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COMMENTARY

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Water Smart Cities Increase Irrigation to Provide Cool Refuge in a Climate Crisis

Stephen J. Livesley[1], Valentina Marchionni[2], Pui Kwan Cheung[1], Edoardo Daly[2], and Diane E. Pataki[3]

[1]School of Ecosystem and Forest Science, University of Melbourne, Melbourne, VIC, Australia, [2]Department of Civil Engineering, Monash University, Clayton, VIC, Australia, [3]School of Biological Sciences, University of Utah, Salt Lake City, UT, USA

Key Points:

- Water smart cities are increasing and targeting irrigation to cope with heat waves and drought
- This irrigation is enabled by stormwater, roof-water, and sewage recycled water storage and reuse
- Targeted irrigation can provide cool refuge to "at risk" animal habitat, remnant vegetation, and residential communities

Correspondence to:

S. J. Livesley,
sjlive@unimelb.edu.au

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Author Contributions:

Conceptualization: Stephen J. Livesley, Edoardo Daly, Diane E. Pataki
Funding acquisition: Stephen J. Livesley, Diane E. Pataki
Investigation: Stephen J. Livesley, Valentina Marchionni, Pui Kwan Cheung, Edoardo Daly, Diane E. Pataki
Resources: Stephen J. Livesley, Edoardo Daly, Diane E. Pataki
Writing – original draft: Stephen J. Livesley, Valentina Marchionni, Pui Kwan Cheung, Edoardo Daly, Diane E. Pataki
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Abstract Water smart cities are increasing their use of irrigation and misting to cope with extreme heat and drought. This is being enabled by widespread use of rainwater tanks, stormwater capture and storage systems, and recycled sewage wastewater to irrigate street trees as well as private and public green spaces. These alternative water resources provide new options for cities to better withstand and function under extreme summer heatwave conditions with little or no impact on drinking water supplies. Small-scale approaches to evaporatively cool urban animals, vegetation habitat, and people are showing initial success. However, ongoing testing and modeling are needed to understand the impacts of scaling up these interventions and to evaluate their cost-effectiveness. We describe current innovations in irrigation of Australian cities to help policy development in other countries and cities experiencing similar climates with episodic summer heatwaves.

1. Introduction

Many regions around the world are experiencing heat waves and extended drought. Recently, summer heatwaves in both the northern and southern hemisphere culminated in unprecedented long and harsh bushfire and wildfire seasons. These events, increasing in frequency and severity, present a real challenge to cities that already experience higher air temperatures due to urban heat islands and global warming. In Australia, which recently experienced devastating heatwaves and wildfires, this phenomenon is driving the development of policy and management approaches to make cities safer and more resilient for humans and other species with new ways of using irrigation to reduce air temperatures, increase thermal comfort and alleviate plant water stress (Figure 1).

Increasing urban irrigation may seem paradoxical in a continent known for intense drought, but the capture, storage, and treatment of alternative water sources (stormwater, roof water, and recycled sewage water) has provided new sources of irrigation that might be a pathway for alleviating urban heat and water stress. In this "Commentary," we consider the scientific basis of selectively increasing urban water use at specific locations and times to provide effective climate adaptation through evapotranspirative cooling and drought amelioration. We present practical examples of irrigation and misting to cool targeted faunal communities within urban green spaces, irrigation to mitigate drought and heat impact of valued vegetation within urban parks and reserves, and finally irrigation and misting to cool human residential communities. These interventions offer an unprecedented opportunity for scientists to collaborate with stakeholders to monitor irrigation programs aimed at local cooling and contribute to adaptive management of extreme urban heat.

2. Irrigation to Provide Cool Refuge and Drought Relief

2.1. Irrigation to Support at Risk Urban Fauna

Many cities have developed in areas of regional biodiversity importance and provide habitat to valued, threatened, and endangered animals. Urban fauna can experience unusually high temperatures as a result of the intersection between global warming, urban heat islands, and discrete heatwave events (Ratnayake et al., 2019). The impact of these high temperature events on vulnerable fauna can be exacerbated by other urban stressors, such as air pollution, traffic, and habitat fragmentation. It has been recognized that discrete heatwaves may well drive the future survival and persistence of sensitive fauna groups in urban habitats.

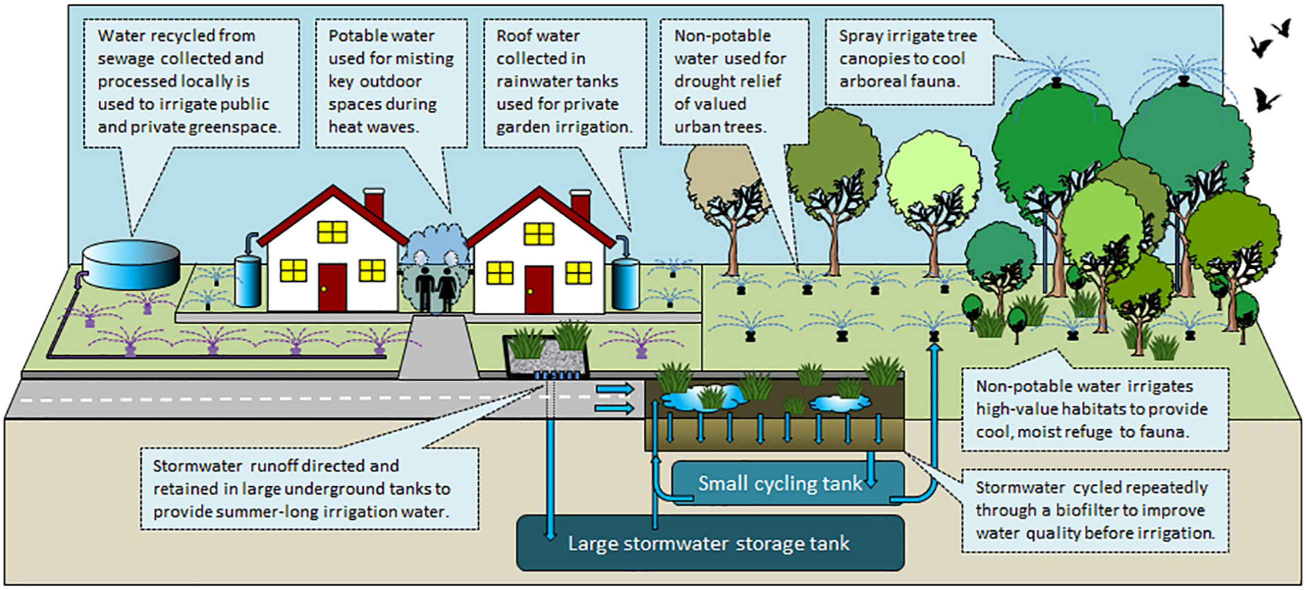

Figure 1. Water smart cities irrigate using stormwater, roof water, and recycled sewage water to provide cool refuge in residential communities and the habitats of vulnerable animal communities during heatwaves. The same irrigation approaches can provide heat and drought relief to remnant or valued vegetation.

As such, understanding and responding to animal exposure during discrete heatwaves in specific habitats is critical for urban animal conservation (Tanner et al., 2017).

Many conservation plans ignore the impact of extreme temperature events and only concentrate on enhancing the adaptive capacity of fauna to climate change (Maxwell et al., 2019). However, ameliorating the condition during climate extremes can help provide broader resilience to the increasing temperature trends. In a review of more than 450 ecological conservation studies between 2008 and 2016, Prober et al. (2019) noted very few climate change conservation strategies intended to ameliorate harmful conditions through engineered physical intervention, such as irrigation cooling. Irrigation can reduce near-surface air temperature, while increasing relative humidity in urban habitats, decreasing average air temperatures by more than 2°C (Broadbent et al., 2018). The reduction of air temperature by irrigation during a heatwave could have a profound impact on ectotherms such as reptiles and amphibians, which have a low tolerance to heat and are also vulnerable to high evaporative water loss (Nowakowski et al., 2018). In Australia, where reptiles and amphibians are diverse and found throughout the continent including large urban centers, the installation of irrigation systems has been proposed as a key method to provide amphibians with refuge from the emerging climate crisis (Shoo et al., 2011). With regards to ectotherm animals, the negative impact of urban heat is hard to predict and, similarly, it is hard to predict the ameliorative potential of irrigation.

One iconic group of mammals found in Australian urban centers in large numbers are the flying foxes. These mammals are attracted to urban centers by the floral diversity and all-year round resource availability that urban vegetation provides. They are not foxes with wings, but are in fact large bats (*Pteropus* spp.), many being threatened species that should be protected from the negative impacts of urbanization, climate change, and extreme temperature events. During heatwaves, air temperatures across most Australian towns and cities can exceed 42°C, a threshold known to lead mortality within flying fox colonies (Ratnayake et al., 2019). In response, park managers in Melbourne, in the temperate southeast of Australia, are experimenting with above-canopy irrigation of roost tree canopies and their understory to evaporatively cool flying foxes. Similarly, local governments in New South Wales and subtropical Queensland are trialing misting systems to cool their flying fox colonies. Irrigation and misting of these flying fox colonies uses potable water to remove concerns of pathogen transfer from nonpotable water sources to either the public or the animals themselves. The effectiveness of irrigation or misting to cool tree-dwelling animals is not well understood, making these trials an important step toward ameliorating the impact of heatwave extremes. In contrast, irrigation of vegetation habitats is likely to reduce the temperature extremes that ground-dwelling animals experience because latent heat cooling will be greatest at the ground surface.

2.2. Irrigation to Support at Risk Vegetation

As Australian cities continue to sprawl, what remains of the natural habitats is severely fragmented into small patches of remnant native vegetation, which become isolated and often degraded. Together with planted trees in streets and parks, these urban green spaces are highly valued for biodiversity conservation (Elmqvist et al., 2015; Tulloch et al., 2016) and urban heat island mitigation (Bowler et al., 2010; Declet-Barreto et al., 2016), as well as active recreation, connection to nature, and community wellbeing (Chiesura, 2004; Pataki et al., 2011). Local governments and communities are now more actively managing these remnant areas of native vegetation to ensure their conservation. This includes irrigation to mitigate the increasing frequency and intensity of urban heat extremes and extended periods of drought.

In the Melbourne metropolitan area, the Millennium drought (2001–2009) and resulting water restrictions contributed to a strategy of sustainable urban stormwater projects. A key benefit of these stormwater harvesting and storage systems is that the water needs to be gradually used so that they are empty and ready to receive runoff from the next rainstorm. As such, irrigation of green space has increased without the use of drinking water, which can improve the health of remnant or valued vegetation that may be suffering from increased heat and drought. For example, an extensive stormwater capture, storage, and irrigation system was designed at Napier Park to provide a more reliable water supply to the stressed on-site vegetation (Marchionni et al., 2019). Specifically, irrigation commenced in 2016 and tree water stress has since measurably decreased, with the unexpected benefit of spontaneous germination of remnant native species occurring in some areas of the park.

Throughout Australia, cities are diversifying their urban water supplies with desalinization plants, stormwater harvesting and recycled sewage wastewater systems. One ambitious recycled wastewater project was implemented in Adelaide, South Australia, to irrigate a 700-ha parkland surrounding Adelaide's city center. These parklands contain remnant and planted vegetation and approximately 70% of recycled water applied is being taken up by this vegetation (Nouri et al., 2019).

In arid and semi-arid regions in particular, the dependency of urban green spaces on supplementary watering is often presumed. Native vegetation and introduced nonnative species may coexist in urban ecosystems, creating unique biotic communities that may be highly dependent on irrigation. However, several studies of urban trees have determined that they are not necessarily as water stressed as commonly assumed (McCarthy & Pataki, 2010; Szota et al., 2019). In many cities, trees can access water from shallow groundwater (Marchionni et al., 2019), past wet seasons (Gómez-Navarro et al., 2019) or leaking pipes (stormwater, sewage, or drinking water) (Lerner, 2002) making supplementary irrigation less effective. In Napier Park, for example, it has been difficult to determine whether reduced tree water stress is a direct result of irrigation because the Millennium drought was followed by two above-average rainfall years in 2010 and 2011.

2.3. Irrigation to Support Residential Communities

Expansive greenspace is known to lower urban air temperatures and improve human thermal comfort both within and outside those greenspaces (Bowler et al., 2010). Norton et al. (2015) suggested irrigating urban greenspace to enhance atmospheric cooling effects in Australian cities if evapotranspiration is limited by soil moisture and vegetation experiences water stress. However, even when vegetation is not water limited, irrigation can enhance greenspace cooling benefits as excess water held on foliar surfaces, organic mulch layers or the mineral soil surface itself can be evaporated providing latent cooling benefits (Vivoni et al., 2020). Furthermore, other methods of evaporative cooling can improve human thermal comfort in outdoor environments, such as evaporative towers or misting systems. Evaporative cooling from irrigation has been found to lower air temperature in the immediate vicinity by 1°C–4°C on average and to significantly improve human thermal comfort (Santamouris et al., 2017).

To help residential communities cope with severe heatwaves, efforts are underway in Australia to strategically deploy irrigation and outdoor misting systems at the neighborhood scale. In Mawson Lakes, a new residential development 12 km north of Adelaide (Mediterranean climate), green space irrigation is supported by the dual supply of harvested stormwater and recycled wastewater. The irrigation of greenspaces in this residential landscape were modeled, and validated through direct measurement, to reduce daily mean temperatures during a heatwave by up to 2.3°C (Broadbent et al., 2018). The Aquarevo residential development in south-east Melbourne (temperate climate) mandates networked rainwater tanks that are triggered to irrigate by digital weather forecasts. These tanks can be triggered to irrigate two days before a forecast large rainfall event, ensuring they are empty to receive roof runoff. These tanks can also be triggered to irrigate on the morning of a forecast heatwave to provide localized evapotranspirative cooling to the property, and collectively to the neighborhood. All Aquarevo homes contribute to a local sewerage system that provide recycled water in return to irrigate greenspaces when rainwater tanks are empty. Home water use and greenspace irrigation impacts on the local microclimate is currently monitored to determine the wider environmental effects of scaling up these technologies to the neighborhood.

Another key feature of heat mitigation in the Aquarevo residential estate are the courtyard misting systems. This approach has been inspired by misting trials in Adelaide, South Australia, where the state-based water utility is promoting increased residential garden irrigation and misting as heat reduction strategies (Johnston, 2019). These misting systems do not require electric fans and require only normal residential water pressures to create aerosol mist spray through their nozzles. Misting cools the air by injecting fine water droplets of ∼10–100 μm diameter. The high contact area between water and air, enhances evaporation and the latent heat cooling effect (Farnham et al., 2015). A misting system can reduce ambient air temperatures by up to 4.0°C (Oh et al., 2020a) and this benefit is only marginally offset by the concurrent humidity increase. Interviewing 141 participants on their thermal comfort before and after exposure to a fan-assisted misting system it was noted that skin wetness resulted, but this was not regarded as a negative by the majority of study participants (Farnham et al., 2015). Interestingly, skin wetness can be responsible for ∼40% of body heat loss under these misting systems (Oh et al., 2020b). The water source for misting systems is restricted to potable water to minimize the potential for air-borne pathogen transfer as aerosols from non-potable water pose a far greater health risk, such as Legionella (Hamilton et al., 2018).

3. Future Research Needs and Irrigation Opportunities for Urban Cooling

Whether these methods of irrigation and misting are an effective climate adaptation measure at the city-scale remains to be seen. Almost two-thirds of the population of Australia is concentrated in its five largest cities. Can irrigation be deployed on a large enough scale to benefit all urban populations, especially those most vulnerable to heat stress? Could there be unintended consequences of increased irrigation and evaporation in these large urban areas? The impacts on increased humidity upon human thermal comfort, or the impacts of increased humidity upon pests and pathogens of concern to human health, are hard to predict. The impacts of large-scale irrigation on climate vary regionally (Lobell et al., 2009) but can impact downwind precipitation patterns, and even increase air temperatures in winter months through as greater near-surface humidity reflects longwave radiation back to the land surface (Puma & Cook, 2010). We suggest that for increased irrigation to benefit the thermal comfort of large urban populations, a combination of experimental monitoring and mesoto global-scale climate modeling is required to evaluate evaporative cooling, latent heat fluxes, and atmospheric humidity at the municipal scale in multiple cities.

4. Conclusion

The targeted use of water in the urban environment is a viable management strategy to actively mitigate heat waves and general summer heat for the benefit of urban animals, vegetation and humans. Irrigation as a heat mitigation strategy is relevant to all towns and cities, including those in low rainfall, arid environments, if alternative water sources can be secured to replace potable water.

Few studies have tested the efficacy of irrigation for the benefit of fauna in urban greenspaces. However, there is ample evidence that relatively small increases in air temperature during a heatwave can negatively impact faunal physiology, behavior, and lead to mortality. Therefore, if targeted irrigation of urban greenspace habitats can decrease air temperatures by 1°C–2°C, this can reduce thermal stress and mortality of vulnerable urban fauna. Irrigation to provide "cool refuge" can be targeted to the habitats of vulnerable fauna so that the intervention is logistically feasible and cost effective.

Making use of stormwater or recycled water to irrigate remnant or valued urban vegetation should increase their resilience to drought and heat. However, the occurrence of plant water stress should not be assumed, but instead tested before investment in irrigation interventions, as there are many reports of mature urban trees that are not directly water stressed even in summer heatwaves and extended droughts. Where water stress does limit urban vegetation survival and growth, irrigation with nonpotable water sources is a viable mechanism to mitigate extreme climate events.

Outdoor evaporative cooling of public spaces could be implemented on a relatively large spatial scale to effectively and fairly provide thermal comfort to all people living in cities, regardless of socio-economic status. To limit pressure on drinking water resources, these measures should where possible use nonpotable water. This is possible for green space irrigation; however, evaporative misting requires potable water to minimize human-health risks. The effects of evaporative cooling on outdoor thermal comfort and indoor building energy use, need to be coupled with climate modeling to evaluate how increased latent heat fluxes and humidity may affect urban and regional climate and hydrology.

References

Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, *97*(3), 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006

Broadbent, A. M., Coutts, A. M., Tapper, N. J., Demuzere, M., & Beringer, J. (2018). The microscale cooling effects of water sensitive urban design and irrigation in a suburban environment. *Theoretical and Applied Climatology*, *134*, 1–23. https://doi.org/10.1007/s00704-017-2241-3

Chiesura, A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning*, *68*(1), 129–138. https://doi.org/10.1016/j.landurbplan.2003.08.003

Declet-Barreto, J., Knowlton, K., Jenerette, G. D., & Buyantuev, A. (2016). Effects of urban vegetation on mitigating exposure of vulnerable populations to excessive heat in Cleveland, Ohio. *Weather, Climate, and Society*, *8*(4), 507–524. https://doi.org/10.1175/WCAS-D-15-0026.1

Elmqvist, T., Setälä, H., Handel, S. N., van der Ploeg, S., Aronson, J., Blignaut, J. N., et al. (2015). Benefits of restoring ecosystem services in urban areas. *Current Opinion in Environmental Sustainability*, *14*, 101–108. https://doi.org/10.1016/j.cosust.2015.05.001

Farnham, C., Emura, K., & Mizuno, T. (2015). Evaluation of cooling effects: Outdoor water mist fan. *Building Research & Information*, *43*(3), 334–345. https://doi.org/10.1080/09613218.2015.1004844

Hamilton, K. A., Hamilton, M. T., Johnson, W., Jjemba, P., Bukhari, Z., LeChevallier, M., & Haas, C. N. (2018). Health risks from exposure to Legionella in reclaimed water aerosols: Toilet flushing, spray irrigation, and cooling towers. *Water Research*, *134*, 261–279. https://doi.org/10.1016/j.watres.2017.12.022

Gómez-Navarro, C., Pataki, D. E., Bowen, G. J., & Oerter, E. J. (2019). Spatiotemporal variability in water sources of urban soils and trees in the semiarid, irrigated Salt Lake Valley. *Ecohydrology*, *12*(8), e2154. https://doi.org/10.1002/eco.2154

Johnston, P. (2019). *Letting your lawn die off? Think again if you want to stay cool*. New South Wales, Australia: The Fifth Estate. Retrieved from https://www.thefifthestate.com.au/urbanism/environment/letting-your-lawn-die-off-think-again-if-you-want-to-stay-cool/Glebe

Lerner, D. N. (2002). Identifying and quantifying urban recharge: A review. *Hydrogeology Journal*, *10*, 143–152. https://doi.org/10.1007/s10040-001-0177-1

Lobell, D., Bala, G., Mirin, A., Phillips, T., Maxwell, R., & Rotman, D. (2009). Regional differences in the influence of irrigation on climate. *Journal of Climate*, *22*(8), 2248–2255. https://doi.org/10.1175/2008JCLI2703.1

Marchionni, V., Guyot, A., Tapper, N., Walker, J. P., & Daly, E. (2019). Water balance and tree water use dynamics in remnant urban reserves. *Journal of Hydrology*, *575*, 343–353. https://doi.org/10.1016/j.jhydrol.2019.05.022

Maxwell, S. L., Reside, A., Trezise, J., McAlpine, C. A., & Watson, J. E. M., et al. (2019). Retention and restoration priorities for climate adaptation in a multi-use landscape. *Global Ecology and Conservation*, *18*, e00649. https://doi.org/10.1016/j.gecco.2019.e00649

McCarthy, H. R., & Pataki, D. E. (2010). Drivers of variability in water use of native and non-native urban trees in the greater Los Angeles area. *Urban Ecosystems*, *13*, 393–414. https://doi.org/10.1007/s11252-010-0127-6

Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williamsa, 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

Nouri, H., Chavoshi Borujeni, S., & Hoekstra, A. Y. (2019). The blue water footprint of urban green spaces: An example for Adelaide, Australia. *Landscape and Urban Planning*, *190*, 103613. https://doi.org/10.1016/j.landurbplan.2019.103613

Nowakowski, A. J., Watling, J. I., Thompson, M. E., Brusch IV, G. A., Catenazzi, A., & Whitfield, S. M. (2018). Thermal biology mediates responses of amphibians and reptiles to habitat modification. *Ecology Letters*, *21*(3), 345–355. https://doi.org/10.1111/ele.12901

Oh, W., Ooka, R., Nakano, J., Kikumoto, H., & Ogawa, O. (2020a). Evaluation of mist-spraying environment on thermal sensations, thermal environment, and skin temperature under different operation modes. *Building and Environment*, *168*, 106484. https://doi.org/10.1016/j.buildenv.2019.106484

Oh, W., Ooka, R., Nakano, J., Kikumoto, H., Ogawa, O., & Choi, W. (2020b). Development of physiological human model considering mist wettedness for mist-spraying environments. *Building and Environment*, *180*, 106706. https://doi.org/10.1016/j.buildenv.2020.106706

Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., & Pincetl, S. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*, *9*, 27–36. https://doi.org/10.1890/090220

Prober, S. M., Doerr, V. A. J., Broadhurst, L. M., Williams, K. J., & Dickson, F. (2019). Shifting the conservation paradigm: a synthesis of options for renovating nature under climate change. *Ecological Monographs*, *89*(1), 1–23. https://doi.org/10.1002/ecm.1333

Puma, M. J., & Cook, B. I. (2010). Effects of irrigation on global climate during the 20th century. *Journal of Geophysical Research*, *115*(D16), 1–15. https://doi.org/10.1029/2010JD014122

Ratnayake, H. U., Kearney, M. R., Govekar, P., Karoly, D., & Welbergen, J. A. (2019). Forecasting wildlife die-offs from extreme heat events. *Animal Conservation*, *22*(4), 386–395. https://doi.org/10.1111/acv.12476

Santamouris, M., Ding, L., Fiorito, F., Oldfield, P., Osmond, P., & Paolini, R. (2017). Passive and active cooling for the outdoor built environment – Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. *Solar Energy*, *154*, 14–33. https://doi.org/10.1016/j.solener.2016.12.006

Shoo, L. P., Olson, D. H., Mcmenamin, S. K., Murray, K. A., Van Sluys, M., Donnelly, M. A., et al. (2011). Engineering a future for amphibians under climate change. *Journal of Applied Ecology*, *48*(2), 487–492. https://doi.org/10.1111/j.1365-2664.2010.01942.x

Tanner, E. P., Elmore, R. D., Fuhlendorf, S. D., Davis, C. A., Dahlgren, D. K., & Orange, J. P. (2017). Extreme climatic events constrain space use and survival of a ground-nesting bird. *Global Change Biology*, *23*(5), 1832–1846. https://doi.org/10.1111/gcb.13505

Szota, C., Coutts, A. M., Thom, J. K., Virahsawmy, H. K., Fletcher, T. D., & Livesley, S. J. (2019). Street tree stormwater control measures can reduce runoff but may not benefit established trees. *Landscape and Urban Planning*, *182*, 144–155. https://doi.org/10.1016/j.landurbplan.2018.10.021

Tulloch, A. I. T., Barnes, M. D., Ringma, J., Fuller, R. A., & Watson, J. E. M. (2016). Understanding the importance of small patches of habitat for conservation. *Journal of Applied Ecology*, *53*(2), 418–429. https://doi.org/10.1111/1365-2664.12547

Vivoni, E. R., Kindler, M., Wang, Z., & Pérez-Ruiz, E. R. (2020). Abiotic mechanisms drive enhanced evaporative losses under urban oasis conditions. *Geophysical Research Letters*, *47*(22), e2020GL090123. https://doi.org/10.1029/2020GL090123