but the result. If you want to hypothesize that heat and/or drought is decreasing photosynthetic capacity (that's possible too), stomatal closure would be a result of this (not the other way around).

Within a day, the light intensity determines the rate of photosynthesis. If the stomata are (partially) closed, the capacity (or potential) of a leaf to photosynthesize is lower than when those are closed. In practise, by measuring the light response curve of photosynthesis, we can determine the capacity (or potential) of a leaf to photosynthesize on that day whereas the varying solar intensity determines the actual rate of photosynthesis. In the analysis, we have analysed e.g. the derived maximum rate of photosynthesis which indicates indeed the capacity than actual photosynthesis during that day as we did not want the possibly varying light conditions during the measurement day to cause extra variation in the results. Otherwise, we fully agree with the reviewer, and we have further clarified and reworded the hypothesis.

L110-112: *"H1) While increasing VPD during heatwaves increases the driving force for transpiration and thus sap flow, it also triggers stomatal closure, ultimately leading to a decrease in photosynthetic rates and a decoupling of VPD and leaf gas exchange rates"*

Methods

- Any references for indicating all sites/tree species as 'drought tolerant' in Table 1? Any definition for 'tolerant'? Wouldn't 'isohydric/anisohydric' be more indicative?

We have changed to isohydric or anisohydric in the Table 1 as per the suggestions and also added the references accordingly.

- Indicate that the values in Table 1 are means from three individuals (selected how?)

We have added in the table caption that the values are from mean of the three individuals where we conducted sap flux and leaf gas measurements.

- CO_2 concentrations for photosynthesis measurements were done under ambient conditions? Or set to 415ppm? If set – how? If not set – what were the ranges?

We have set the CO_2 concentrations at 415 PPM during the measurements as the instrument has the functionality for a user to adjust temperature, humidity, radiation and CO_2 concentration. Now, the words "ambient conditions" from the sentence is removed.

Results

- The climate in the two years is described two times in Methods as well as here. It is thus redundant.

We have removed it from the methods and reworded briefly:

L110-111: *" The summer of 2021 experienced elevated temperatures at 21.6°C, which were 21% higher, along with minimal rainfall at 86 mm, showing a 51% deficit compared to the reference period."*

> - I am still of the opinion that mean soil moisture is meaningless (Table 2). Since the soil texture has been estimated, it is possible to provide estimated relative or absolute available water instead. It seems that this has been provided in the appendix but should be in the main document.

We have added the available water capacity in the main text.

L269: "The soil water availability varied from 12.9% to 25% at the four sites (Appendix A1)."

> *- That vpd is not significant as a driver for street trees at some time seems purely related to data availability. The impression should be avoided that the data actually show that there is no relation between vpd and sapflux.*

We have reworded the sentence to avoid the misinformation.

L298: *"During wet period, VPD explained a higher share of the variation of J_s at Park, Forest and Orchard site. At Street site, data availability was low and thus, the relationship could not be tested during wet period (Fig. 7)."*

> *Discussion*
> *- If any, a summary in the beginning of a discussion should be brief and should avoid conclusions (that come in the end). In any case, it should be clearly indicated that the hot (not the dry!) conditions drive water use (measured AS sapflux, or measured with sapflux METHODOLOGY).*

We have modified the summary according to the comment.

L346-350: *"In this study, we assessed the response of urban tree water use and leaf gas exchange during hot and dry summer 2021, across four urban green areas in Helsinki. Results indicated increased sap flux density in trees during the hot and dry periods, whereas carbon assimilation, stomatal conductance, and leaf-level transpiration remained largely unaffected. Sap flux density increase in such periods varied among the studied urban sites with distinct tree species and growth conditions. VPD emerged as the primary factor influencing tree water use in the heatwave and dry conditions. "*

- I generally fully agree with the statements about the overall findings, but the word 'adaptations' is clearly not used in the correct frame. Observations just didn't indicate any stress apart from a mild stomata response.

We have removed the word "adaptations" and reworded accordingly.

L350-352: *"In summary, the urban trees in our study exhibited typical functioning during the summer of 2021, suggesting that the hot and dry conditions did not induce significant physiological changes or adjustments. However, we found some interesting insights that we will discuss further in this chapter."*

- I appreciate highlighting the also investigated differences between the urban green sites with regard to climate. (But check the logic throughout the text. For example, it should be the temperature that is affected by pervious cover at the street site (also in the example of Los Angeles), which is then affecting vpd. If the temperature difference is really only marginal, a reason for the vpd effect is missing and needs to be provided).

We agree with the reviewer and reword the sentence there to highlight the role of temperature as the driver for increased VPD and checked the logic throughout the text.

Line 370-371: "*At the Street site, VPD was higher than at the other three sites because of the higher air temperature likely due to the larger cover of impervious surface*."

- Similar as has been stated before, the decrease of soil moisture is not a good indication of how much water is still there to transpire. Nevertheless, a decrease of 58 to 62 percent also give room for the assumption that there is quite some remaining water to transpire left.

We fully agree that relative water content or some other similar index describing the water available from plants and microbes considering also the soil water holding properties is better indicator that soil moisture content alone. Nevertheless, we think that there was a slight misunderstanding here as we are stating in the text that the soil moisture decreased by certain percentage during the heatwave and drought whereas we did not state here the pre- and post-event soil water contents. We improved the sentence to avoid further misunderstanding.

Line 416-419: "*During the dry period of this study*, *soil moisture content was notably reduced, ranging from 18% to 62% less compared to the wet period across all four locations. Similarly, during the heatwave period, the soil moisture content dropped significantly, ranging from 30% to 58% lower than the pre-heatwave period at all sites, except for the Street site.*"

- Non-stomatal effects that were triggered before stomatal responses are possible but I don't see any indication of it. Does the An decreased relatively larger than gs? If not, it is probably not playing an important role here.

We agreed with the reviewer that there is no indication of non-stomatal effects. Thus, we have removed the part regarding the non-stomatal effects from the discussion section. Moreover, we also didn't see any changes in A/ci analysis.

- Note that the species-specific saturation of the sapflux/vpd curve can be explained by specific wood properties that allow for a certain maximum conductance only.

Thank you and fully agreed with the reviewer.

- Note that sapflux cannot be explained (generally) by many factors. You may use 'influenced' if necessary. On the other hand, this rarely seems relevant here.

We agree and here, we changed the word "explained" with "influenced" as .

- Some parts of the discussion can certainly be shortened, partly because of redundancy.

We have shortened the discussion part as per the suggestions.

Mentioned references

Ariluoma M, Ottelin J, Hautamäki R, Tuhkanen E-M, Mänttäri M. 2021. Carbon sequestration and storage potential of urban green in residential yards: A case study from Helsinki. Urban Forestry & Urban Greening 57: 126939.

Russo A, Escobedo FJ, Timilsina N, Zerbe S. 2015. Transportation carbon dioxide emission offsets by public urban trees: A case study in Bolzano, Italy. Urban Forestry & Urban Greening 14(2): 398-403.