Species-specific effects of the Urban Heat Island on tree growth across Berlin

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**This document serves as a brief overview and outline** .

# Introduction

Berlin features the most intense Urban Heat Island (UHI) in Germany due to its large extent and development intensity (Kuttler et al., 2015), with temperature increases of up to during day-time and on average for night-times (2001-2010, Fenner et al., 2014) in urban rural areas. Consequently, urban green (infrastructure) systems are subjected to increased heat more frequently, potentially affecting their process dynamics - either positively or adversely. Their performance and health, however, is closely tied to local energy budgets (Grimmond et al., 1996 ; Hertel and Schlink, 2019), which in turn are decisive for controlling human wellbeing (e.g. Maras et al., 2016), amongst other factors. Assessing the effect of increased temperatures on green infrastructure, as part of the urban landscape, is therefore instrumental for understanding, and ultimately mitigating, the potential impact of future warming on increasingly urban societies (Norton et al., 2015).

Trees, in particular, provide shading as well as transpirative cooling in their vicinity (Endlicher et al., 2016; Gillner et al., 2015; Oke, 1982), and therefore can reduce ambient temperatures, infrastructure power-consumption and (human) thermal discomfort (e.g. Gulyás et al., 2006; Akbari et al., 2001; Hoyano, 1988; Mayer and Höppe, 1987); simultaneously, they provide numerous other environmental, cultural and psychological services and/or benefits (see Tzoulas et al., 2007 for review). Further, recent tree growth dynamics as a proxy for on-going and future warming may provide an additional line of evidence to support the growing knowledge base on future climate-vegetation dynamics (Zhao et al., 2016) and may aid in mitigation and adaptation efforts (Brune, 2016; Pretzsch et al., 2017).

Trees and green infrastructure in urban areas show a tendency for enhanced growth rates and/or productivity compared to rural counterparts (Jia et al., 2018; Pretzsch et al., 2017), yet feature a broad range of effect size ranges and, in some cases, signs specific to species and locality. Zhao et al. (2016) showed that growth rates increased within urban clusters as urbanization intensifies using remotely sensed vegetation indices. Similarly, for Berlin, Dahlhausen et al. (2018), identified positive growth modulation in highly urbanized environments for *Tilia cordata* Mill (using growth increments), the most abundant tree of the city, which they attributed to the UHI effect, while intermediate development intensity showed indications of being least favorable for tree growth. Further, Moser-Reischl et al. (2019) identified positive associations between air temperature and radial growth for two species commonly selected by urban planners (*T. cordata*, *Rubinia pseudoacacia*) in Munich. By contrast, Gillner et al. (2014) highlight decreased growth for *Acer* species (*A. platanoides* and *pseudoplatanus*), *Platanus x hispanica* and *Quercus rubra* with higher summer temperatures of the preceding year, especially when compounded with drought, in another German metropolis (Dresden). Differences in growth trends may result from contrasting intrinsic inter- and intra-specific characteristics, but are indeed affected by other processes and factors, such as water availability, pollution and road-salt loading, structural impedance through infrastructure or management, etc. (Pauleit et al., 2002; Quigley, 2004; Randrup et al., 2001; Rhoades and Stipes, 1999). Under climate change, atmospheric drought will likely be compounded with high temperatures - and intensified UHIs - more frequently, adding further stress to current urban disturbance regimes (Roloff et al., 2009).

Conditions affecting tree growth can vary greatly within urban areas or regions, and need to be accounted for when establishing relationships with pertinent drivers, such as the UHI effect. This typically complicates the extrapolation from individual sampling sites toward predicting effect sizes across entire urban areas and tree stocks. This is especially the case for studies reliant on labour-intensive methods which are limited logistically by sampling effort, reducing sample sizes, as well as species and spatial coverage. To complement detailed dendroecological analyses of climate-growth relationships in Berlin for key species, we propose inferring growth modulation from a large data set in excess of 650000 individuals provided by the Berlin Senate Administration (Senatsverwaltung). This data set contains information on location, species, trunk diameter (at breast height; ), and height, amongst other variables for street and park trees. In a space-for-time substitution, growth of individual species can be assessed across the entire cite of Berlin, and related to effects of the UHI, while accounting for other location-specific factors, such as street characteristics, development intensity, available soil volume, etc. Similar applications are found in Quigley (2004), who inferred absolute growth potential for species across successional groups, and between rural and urban species, yet lacked spatially-explicit effect size estimates or predictions of maximum potential. Similarly, Pretzsch et al. (2017) applied linear hierarchical models to infer growth modulation for different cities, time periods and locations (urban rural). By contrast, we propose applying a statistical model (see Section??) that is spatially explicit, while also allowing to account for the nested nature of the data set (e.g. streets and districts) as well as other pertinent factors. This also allows to infer the absolute growth potential of species given, for example, a specific location, age or UHI magnitude.

We acknolwedge results from (Gregg et al., 2003), which indicated impeded growth adjacent to intense urban clusters, rather than enhancement within them.

# Proposed methods and data requirements

# Preliminary results

Some results

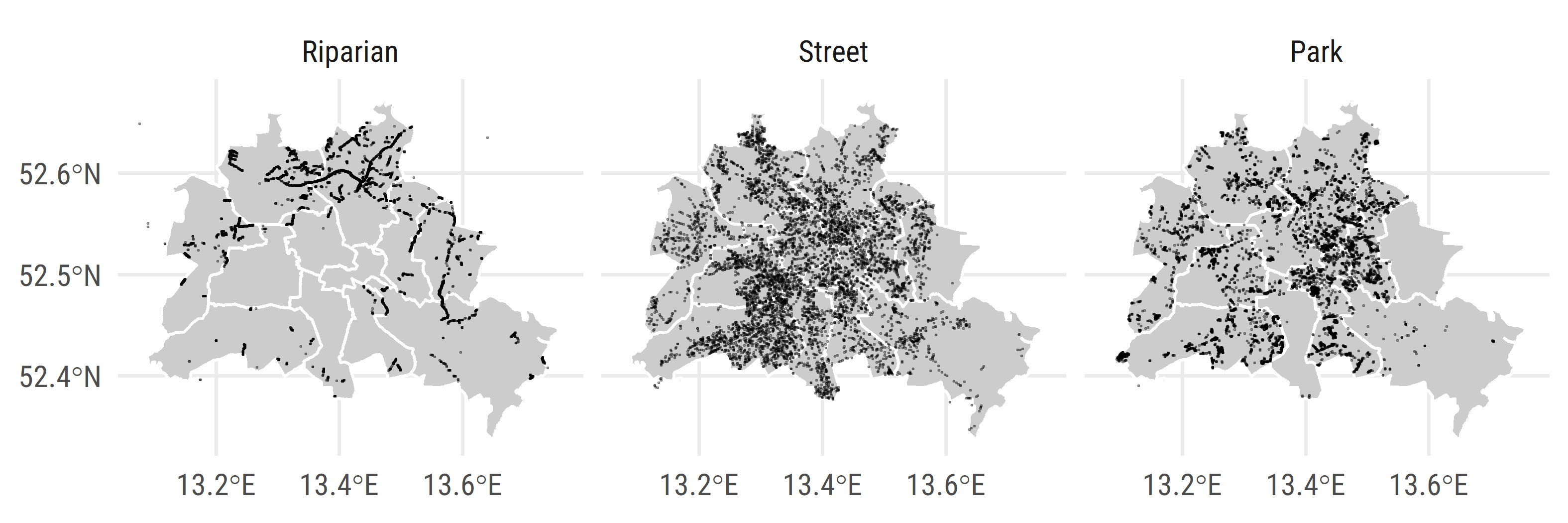


Figure 1: A plot of random numbers

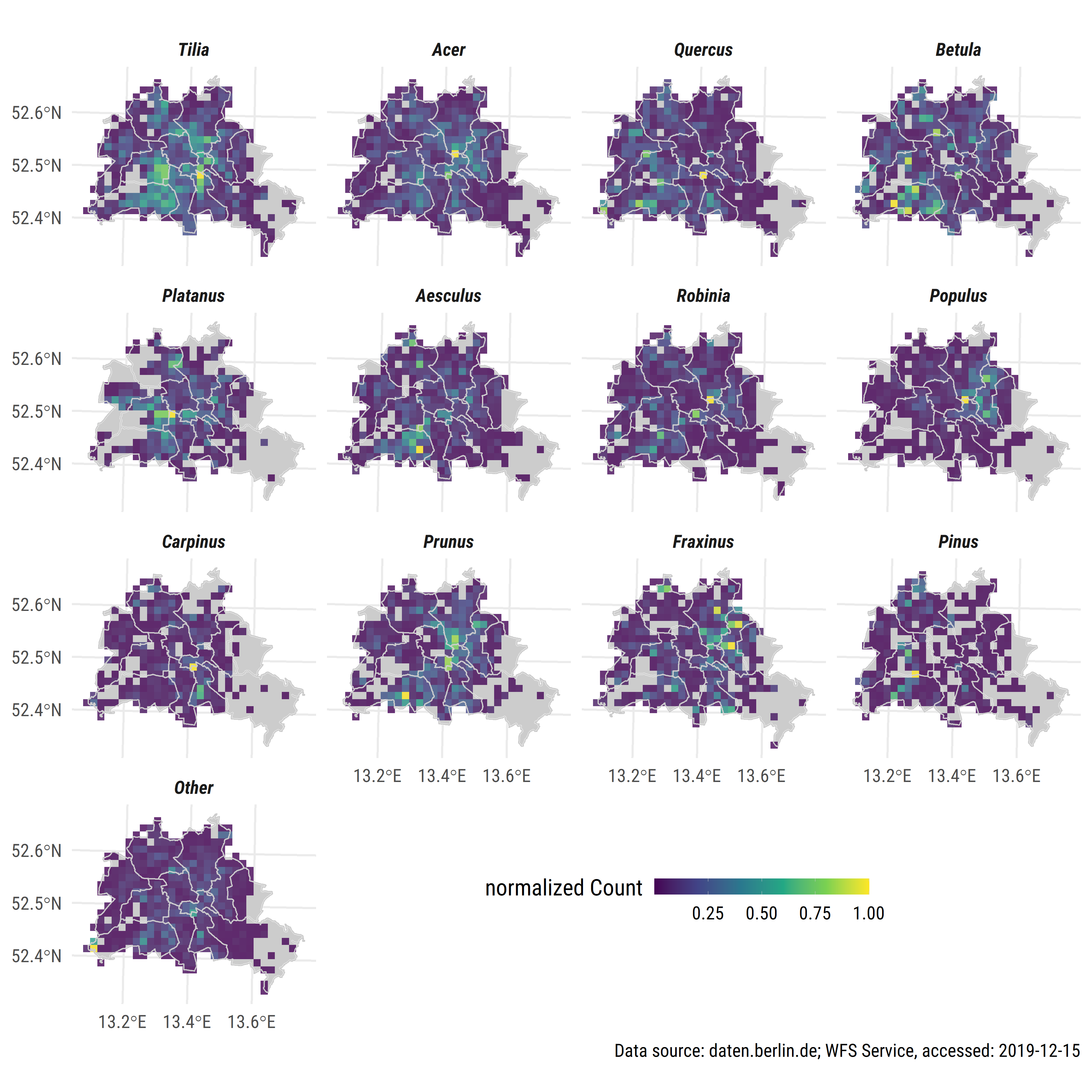


Figure 2: A plot of random numbers

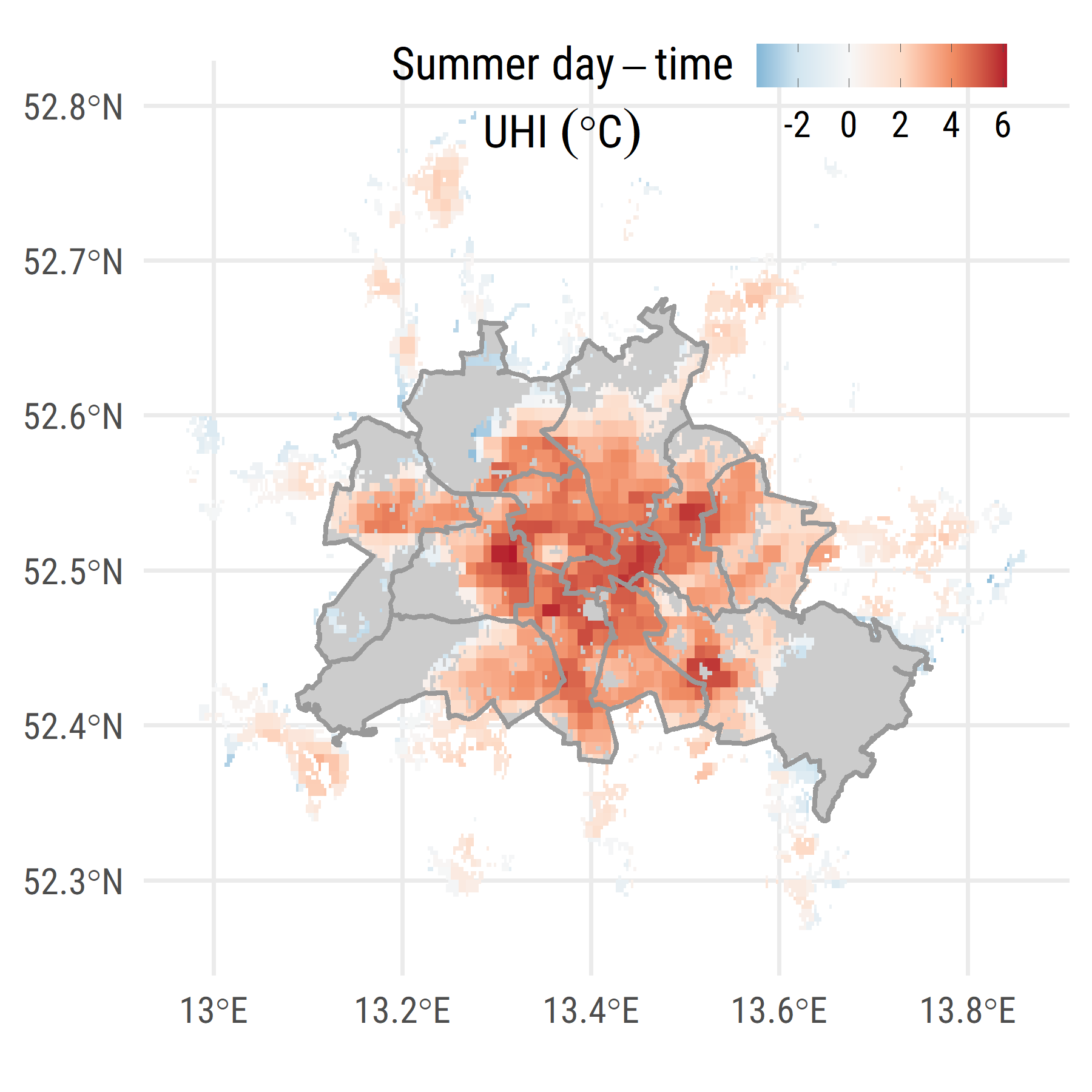


Figure 3: A plot of random numbers

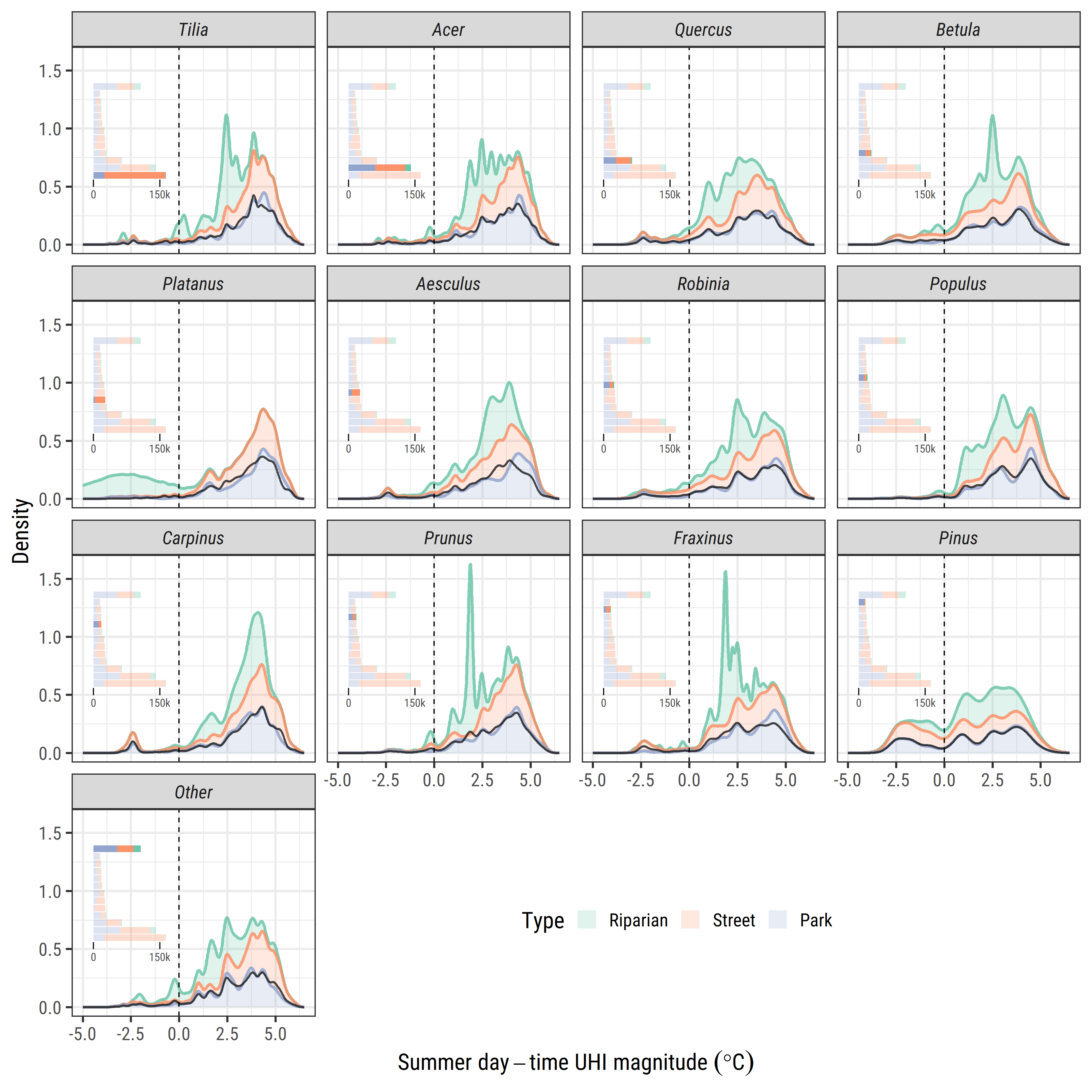


Figure 4: A plot of random numbers

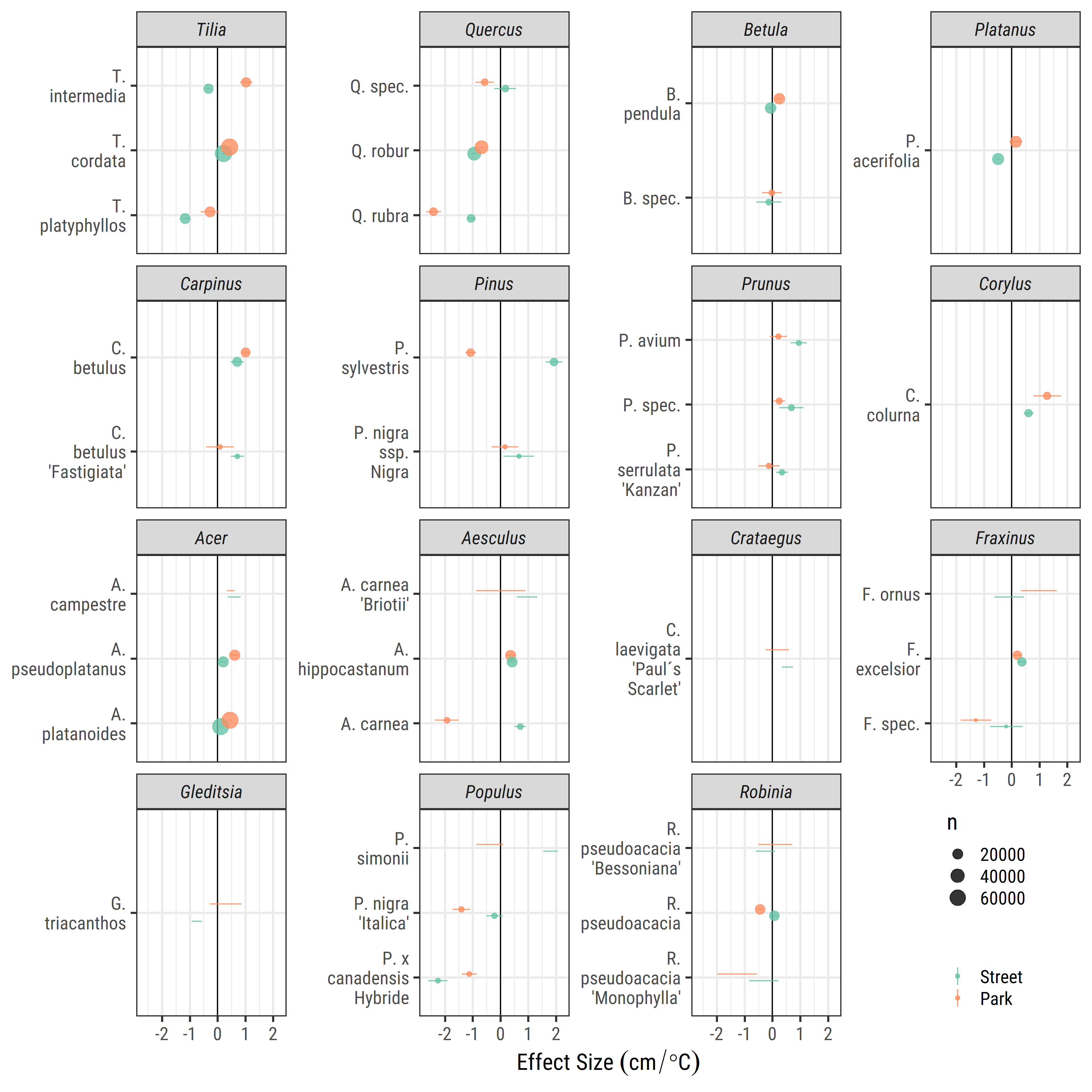


Figure 5: A plot of random numbers

Figure ?? shows how we can have a caption and cross-reference for a plot

# Outlook

# Acknowledgements

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# References

Akbari, H., Pomerantz, M., Taha, H., 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy, Urban Environment 70, 295–310. <https://doi.org/10.1016/S0038-092X(00)00089-X>

Brune, M., 2016. Urban trees under climate change. Potential impacts of dry spells and heat waves in three German regions in the 2050s (No. Report 24). Climate Service Center Germany, Hamburg.

Dahlhausen, J., Rötzer, T., Biber, P., Uhl, E., Pretzsch, H., 2018. Urban climate modifies tree growth in Berlin. Int J Biometeorol 62, 795–808. <https://doi.org/10.1007/s00484-017-1481-3>

Endlicher, W., Scherer, D., Büter, B., Kuttler, W., Mathey, J., Schneider, C., 2016. Stadtnatur fördert gutes Stadtklima, in: Ökosystemleistungen in Der Stadt – Gesundheit Schützen Und Lebensqualität Erhöhen, 3.1. TEEB DE. TU Berlin, UFZ Leipzig, Berlin, Leipzig, pp. 51–63.

Fenner, D., Meier, F., Scherer, D., Polze, A., 2014. Spatial and temporal air temperature variability in Berlin, Germany, during the years 2001–2010. Urban Climate, ICUC8: The 8th International Conference on Urban Climate and the 10th Symposium on the Urban Environment 10, 308–331. <https://doi.org/10.1016/j.uclim.2014.02.004>

Gillner, S., Bräuning, A., Roloff, A., 2014. Dendrochronological analysis of urban trees: Climatic response and impact of drought on frequently used tree species. Trees 28, 1079–1093. <https://doi.org/10.1007/s00468-014-1019-9>

Gillner, S., Vogt, J., Tharang, A., Dettmann, S., Roloff, A., 2015. 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>

Gregg, J.W., Jones, C.G., Dawson, T.E., 2003. Urbanization effects on tree growth in the vicinity of New York City. Nature 424, 183–187. <https://doi.org/10.1038/nature01728>

Grimmond, C., Souch, C., Hubble, M., 1996. Influence of tree cover on summertime surface energy balance fluxes, San Gabriel Valley, Los Angeles. Clim. Res. 6, 45–57. <https://doi.org/10.3354/cr006045>

Gulyás, Á., Unger, J., Matzarakis, A., 2006. Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements. Building and Environment 41, 1713–1722. <https://doi.org/10.1016/j.buildenv.2005.07.001>

Hertel, D., Schlink, U., 2019. Decomposition of urban temperatures for targeted climate change adaptation. Environmental Modelling & Software 113, 20–28. <https://doi.org/10.1016/j.envsoft.2018.11.015>

Hoyano, A., 1988. Climatological uses of plants for solar control and the effects on the thermal environment of a building. Energy and Buildings 11, 181–199. <https://doi.org/10.1016/0378-7788(88)90035-7>

Jia, W., Zhao, S., Liu, S., 2018. Vegetation growth enhancement in urban environments of the Conterminous United States. Global Change Biology 24, 4084–4094. <https://doi.org/10.1111/gcb.14317>

Kuttler, W., Miethke, A., Dütemeyer, D., Barlag, A.-B. (Eds.), 2015. Das klima von essen = the climate of essen. Westarp Wiss., Hohenwarsleben.

Maras, I., Schmidt, T., Paas, B., Ziefle, M., Schneider, C., 2016. The impact of human-biometeorological factors on perceived thermal comfort in urban public places. <https://doi.org/http://dx.doi.org/10.18452/18162>

Mayer, H., Höppe, P., 1987. Thermal comfort of man in different urban environments. Theor Appl Climatol 38, 43–49. <https://doi.org/10.1007/BF00866252>

Moser-Reischl, A., Rahman, M.A., Pauleit, S., Pretzsch, H., Rötzer, T., 2019. Growth patterns and effects of urban micro-climate on two physiologically contrasting urban tree species. Landscape and Urban Planning 183, 88–99. <https://doi.org/10.1016/j.landurbplan.2018.11.004>

Norton, B.A., Coutts, A.M., Livesley, S.J., Harris, R.J., Hunter, A.M., Williams, N.S.G., 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning 134, 127–138. <https://doi.org/10.1016/j.landurbplan.2014.10.018>

Oke, T.R., 1982. The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society 108, 1–24. <https://doi.org/10.1002/qj.49710845502>

Pauleit, S., Jones, N., Garcia-Martin, G., Garcia-Valdecantos, J.L., Rivière, L.M., Vidal-Beaudet, L., Bodson, M., Randrup, T.B., 2002. Tree establishment practice in towns and cities – Results from a European survey. Urban Forestry & Urban Greening 1, 83–96. <https://doi.org/10.1078/1618-8667-00009>

Pretzsch, H., Biber, P., Uhl, E., Dahlhausen, J., Schütze, G., Perkins, D., Rötzer, T., Caldentey, J., Koike, T., Con, T. van, Chavanne, A., Toit, B. du, Foster, K., Lefer, B., 2017. Climate change accelerates growth of urban trees in metropolises worldwide. Scientific Reports 7, 1–10. <https://doi.org/10.1038/s41598-017-14831-w>

Quigley, M.F., 2004. Street trees and rural conspecifics: Will long-lived trees reach full size in urban conditions? Urban Ecosystems 7, 29–39. <https://doi.org/10.1023/B:UECO.0000020170.58404.e9>

Randrup, T.B., McPherson, E.G., Costello, L.R., 2001. A review of tree root conflicts with sidewalks, curbs, and roads. Urban Ecosystems 5, 209–225. <https://doi.org/10.1023/A:1024046004731>

Rhoades, R.W., Stipes, R.J., 1999. Growth of trees on the Virgina Tech Campus in response to various factors 7.

Roloff, A., Korn, S., Gillner, S., 2009. The Climate-Species-Matrix to select tree species for urban habitats considering climate change. Urban Forestry & Urban Greening 8, 295–308. <https://doi.org/10.1016/j.ufug.2009.08.002>

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landscape and Urban Planning 81, 167–178. <https://doi.org/10.1016/j.landurbplan.2007.02.001>

Zhao, S., Liu, S., Zhou, D., 2016. Prevalent vegetation growth enhancement in urban environment. PNAS 113, 6313–6318. <https://doi.org/10.1073/pnas.1602312113>

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### Colophon

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