Supporting information S3: Reviewed microclimate papers

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Source	Microclimate indices
Aalto, J., Tyystjärvi, V., Niittynen, P., Kemppinen, J., Rissanen, T., Gregow, H., & Luoto, M. (2022). Microclimate temperature variations from boreal forests to the tundra. *Agricultural and Forest Meteorology*, *323*, 109037. https://doi.org/10.1016/j.agrformet.2022.109037	aggregated the quality-checked temperature time series to monthly means (T_{avg}), maxima (T_{max}) and minima (T_{min}); used the 95th percentile to calculate T_{max} to avoid error from measurement; three measurement heights * three summary statistics (T_{avg}, T_{max}, T_{min}) * 12 months → total of 108 response variables
Allen, D. C. (2016). Microclimate modification by riparian vegetation affects the structure and resource limitation of arthropod communities. *Ecosphere*, *7*(2), e01200. https://doi.org/10.1002/ecs2.1200	Daily minimum temperature (°C) (mean+sd), Daily maximum temperature (°C) (mean+sd), Daily temperature coefficient of variation (mean+sd)
Caron, M. M., Zellweger, F., Verheyen, K., Baeten, L., Hédl, R., Bernhardt-Römermann, M., Berki, I., Brunet, J., Decocq, G., Díaz, S., Dirnböck, T., Durak, T., Heinken, T., Jaroszewicz, B., Kopecký, M., Lenoir, J., Macek, M., Malicki, M., Máliš, F., … De Frenne, P. (2021). Thermal differences between juveniles and adults increased over time in European forest trees. *Journal of Ecology*, *109*(11), 3944–3957. https://doi.org/10.1111/1365-2745.13773	temperature offset values were calculated as the difference between the daily temperature statistics (T_{min}, T_{mean} and T_{max}) recorded inside the forest and the respective temperature statistic recorded by the closest weather station; daily temperature offsets were aggregated to calculate monthly means
Davis, K. T., Dobrowski, S. Z., Holden, Z. A., Higuera, P. E., & Abatzoglou, J. T. (2019). Microclimatic buffering in forests of the future: the role of local water balance. *Ecography*, *42*(1), 1–11. https://doi.org/10.1111/ecog.03836	data were aggregated to daily maximum and minimum; calculated daily buffering for each plot: delta maximum temperature (ΔMXT), delta minimum temperature (ΔMNT), and delta maximum VPD (ΔVPD), by subtracting the values at each sensor from the reference
De Frenne, P., Lenoir, J., Luoto, M., Scheffers, B. R., Zellweger, F., Aalto, J., Ashcroft, M. B., Christiansen, D. M., Decocq, G., de Pauw, K., Govaert, S., Greiser, C., Gril, E., Hampe, A., Jucker, T., Klinges, D. H., Koelemeijer, I. A., Lembrechts, J. J., Marrec, R., … Hylander, K. (2021). Forest microclimates and climate change: Importance, drivers and future research agenda. *Global Change Biology*, *27*(11), 2279–2297. https://doi.org/10.1111/gcb.15569	linear relationship of microclimate and macroclimate: T_{micro} = intercept + slope * T_{macro} slope = 1: coupling, 0 < slope < 1: buffering, slope = 0: decoupling

De Frenne, P., Zellweger, F., Rodríguez-Sánchez, F., Scheffers, B. R., Hylander, K., Luoto, M., Vellend, M., Verheyen, K., & Lenoir, J. (2019). Global buffering of temperatures under forest canopies. *Nature Ecology & Evolution*, *3*(5), 744–749. https://doi.org/10.1038/s41559-019-0842-1	summary statistics: maximum, mean and minimum temperatures through time; magnitude of temperature offset calculated as understory temperature minus the temperature outside the forest; temperature values of longer time series were always aggregated per season and/or year
Ehbrecht, M., Schall, P., Ammer, C., & Seidel, D. (2017). Quantifying stand structural complexity and its relationship with forest management, tree species diversity and microclimate. *Agricultural and Forest Meteorology*, *242*, 1–9. https://doi.org/10.1016/j.agrformet.2017.04.012	minimum and maximum values per day were used to calculate mean daily amplitudes of temperature → mean daily temperature amplitude (Δ°C)
Finocchiaro, M., Médail, F., Saatkamp, A., Diadema, K., Pavon, D., Brousset, L., & Meineri, E. (2024). Microrefugia and microclimate: Unraveling decoupling potential and resistance to heatwaves. *Science of The Total Environment*, *924*, 171696. https://doi.org/10.1016/j.scitotenv.2024.171696	four response variables for each site: daily mean temperatures (T_{Mean}), 5th percentile of daily minimum temperatures (T_{Min}), 95th percentile of daily maximum temperatures (T_{max}), and daily thermal amplitude calculated as the difference between daily maximum and minimum temperature (T_{Ampl})
Finocchiaro, M., Médail, F., Saatkamp, A., Diadema, K., Pavon, D., & Meineri, E. (2023). Bridging the gap between microclimate and microrefugia: A bottom-up approach reveals strong climatic and biological offsets. *Global Change Biology*, *29*(4), 1024–1036. https://doi.org/10.1111/gcb.16526	linear regression analysis with difference in temperature between the sites' microclimate and macroclimate as response variable and macroclimate temperature as explanatory variable → regression slope of the model as a measure of decoupling between macro- and microclimate
Frey, S. J. K., Hadley, A. S., Johnson, S. L., Schulze, M., Jones, J. A., & Betts, M. G. (2016). Spatial models reveal the microclimatic buffering capacity of old-growth forests. *Science Advances*, *2*(4), e1501392. https://doi.org/10.1126/sciadv.1501392	cumulative degree days (CDDs) > 0°C and > 10°C; mean, minimum and maximum of the mean monthly temperatures; variability in temperature as SD of mean weekly temperature
Gagliardi, S., Avelino, J., Virginio Filho, E. D. M., & Isaac, M. E. (2021). Shade tree traits and microclimate modifications: Implications for pathogen management in biodiverse coffee agroforests. *Biotropica*, *53*(5), 1356–1367. https://doi.org/10.1111/btp.12984	mean + sd daily maximum air temperature (T_{max}), mean + sd daily minimum air temperature (T_{min}), mean + sd daily air temperature range (T_{range})
Gril, E., Spicher, F., Greiser, C., Ashcroft, M. B., Pincebourde, S., Durrieu, S., Nicolas, M., Richard, B., Decocq, G., Marrec, R., & Lenoir, J. (2023). Slope and equilibrium: A parsimonious and flexible approach to model microclimate. *Methods in Ecology and Evolution*, *14*(3), 885–897.	hourly temp records for micro and macro → slope from linear mixed models with months as random intercept; mean equilibrium per month from slope as equilibrium = intercept/(1 – slope); slope corresponds to buffering effect

https://doi.org/10.1111/2041-210X.14048	
Haesen, S., Lembrechts, J. J., De Frenne, P., Lenoir, J., Aalto, J., Ashcroft, M. B., Kopecký, M., Luoto, M., Maclean, I., Nijs, I., Niittynen, P., Van Den Hoogen, J., Arriga, N., Brůna, J., Buchmann, N., Čiliak, M., Collalti, A., De Lombaerde, E., Descombes, P., … Van Meerbeek, K. (2021). ForestTemp – Sub-canopy microclimate temperatures of European forests. *Global Change Biology*, *27*(23), 6307–6319. https://doi.org/10.1111/gcb.15892	offset = difference of monthly temp means ΔT = sub-canopy T°C - free-air T°C
Huang, Y., Stein, G., Kolle, O., Kübler, K., Schulze, E.-D., Dong, H., Eichenberg, D., Gleixner, G., Hildebrandt, A., Lange, M., Roscher, C., Schielzeth, H., Schmid, B., Weigelt, A., Weisser, W. W., Shadaydeh, M., Denzler, J., Ebeling, A., & Eisenhauer, N. (2023). Enhanced stability of grassland soil temperature by plant diversity. *Nature Geoscience*, 1–7. https://doi.org/10.1038/s41561-023-01338-5	soil temperature offset = vegetation plot soil temperature - mean soil temperature of bare plots; soil air temperature offset = air temperature - soil temperature; data aggregated to daily level → daily mean soil temperature offset; dimensionless measure of ecosystem stability: ratio between the mean and standard deviation of soil temperature over hours within a day, or over days within a year
Kašpar, V., Hederová, L., Macek, M., Müllerová, J., Prošek, J., Surový, P., Wild, J., & Kopecký, M. (2021). Temperature buffering in temperate forests: Comparing microclimate models based on ground measurements with active and passive remote sensing. *Remote Sensing of Environment*, *263*, 112522. https://doi.org/10.1016/j.rse.2021.112522	95th percentile of daily maximum offset
Miller, B. D., Carter, K. R., Reed, S. C., Wood, T. E., & Cavaleri, M. A. (2021). Only sun-lit leaves of the uppermost canopy exceed both air temperature and photosynthetic thermal optima in a wet tropical forest. *Agricultural and Forest Meteorology*, *301–302*, 108347. https://doi.org/10.1016/j.agrformet.2021.108347	local (leaf) temperature maxima
Ray, C. A., Kapas, R. E., Opedal, Ø. H., & Blonder, B. W. (2023). Linking microenvironment modification to species interactions and demography in an alpine plant community. *Oikos*, *2023*(3), e09235. https://doi.org/10.1111/oik.09235	temperature data collected at 20-min intervals, summarized as yearly maximum and minimum temperatures
Scheffers, B. R., Edwards, D. P., Diesmos, A., Williams, S. E., & Evans, T. A. (2014). Microhabitats reduce animal's exposure to climate extremes. *Global Change Biology*, *20*(2), 495–503.	box and whisker plots to display the temperature profile of each habitat in comparison to ambient conditions (macrohabitat measures); used Crawley's (2007) definition of extreme outlier events = all

https://doi.org/10.1111/gcb.12439	temperature measurements from ambient samples that exceeded the lowest datum above 1.5 times the interquartile range of the upper quartile; for each microhabitat pair quantified the number of hours spent at these extreme temperatures
Schnabel, F., Beugnon, R., Yang, B., Richter, R., Eisenhauer, N., Huang, Y., Liu, X., Wirth, C., Cesarz, S., Fichtner, A., Perles-Garcia, M. D., Hähn, G. J. A., Härdtle, W., Kunz, M., Castro Izaguirre, N. C., Niklaus, P. A., Von Oheimb, G., Schmid, B., Trogisch, S., … Bruelheide, H. (2025). Tree Diversity Increases Forest Temperature Buffering via Enhancing Canopy Density and Structural Diversity. *Ecology Letters*, *28*(3), e70096. https://doi.org/10.1111/ele.70096	monthly minimum, median, and maximum microclimate temperatures per plot; minimum and maximum monthly temperatures were calculated by taking the median of the 5% lowest and 95% highest temperatures (= 2.5th and 97.5th quantile); temporal stability of the microclimate calculated as inverse of coefficient of variation $S = \mu / \sigma$ (μ = mean, σ = standard deviation of hourly temperature measurements per month or year)
Vanwalleghem, T., & Meentemeyer, R. K. (2009). Predicting Forest Microclimate in Heterogeneous Landscapes. *Ecosystems*, *12*(7), 1158–1172. https://doi.org/10.1007/s10021-009-9281-1	dataset was first summarized at three different time scales: monthly, daily, and hourly; mean, maximum, and minimum temperature values calculated for each time scale, resulting in the independent variables: mean, maximum, and minimum monthly temperature ($T_{month,mean}$, $T_{month,max}$, $T_{month,min}$), mean, maximum, and minimum daily temperature ($T_{day,mean}$, $T_{day,max}$, $T_{day,min}$), and hourly temperature (T_{hour})
Zellweger, F., Coomes, D., Lenoir, J., Depauw, L., Maes, S. L., Wulf, M., Kirby, K. J., Brunet, J., Kopecký, M., Máliš, F., Schmidt, W., Heinrichs, S., Den Ouden, J., Jaroszewicz, B., Buyse, G., Spicher, F., Verheyen, K., & De Frenne, P. (2019). Seasonal drivers of understorey temperature buffering in temperate deciduous forests across Europe. *Global Ecology and Biogeography*, *28*(12), 1774–1786. https://doi.org/10.1111/geb.12991	aggregated the hourly temperature data to three daily temperature statistics: minimum daily (T_{min}), mean daily (T_{mean}) and maximum (T_{max}) daily temperature; defined temperature offset values as the difference between the daily temperature statistics (T_{min}, T_{mean} and T_{max}) measured inside forest and the respective temperature statistic recorded by the closest official weather station → used offsets of T_{min}, T_{max}, and T_{mean} as dependent variables; aggregated daily temperature offsets to calculate monthly means and means across seasons; offset value for the absolute daily minimum temperature only during winter and spring
Zellweger, F., De Frenne, P., Lenoir, J., Vangansbeke, P., Verheyen, K., Bernhardt-Römermann, M., Baeten, L., Hédl, R., Berki, I., Brunet, J., Van Calster, H., Chudomelová, M., Decocq, G., Dirnböck, T., Durak, T., Heinken, T., Jaroszewicz, B., Kopecký, M., Máliš, F., … Coomes, D. (2020). Forest microclimate dynamics drive plant responses to warming. *Science*, *368*(6492), 772–775. https://doi.org/10.1126/science.aba6880	microclimate data aggregated to daily mean temperatures; temperature buffering = daily maximum macroclimate temperature - daily maximum microclimate temperature

Zhang, D., Brandle, J. R., Hubbard, K. G., Hodges, L., & Daningsih, E. (1999). The Response of Muskmelon Growth and Development to Microclimate Modification by Shelterbelts. *HortScience*, *34*(1), 64–68. https://doi.org/10.21273/HORTSCI.34.1.64	all parameters were sampled every minute and hourly averages were recorded; daily mean values were calculated from hourly averages
Zhang, S. (2022). *Tree species diversity effects on microclimate buffering, throughfall regulation and litter decomposition in young forest plantations* [Dissertation, Ghent University]. http://hdl.handle.net/1854/LU-01GM376G5Z6P0C0KQA2Y16VQXH	hourly observations summarised into daily statistics → maximum and minimum daily values; daily offset values calculated based on these daily maximum and minimum values measured in the forest and the open field plots