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Potential Consequences for Management, Urban Ecosystems, and the Urban Public

Adapting Urban Forests to Climate Change

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Trees in natural forests will experience large range shifts due to climate change alone (Aitken et al. 2008), and the suite of pre-urban native species well adapted to future urban climates is likely to be reduced.

Urban forests provide many important ecosystem service benefits to humans, such as climate regulation, improved health outcomes, and psychological well-being (Bolund and Hunhammar 1999; Frumkin 2013). They are also critical to the functioning of urban ecosystems, provision of food and habitat for fauna (Goddard et al. 2010), and regulation of the environment for plant communities. These benefits are driven by the structure and composition of the urban forest, which in turn is shaped by the climate of the city (Kendal et al. 2012; Ramage et al. 2012).

It is now clear that human-induced climate change is leading to environmental change across the globe. While there has been much scientific effort applied to understanding the drivers of climate change and mitigating its impacts, we must now also begin to focus on adapting our cities to climate change (IPCC 2013). This is a particularly important topic for urban landscape managers, who will be among the first to have to deal with the effects of climate change, but who also have a unique capacity to contribute to the adaptation of cities through careful tree selection and management.

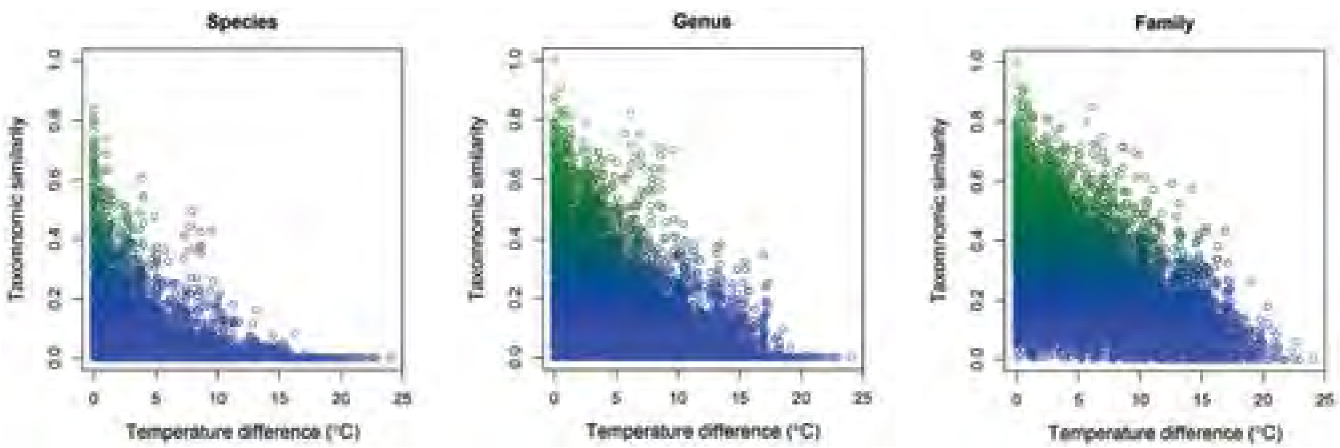
Impacts of Climate Change on Urban Forests

While models predict that different places will experience climate change differently, there is almost universal consensus that climate change will lead to increased levels of carbon dioxide in the atmosphere, higher average temperatures, sea level rises, and more frequent extreme weather events, such as floods, storms, and droughts across the globe (IPCC 2013). Current forecasts suggest that levels of carbon dioxide will rise from 280 to over 400 parts per million, temperatures will rise from 1.5 to 4.5 degrees Celsius, and sea levels will rise by one metre (IPCC 2013).

These changes are likely to have immediate impacts on the urban forest. Storm damage can lead to trees being uprooted and the loss of limbs (Jim and Liu 1997). Floods, droughts, and sea level rises will lead to tree mortality and a reduction in the benefits provided by trees that are not well adapted to new conditions. Longer-term effects will include changes in plant phenology (which refers to the timing of seasonal events, such as flowering and leaf unfolding) (Gordo and Sanz 2010), and most importantly changes in species composition (Kendal et al. 2012; Ramage et al. 2012). It must be acknowledged that there may also be some positive effects of climate change; some tree species will be better suited to future climates, and increasing levels of carbon dioxide have a generally positive effect on plant growth (Drake et al. 1997).

Temperature is a major driver of the species composition of natural (Woodward and Williams 1987) and urban (Kendal et al. 2012) forests. While there is likely to be some plasticity in the response of established trees to a changing climate, even small increases in temperature are likely to result in some species declining or becoming more difficult to establish, to be replaced over time by other species that perform better in warmer climates (Fig. 2). These changes in species are also likely to lead to "trait shifts". For example, the urban forest species most likely to be lost in Melbourne, Australia, are likely to come from a pool of cool-climate, broad-leaved, bright green leaved deciduous trees that are currently widely planted (Fig. 3–5), while the species most likely to replace these come from a pool of narrower-leaved, grey-green, foliaged evergreen trees (Fig. 6–8) (Kendal 2011).

There are also a number of indirect impacts of climate change likely to affect the health and composition of the urban forest. Changes in the distribution and abundance of pests, diseases, and herbivorous insects are likely to have enormous impacts on some species (or higher taxonomic groups) (Tubby and Webber 2010). In addition, there may be a feedback loop, as stress due to increased temperatures leads to increased vulnerability to attack by pests and diseases for some tree species.



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A global, pairwise comparison of the similarity of 151 urban forest inventories and temperature difference of the cities they were from (data from Kendal et al. 2012, 2013). Even a small change in temperature leads to large changes in tree inventories.


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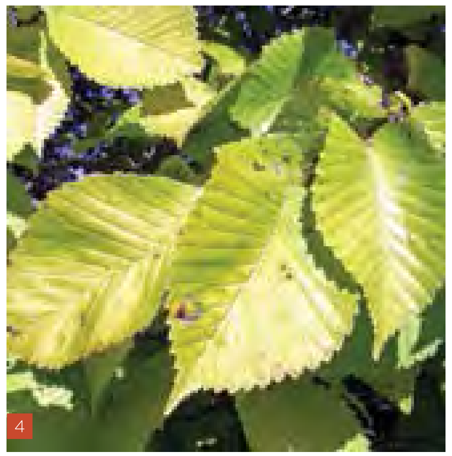
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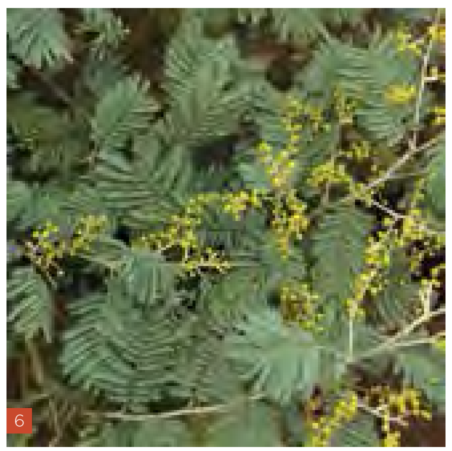
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1. Bare broad-leaved deciduous trees are part of the typical inner city streetscape in Ballarat, Australia, in winter.

3–5. Leaves of common broad-leaved deciduous trees: *Platanus spp.*, *Ulmus glabra* 'Lutescens', and *Aesculus hippocastanum*.

6–8. Leaves of common evergreen trees in South-eastern Australia: *Acacia dealbata*, *Corymbia citriodora*, and *Eucalyptus melliodora*.

9. In response to climate change, changing species selection can lead to landscapes with very different appearances from traditional landscapes, such as the Arid Garden at the Royal Botanic Gardens Melbourne.


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Synergies in the Effect of Urbanisation and Climate Change

A number of environmental phenomena associated with urbanisation, such as the urban heat island effect, changes to hydrology, and chemical cycling, also influence the urban forest (Grimm et al. 2008). Some of these are magnified by the effects of climate change. Urbanisation leads to reduced water infiltration into soils and reduced water available for trees, as water is captured and piped into streams and drains. Droughts in places, such as South-eastern Australia, are predicted to become more common and more severe under future climates, leading to likely further reductions in water available for trees. The urban heat island is a universal phenomenon affecting cities, where the removal of vegetation reduces shading and transpiration, and the creation of impermeable surfaces, such as concrete and asphalt, absorb heat that is released overnight. This can lead to temperature increases of up to five degrees Celsius in some cities (Grimm et al. 2008). Loss of tree canopy due to climate change-driven decline and mortality is likely to increase the urban heat island effect, leading to additional temperature increases beyond those predicted by climate change alone. This could in turn exacerbate the effects of temperature stress on vulnerable species.

In adapting the urban forest to climate change, there is a risk of *maladaptation* (Barnett and O'Neill 2010). Replacing dense canopied trees with more open canopied species that are better adapted to warmer conditions may lead to increased urban heat island effects and exacerbate temperature increases. Similarly, there has been a trend towards low-maintenance xeriscaping, where turf or groundcover vegetation is replaced with hard surfaces, such as granitic sand or gravel. This is also likely to contribute to an increased urban heat island effect.

Similarly, policy responses to drought in south-eastern Australia have included restricting the availability of irrigation water for the urban forest (Hatton MacDonald et al. 2010). If this policy response continues, the negative effects of climate change on vulnerable species are likely to be hastened as even less water is available to trees through these stressful periods.

The urban heat island effect combined with climate change forecasts could lead to future urban environments that are up to 10 degrees Celsius warmer and very different from those that existed prior to urbanisation. While this is a worst-case scenario, even conservative forecasts would put the combined effect of climate change and the urban heat island at four to five degrees Celsius in many cities and towns around the world. This would be equivalent to a temperature shift from Washington D.C. to Los Angeles, from Melbourne to Sydney, or from London to Rome.

These combined effects mean that some native tree species that were well adapted to pre-urban landscapes, and may have been successful urban trees historically, are less likely to perform well in the future. Trees in natural forests will experience large range shifts due to climate change alone (Aitken et al. 2008), and the suite of pre-urban native species well adapted to future urban climates is likely to be reduced. This poses challenges for urban ecology, particularly in the new world, which has focused on the conservation of native biodiversity in urban areas. In the future, as there is increasing mixing of native biodiversity with introduced species, the definition of "natural" will no doubt change.

Changes to the composition and the traits of the urban forest will lead to changes in the sense of place and identity of cities.

Flow-On Effects of Changes to the Urban Forest

The changes to the urban forest will have a number of important flow-on effects for management, urban ecosystems, and the urban public. With regard to management activities, these will include increased tree removal, pruning, and planting in response to damage, decline, and mortality. There will also be greater uncertainty about the outcomes of management actions in the urban forest. Trees that have performed reliably in the past may no longer do so under future climates, while trees that have performed poorly may turn out to be much improved.

Trees are a keystone of urban ecosystems (Stagoll et al. 2012) and changes in species composition will have flow-on effects for urban biodiversity. Apart from the direct changes to biodiversity through the loss of native trees, many native fauna species are dependent on specific tree species or tree characteristics (for example, large hollows) that may become less common. In natural forests, there will be range shifts in flora and fauna in response to climate change. It is less clear how these processes will operate in more managed urban systems; should urban forest managers facilitate these range shifts? Urban ecological research is urgently required to guide these decisions.

It is possible that trait shifts will lead to the changes in the provision of ecosystem services. In Melbourne, it is likely that a shift to smaller-leaved evergreen species will result in less pollution and rainfall interception, and reduced passive solar performance through sparser canopies providing less shade in summer and more shade in winter (Kendal 2011). There may also be health implications as some evergreen species that are likely to become more dominant (for example, *Eucalyptus* spp.) emit higher levels of Volatile Organic Compounds (VOCs) (that can lead to respiratory problems) than broad-leaved deciduous trees (Bernard et al. 2001).

Perhaps the most important flow-on effect of trait shifts will involve people's perceptions and experience of the urban forest. Trees are an important component of the sense of place of cities; plane trees contribute to the identity of Paris (Fig. 13), while palm trees shape people's image of Miami. Many cities in South-eastern Australia have a strong European colonial heritage expressed in its many broad-leaved deciduous trees (Fig. 1, 11, 14) that is likely to change under future climates. Conversely, the native trees planted in a city help to create a unique identity that distinguishes one city from another (Fig. 12). Changes to the composition and the traits of the urban forest will lead to changes in the sense of place and identity of cities (Fig. 9, 10).

Conclusion

Climate change is already affecting the health and well-being of the urban forest in cities around the world. Urban forest managers have a unique opportunity to shape these cities' adaptation to climate change through sensible plant selection of a diverse range of trees that are likely to perform well and maintain or improve ecosystem services and ecological functioning. Recognising the importance of trait shifts as a result of this adaptation will allow managers to plan for a healthy urban forest that satisfies cultural and natural heritage needs.

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Adapting to Climate Change

There are several broad principles that can be used to guide future planning of the urban forest in response to climate change.

1. Diversity is good. Increasing the species diversity of the urban forest will reduce the impact of loss of particular species, and increase the likelihood of having trees that will be better adapted to future climates.

2. Some kinds of diversity are better than others. We do know something about the likely effect of climate change. Clearly, additional diversity should be coming from trees better adapted to warmer conditions; planting a greater diversity of trees from cooler climates will provide little protection against climate change.

3. Remember genetic diversity. Genetic diversity within species will also provide some protection from the effects of climate change (Aitken et al. 2008; Lohr 2013). There has been a great increase in the use of clonal plant material due to recent advances in nursery production techniques. While the extensive use of clonal material may provide uniform form and function in present climates, it may lead to uniform decline and failure in future climates. It may also be possible to use better adapted selections of the same species.

4. Think about traits as well as species. The effect of trait shifts on the provision of ecosystem services, biodiversity and sense of place is potentially very important. In some cases, it may be possible to substitute vulnerable species with better adapted species that have similar traits to maintain sense of place as ecosystem function.

5. Keep an open mind about species performance. We tend to judge species based on past performance. However, it is likely that the performance of many species will change under future climates. Species that have been reliable in the past may not be in the future and vice versa. Being able to recognise these changes is critical to be able to adapt to them

6. Be aware of maladaptation and feedback loops. Some obvious adaptation strategies, such as the use of more heat and drought-tolerant species, can in fact exacerbate the local effects of climate change. For example, where replacement tree species have much sparser canopies than those they are replacing, there could be an increase in the urban heat island effect. More trees may be required to ensure no net-loss in canopy cover.

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10. Changing species selection can lead to large trait shifts in the plants being used in the urban forest, which may also lead to incongruous landscapes, such as these palm trees in front of the neo-Gothic St Patrick's Cathedral in Ballarat.

11. Broad-leaved deciduous trees express Australia's strong European colonial heritage at Ballarat Town Hall.

12. Landscapes using native trees and shrubs have a distinctive appearance, such as this *Eucalyptus melliodora* in a suburban linear park in Melbourne, compared to more cosmopolitan streetscapes using European trees.

13. Plane trees contribute to the identity of Paris (Photo: Chelsea Sia).

14. Broad-leaved deciduous trees, in autumn, create a sense of place in Royal Parade, Melbourne.