Response to Reviewer 2:

Dear Referee 2

The authors thank you for the constructive and useful comments and for your valuable time spent reviewing our manuscript “Can riparian vegetation shade mitigate the expected rise in stream temperatures during heat waves in a pre-alpine river?” by H. Trimmel, P. Weihs, H. Formayer, D. Leidinger and G. Kalny. You have been addressing many issues to clarify and improve readability of the manuscript. Below we address all your general and specific comments.

<u>General comments</u>

No.	Comment	Response
1	During reading the paper it is difficult to keep the focus/aims of the paper in memory. The overall objective is formulated in the title but in the text the reader will find other (sub)aims at several positions in different sections. The differentiation between objectives and methods is not appropriate. It is hard to follow the central theme of the paper since the structure of the paper is a little bit confusing.	We agree and worked on a clearer, more focused presentation of the aims. The authors agree that the Methods section is not well organized and difficult to follow. We included several subheadings and restructured this section to make it easier to read.
2	The paper includes 4 tables and 4 figures with a lot of information content but this is not represented adequate in the text, especially in the sections “Results“ and “Methods” more clear links between text and figures/tables would be helpful to understand the intention of the paper.	We agree. We tried to improve this in the revised version and added more links between text and figures/tables.

<u>Specific comments:</u>

No.	Comment	Response
3	P 1, title: the overall objective is formulated here. See also p 4, lines 22ff “The aim of this study. . .” and p 8, lines 9ff “ The focus of this study. . ..” are mentioned in different sections. The reader should find aims and focus of a paper at the beginning of the text to keep the central theme in mind.	We worked to clarify the overall structure but still kept the aims of the study at the end of the Introduction because they are derived from the state of the art. If wished they can be moved to the beginning of the Introduction as well.
4	P 1, line 13: “and turbulent energy fluxes were analysed”	This was corrected.
5	P 2, line 4: “ play a superior role. . .” please clarify	Alternative formulation: “Above that riparian ecosystems play a superior role in determining the vulnerability of natural and human systems to climate change in the 21st century (Capon et al. 2013).”
6	P 2 line 19: “summer and winter half-year” please clarify- which months/from-to?	Alternative formulation: “summer (Apr – Sep) and winter half-year (Oct to Mar)”

7	P 2, line 22: " autumn" please clarify- which months?	Alternative formulation: " .. increase from October to March ..."
8	P 3, line 1: " Austrian river temperatures. . ." which rivers were regarded – discharge values or other meaningful parameters were helpful. Is the Danube representative for the study area of this paper? Why?	Alternative formulation: "Since 1980 230 stations of the Austrian hydrographic central office of different elevation, distance from source and catchment area recorded an increase of stream temperature. The data were elevation corrected using External Drift Top-Kringing (Skøien et al. 2006) and a mean trend calculated using the Mann-Kendall-Test (Burn and Hag Elnur, 2002) by BMLFUW (2011). A mean trend of 1.5 °C during summer (Jun - Aug) and 0.7 °C during winter (Dec - Feb) was calculated (APCC 2014, BMLFUW 2011). Melcher et al. (2013) analysed 60 stations and found a similar trend of 1 °C within the last 35 years regarding mean August temperatures, which was independent of the river type. The annual mean temperature of the river Danube has been rising (Webb and Nobilis 1995) and is likely to continue to rise to reach a value of between 11.1 and 12.2 °C by 2050 compared to around 9 °C at the beginning of the 20th century at the border to Slovakia (Nachtnebel et al. 2014). Close to Vienna the increase will be up to 12.7 °C (Dokulil 2013). Due to the size of the river Danube amplitudes and extremes cannot be compared to smaller rivers like Pinka, but trends in mean water temperature values are comparable (BMLFUW, 2011)."
9	P 3, line 6: "indirect effects of climate change" – is it possible to quantify these uncertainties?	"For the study region during summer heat waves neither groundwater nor snow melt contributions change are expected (APCC). Apart from rising air temperatures and discharge changes, anthropogenic influences like discharge from waste water treatment plants and cooling water can influence stream temperatures in a negative way and are therefore presently illegal in Austria (WRG 1959). Other consequences of climate change are changes in sediment loads in river systems due to changes in mobilization, transport and deposition of sediment, which is expected to be very likely (APCC 2014). Sediment changes might alter the bed conduction flow as well as flow velocity, which can influence the magnitude and variability of stream temperature. Artificial changes which deteriorate the situation are presently illegal in Austria as well (WRG 1959). Discharge reductions on the other hand have already been observed. From 1982 to 1990 the mean discharge of the river at the lower boundary of the study region decreased by 5.7 % (Mader et al. 1996) and has been further decreasing (APCC 2014). During the period 2008-2012 the mean discharge lay 20% below the values of 1982 (BMLFUW 2014). Van Vliet (2011) predicted a stream temperature rise of 0.3 °C and 0.8 °C on average for discharge reductions of 20 % and 40 % respectively. This article focused only on the increase in air temperature caused by climate change." BMLFUW Abteilung I/4 – Wasserhaushalt, Hydrographisches Jahrbuch von Österreich 2013, Wien, 2015. WRG – Wasserrechtsgesetz (water right law), BGBI. Nr. 215/1959, 1959.
10	P 3, line 30: "energy loss" – is it possible to assess/quantify?	Transpiration of the riparian vegetation causes additional energy loss of the system, which is small compared to the effects of shading and wind reduction. We calculated a reduction of 0.18°C if maximum vegetation cover is assumed. We suggest to include following explanation in the Introduction: "Transpiration of riparian vegetation only indirectly affects stream

		temperature. It increases air humidity and reduces air temperature close to the river, so air humidity and air temperature gradients are reduced. Benyahya et al. (2012) and Chen et al. (1993), recorded a difference in air humidity between open and forested stations of 5 % and 11 % and a difference of air temperature in 0.5 % and 0.61 °C respectively." This paragraph is now included in the "Methods" subsection "Uncertainties": "Microclimatic differences caused by vegetation shading, wind reduction and transpiration had been recorded during 5 July to 14 August 2015. Air temperature differences between forested and open stream reaches amounted to 1.5 °C on average. Differences in relative humidity was 11.8 % on average. Which is in accordance with Benyahya et al. (2012) and Chen et al. (1993), who recorded a difference in air humidity between open and forested stations of 5 % and 11 % and a difference of air temperature in 0.5 % and 0.61 °C respectively. Vegetation shading as well as the wind reduction caused by vegetation is included in the model. The micro scale changes in air temperature and air humidity of different river sections caused by transpiration are not included in the simulation, but Heat Source is not sensitive to these differences. Simulations were performed to estimate the error caused by this simplification and only a maximum error in water temperature of 0.18°C was calculated." Chen, J., Franklin, J.F., Spies, T.A., Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest. Agricultural and Forest Meteorology 63, 219-237, 1993.
11	P 4, line 26: "Sections". An outline of different sections would be helpful at the beginning of the paper maybe combined with clearly formulated objectives and aims of the paper.	We worked to clarify the overall structure but still kept the aims of the study at the end of the Introduction, because they are derived from the state of the art. If wished they can be moved to the beginning of the Introduction as well. The sections were integrated into the scope of the study which is described at the beginning of the Methods.
12	P 5, line 3: "river Pinka": which type of river represents Pinka compared to others in Austria?	We suggest to add: "According to Muhar et al (2004), who categorized all Austrian rivers with catchment areas > 500 km² corresponding to their annual discharge Pinka falls in the smallest of the 5 categories with 0 – 5 m³/s mean annual discharge." Muhar S, Poppe M, Egger G, et al (2004) Flusslandschaften Österreichs: Ausweisung von Flusslandschaftstypen anhand des Naturraums, der Fischfauna und der Auenvegetation. Bundesministerium für Bildung, Wissenschaft und Kultur, Wien
13	P 5, line 9: "highest temperature increases and . . ...reductions. . ." - how much? Please clarify.	Alternative formulation: "In this region air temperature rose by 2°C since 1880. Precipitation was reduced in the HISTALP region corresponding to our study region by 10-15%, which is the largest reduction in precipitation in Austria (Auer et al. 2007, Böhm et al. 2009, Böhm et al. 2012)." Auer, I., Böhm, R., Jurkovic, A., Lipa, W., Orlik, A., Potzmann, R., Schöner,

		W., Ungersböck, M., Matulla, C., Briffa, K., Jones, P., Efthymiadis, D., Brunetti, M., Nanni, T., Maugeri, M., Mercalli, L., Mestre, O., Moisselin, J.-M., Begert, M., Müller-Westermeier, G., Kveton, V., Bochnicek, O., Stastny, P., Lapin, M., Szalai, S.,Szentimrey, T., Cegnar, T., Dolinar, M., Gajic-Capka, M., Zaninovic, K., Majstorovic, Z. and Nieplova, E.,. HISTALP—historical instrumental climatological surface time series of the Greater Alpine Region. International Journal of Climatology 27, 17–46. doi:10.1002/joc.1377, 2007. Böhm, R.: Changes of regional climate variability in central Europe during the past 250 years, The European Physical Journal Plus, 127, doi:10.1140/epjp/i2012-12054-6, 2012. Böhm, R., Auer, I., Schöner, W., Ganekind, M., Gruber, C., Jurkovic, A., Orlik, A. and Ungersböck, M.: Eine neue Webseite mit instrumentellen Qualitäts-Klimadaten für den Grossraum Alpen zurück bis 1760, Wiener Mitteilungen Band 216: Hochwässer: Bemessung, Risikoanalyse und Vorhersage, 2009.
14	P 7, line 11: “flow volume” – discharge	We agree. The term “discharge” is used in the revised version.
15	P 7, line 26: “no deep groundwater influence” - means there is one? Significant/insignificant - please clarify	The groundwater influence of the Pinka in the study region is possible but unknown. During this article only simulations during low flow conditions were conducted. It it assumed, that during low flow conditions there is no influence of deep groundwater. We suggest to use a more direct formulation: “The sediment of this region is very inhomogeneous and the spatial distribution of the groundwater level is unknown (Pahr 1984). For low flow conditions it was assumed that there was no deep groundwater influence.” In the end of the description of the model Heat Source we suggest to include: “The measurements fitted the simulation very well (average hourly was RMSE 0.88 °C for all measurement stations) so we conclude that all assumption were good and the model fit to be used for predictions.” In the Discussion we suggest to add: “Ground water influence was unknown and no ground water influence was assumed in the model. Although the model performed good (RMSE 0.88) there might be some ground water influence between DFS 45 and 55 where the measurements lie below the simulation results.”
16	P 7, lines 27ff: “Tributaries. . .partly estimated. . .adding a fixed offset. . ..was supplemented. . .” is this conform to the state of the art? Or part of model uncertainties?	Ideally the stream temperature and discharge of every single tributary should be measured. Practically this is very difficult for larger river sections. In our case the interpolated tributaries have less than 5 % of the discharge of the main river and are not influenced by tempered waste or cooling water. Thus we consider it part of the model uncertainties and state of the art at the same time.
17	P 8, line 9: “The focus. . .” see above	This sentence was integrated into the aims at the end of the Introduction.
18	P 8, line 18: “no significant changes in vegetation cover as it was the case in other studies performed earlier in the year” – what does significant mean in this	The authors admit that this sentence is confusing and suggest to omit it. To clarify the vegetation development stage we suggest to insert in the new Section 2.3.2 (Vegetation and morphology): “The riparian vegetation situation was taken after the phenological phase of leaf development was finished and leaves were already fully developed

	context?	(Ellenberg 2012). Ellenberg, H. and Leuschner, H: Vegetation Mitteleuropas mit den Alpen, 6.Auflage, Verlag Eugen Ulmer, Stuttgart, XXIV+1134pp, 2012.
19	P 9, lines 15-25: Are these lines part of the results or taken from literature (which one?) - please clarify and quantify the mentioned effects if possible.	This part was complemented with quantitative information and discussion material moved to the Discussion.
20	P 9 line 33: ". . .up to 4.1 ◦ C (Table 2): Why is "max" lower than "20a" (Table 2, P 21)?	The future climate episodes used in this study were selected using 5 day mean air temperature thresholds. As they simulate realistic potential episodes they differ in global radiation, wind speed and humidity (see Table 2). Lesser amount of global radiation sums, as it is the case during the Max event of 2085 can lead to lower stream temperature and lower maximum air temperature despite higher mean air temperature. In the revised version this is described more in detail in section 3.2: "During the 20 year return event of 2085 on the other hand global radiation was higher than the Max event (20.9 MJ m^{-2} d^{-1}) of this climate period (Table 2). For the mean water temperature at the model boundary an increase of +4.1 °C for a 20 year return event of 2085 in respect to 2013 was simulated (Table 2). For the Max event of 2085, which had 2.2 MJ m^{-2} d^{-1} lower global radiation input a slightly lower temperature increase (+4.0 °C) was simulated (Table 3)."
21	P 11, line 8: "incoming solar radiation which"	This sentence is removed, because it is too imprecise.
22	P 11, line 10: A more detailed quantifiable description of figure 4 is desirable.	Alternative formulation: "Looking at the longitudinal distribution of water temperature along the river it can be seen that increases in mean stream temperature caused by increases of future air temperature affected all parts of the river (Fig. 4a-c). The maximum values showed a similar distribution as the mean values on a higher level. The average difference between mean and maximum values of the STQ scenario was 3.92 °C, 3.35 °C and 3.91 °C, the maximum difference between maximum values was 5.51 °C, 4.89 °C and 5.51 °C and the standard deviation of this difference was 0.71, 0.66 and 0.71 for 2030, 2050 and 2085 respectively (Fig. 4a-c). V0 scenarios were always warmer than STQ scenarios, V100 scenarios were always cooler than the STQ scenarios. The mean difference along the river between V0 and STQ was 1.25 °C, 1.26 °C and 1.13 °C, the maximum difference was 1.81 °C, 1.85 °C and 1.66 °C, the standard deviation was 0.35, 0.36 and 0.32 for 2030, 2050 and 2085 respectively. The mean difference between STQ and V100 was 1.42 °C, 1.52 °C, and 1.26 °C, the maximum difference was 1.92 °C, 2.05 °C and 1.72 °C, the standard deviation of this difference was 0.46, 0.49 and 0.41 for 2030, 2050 and 2085 respectively (Fig. 4a-c). Water temperature was especially sensitive to the removal of vegetation within the first 10 km (DFS 11 - 21) where there were dense forests which prevented the cool headwaters from warming (Fig. 4d). At DFS 11 - 21 temperatures increased by 1.4 °C when removal of vegetation is assumed (V0-STQ). Additional tree cover (V100) caused a reduction of -0.9 °C compared to the STQ scenario (Fig. 4d).

		This can be explained by the slower flow velocities (last 30 km - DFS 32-62: 0.003 m m^{-1}, 0.4 m s^{-1}) in comparison to the steeper upstream sections (first 10 km - DFS 11-21: 0.017 m m^{-1}, 0.6 m s^{-1}), which gave short wave radiation in unshaded sections more time to heat the water column. For the Pinka the benefit of additional tree cover maximizing riparian shade became more distinct in the downstream sections (DFS 25-55) where the additional tree cover caused a change of 1.75°C while removal only caused a change of around 1.25°C (Fig. 4d)."
23	P 11, line 11: "Uncertainties. . ." Model uncertainties should be a section following section 2.3. In the Results-section uncertainties should be discussed referring to the relevance to quantifiable results and the author's conclusions. Discussions about the model should be conducted before.	This part was shortened and integrated into the Discussion and Methods, where a new subsection was created as suggested. Uncertainties relevant for the direct evaluation of results are kept in the Results section.
24	P 12, line 12: "is not expected to increase. . ." – source? Please clarify.	We agree that this formulation is confusing. We suggest to restructure the Discussion section to treat the magnitude of stream temperature rise and vegetation influences in separate subsections. We suggest following explanation: "The water temperature difference between full and no vegetation showed no clear trend for future conditions. This can be explained considering that global radiation - the main parameter, that is affected by riparian vegetation (Leach and Moore 2010, Li et al 2012) - is the main parameter that contributes to heating of the water column (Benyahya et al 2012, Hannah et al. 2008, Maheu et al. 2014) and is not expected to be affected by climate change (APCC 2014). Therefore the ability of the vegetation to alter the stream's microclimate and water temperature is likely to remain the same." Leach JA, Moore RD (2010) Above-stream microclimate and stream surface energy exchanges in a wildfire-disturbed riparian zone. Hydrol Process n/a-n/a. doi: 10.1002/hyp.7639 Li G, Jackson CR, Kraseski KA (2012) Modeled riparian stream shading: Agreement with field measurements and sensitivity to riparian conditions. J Hydrol 428–429:142–151. doi: 10.1016/j.jhydrol.2012.01.032 Maheu A, Caissie D, St-Hilaire A, El-Jabi N (2014) River evaporation and corresponding heat fluxes in forested catchments, Hydrol Process 28:5725–5738. doi: 10.1002/hyp.10071
25	P 12, line 26: "by other studies." Which studies? Please specify.	The sentence is changed to "The values predicted in this article were clearly above the model uncertainty and lie in the upper region of the values published by other studies (BMLFUW 2001, Dokulil 2013, Melcher et al. 2013, 2014)." and moved to the end of the new section 4.2 (Magnitudes of stream temperature rise)
26	P 12, line 27: "For Austrian rivers. . ." which ones?	"From 1980 to 2011 230 stations of the Austrian hydrographic central office of different elevation, distance from source and catchment area recorded an increase of stream temperature (BMLFUW 2011)."

27	P 12, line 28: “An increase. . .” which scenarios were used? Is the Danube comparable with Pinka referring to the focus of this paper?	“Dokulil (2013) extrapolated the quadratic regression of the period 1900-2006 of the river Danube near Vienna and predicted an increase of up to 3.2 °C by 2050 in respect to 1900 (0.21 °C / decade). Using linear regression the increase was only 2.3 (0.15 °C / decade), but using the linear trend beginning from 1970 the increase was 3.4° C (0.23 °C / decade). Due to the size of the river Danube daily amplitudes and extremes are not comparable to the Pinka, but trends in mean water temperature values are comparable though.”
28	technical corrections: P 2, line 18 and 20: 15 % P 5, line 14: 0.46 ms-1 P 7, line 7: 50 m	These have been corrected.