Potential effects of climate change on Melbourne's street trees and some implications for human and non-human animals

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INTRODUCTION

Melbourne has an extensive canopy of street trees that provides an important urban amenity and contributes both to human health and wellbeing and as food and habitat for non-human animals. There is some evidence that the composition of Melbourne's street trees is likely to change as a result of climate change (Kendal et al. 2011). However, we know little about what these changes may be, and what this could mean for Melbourne's human, avian and mammal inhabitants.

Trees in urban landscapes have many important benefits to humans such as improved health outcomes (Mitchell & Popham 2008), psychological wellbeing (Kaplan 1995; Ulrich et al. 1991) and the provision of ecosystem services (Bolund & Hunhammar 1999). Street trees in particular have been linked to reduced incidence of asthma (Lovasi et al. 2008), increased house prices (Orland et al. 1992) and reduced air pollution (Yang et al. 2005). Street trees also provide benefits to non-human animals. The Rainbow Lorikeet (*Trichoglossus haematodus*) has expanded its range in urban Melbourne significantly which has been partly attributed to the planting of more native street tree species (Fitzsimons et al. 2003; Shukuroglou & McCarthy, 2006). Similarly, the Grey-headed Flying Fox (*Pteropus poliocephalus*) has become increasingly common in Melbourne, again at least partly due to the increased availability of food resources in streetscape plantings over native vegetation (Williams et al. 2006).

There are probably more than a million street trees planted across greater Melbourne (Frank et al. 2006), and more than half of Melbourne's residences have a street tree in the adjoining streetscape (Kirkpatrick et al. 2011). However, these street trees are not distributed evenly. The composition of street trees can differ greatly in different suburbs (Fairman et al. 2010). There are significant socioeconomic and climatic gradients occurring from Melbourne's west to east (ABS 2006; BOM 2011). A study of the distribution of street trees in major Australian cities including Melbourne found that the likelihood of having a street tree is correlated with household income (Kirkpatrick et al. 2011).

Global climate change is predicted to lead to a warmer and drier climate across much of south-eastern Australia, with a many models predicting at least several degrees of warming (Hennessy et al. 2007). In temperate areas, climate change is predicted to lead to the distribution of native trees moving towards the poles (Iverson & Prasad 1998), with particular locations losing some species better adapted to cooler locations and gaining species that are better adapted to warmer climates. Plant functional traits such as leaf width and canopy height change along climatic gradients (Fonseca et al. 2000). The trait profile of particular vegetation communities is predicted to change with climate change for traits such as the seasonal timing (phenology) of leaf and flower development (Hanninen & Tanino 2011) and leaf traits such as leaf mass per area and leaf lifespan (Wright et al. 2005). There have been few studies of the effect of climate change on cultivated urban vegetation, although it has been predicted to allow a wider range of plants from warmer climates to be grown and to affect the range and virulence of pests and diseases (Bisgrove & Hadley 2002).

Most studies exploring street trees and climate change have focussed on the role street trees can play in mitigating the effects of climate change through carbon sequestration e.g. (McPherson et al. 1994; Gill et al. 2007). One study has explored the likely impact of climate-change induced drought on the suitability of particular street trees (Roloff et al. 2009), however recent research suggests that temperature rather than rainfall is a key driver of the distribution of urban vegetation (Kendal et al. 2011). Human behaviours such as irrigation (particularly during establishment) allow the barrier of inadequate rainfall to be overcome for many species, while temperature cannot easily be overcome. Cities with even relatively small temperature differences have relatively large differences in the taxonomic composition of their cultivated floras (Kendal et al. 2011). It is likely that some street tree taxa that have been well adapted to Melbourne's historic climate are likely to be less well adapted to future climates, while other taxa may become better adapted to Melbourne's future climate.

This paper explores how the composition of Melbourne's street tree may change under current climate change scenarios, and what the impact of this may be for both humans and non-human animals living in Melbourne.

TECHNIQUES

Study area

Melbourne's is the second largest city in Australia with a population of approximately 4 million people at the relatively low density of approximately 1500 people/km^2 (ABS 2011). It has a temperate climate with a long term mean annual temperature of 15.0°C, and a mean annual rainfall varying from 500 mm/year in the west to over 1000 mm/year in the east (BOM 2011).

Melbourne's urban tree canopy is dominated by cultivated rather than remnant or spontaneous species. There is a relatively small amount of remnant native vegetation remaining in conservation reserves, particularly along creek corridors; inner Melbourne has as little as 1.7% of the pre-urban vegetation remaining, with outer Melbourne having as much as 16% (McDonnell, 2005). The majority of street trees have been planted by local government or on behalf of local government by real estate developers (e.g. Hume City Council, 2003). There are also some cases where remnant indigenous trees have been retained in the streetscape, or trees and other vegetation has been planted by residents.

In streetscapes, approximately 60% of the trees are native to the continent of Australia, including a wide range of *Eucalyptus* sp. and related species such as Red Flowering Gum (*Corymbia ficifolia)* and Queensland Brush Box (*Lohphostemon confertus*), and small native trees such as Snow-in-Summer (*Melaleuca linariifolia*) and Willow Bottlebrush (*Callistemon salignus*). Common exotic species include Purple-leaf Cherry Plum (*Prunus cerasifera* 'Nigra') and the London Plane Tree (*Platanus* x *acerifolia*) (Frank et al. 2006). However, the composition of street trees can vary greatly across suburbs. A comparison of the 10 most abundant street tree species in two particular municipalities (the centrally located City of Melbourne and the Hume City Council, located on Melbourne's north-western fringe) shows only two species in common, Pin Oak (*Quercus palustris*) and Eucalypts (*Eucalyptus* spp.) (Fairman et al. 2010). The City of Melbourne municipal area had fewer native species and a a higher proportion of large, coarse foliaged deciduous trees such as the London Plane Tree (*Platanus* x *acerifolia*), American Elm (*Ulmus americana*) and Norway Maple (*Acer platanoides*) than Melbourne generally. The Hume City Council municipal area had more native species such as Yellow Gum (*Eucalyptus leucoxylon*) and Willow Bottlebrush (*Callistemon salignus*) and several finer foliaged exotic deciduous species such as Ash (Fraxinus spp.) and Black Locust (*Robinia pseudoacacia*) than Melbourne generally.

Data Sources and analysis

The 50 most common street tree taxa planted in greater Melbourne (23 of the 31 municipalities) was obtained from a journal article by Frank *et al*. (2006). The 10 most common species in two different municipal areas (the City of Melbourne and the Hume City Council) was obtained from a masters thesis (Fairman et al. 2010). Other cities where these taxa are also cultivated was determined by examining 72 published species lists of streetscape, park and garden floras. The mean temperature of occurrence of each species was calculated as the mean annual temperature of all cities where the species had been recorded (see Kendal et al. 2011 for details of the methods used to select the species lists and collect temperature information about the cities). Taxa that had a mean temperature of occurrence less than 13.5°C (1.5°C cooler than Melbourne) were classified as potentially at risk in future climates. Taxa that were not listed as common in Melbourne but occurred in at least five other cities and had a mean temperature of occurrence more than 16.5°C and less than 21°C were also included for comparison as potentially becoming more suited to Melbourne in a warmer climate.

The mean temperature of occurrence was validated by comparing species-level results with USDA plant hardiness zone data where available. USDA plant hardiness zones are a commonly used measure of assessing the suitability of plant species for a particular location based on mean annual minimum temperatures (Cathey 1990). Melbourne would be located approximately in zone 9B, which includes areas with a mean annual minimum temperature of +1°C to -1°C. USDA plant hardiness zones for each taxa were identified from published literature where possible (e.g. Gilman & Watson, 1993). Where taxa were aggregated to the genus level in plant lists, corresponding USDA plant hardiness zones were derived from averages of several commonly planted taxa. There was a strong correlation between the calculated mean temperature of occurrence and mean USDA plant hardiness zone (r=0.82).

Some key characteristics (traits) of street trees likely to influence the benefits provided to humans and non-human animals were identified, including height, leaf width, seasonality (evergreen or deciduous) and nativeness (to the continent of Australia). This trait-based approach draws on techniques commonly used in ecology and allows comparison of taxonomically distinct vegetation (Cornelissen et al., 2003). For each taxa, traits were determined from published information in floras (Spencer, 2000) and plant databases (Burnley 2002). Leaf width was calculated as the "maximum diameter of an imaginary circle that can be fitted anywhere within a leaf" (Cornelissen et al., 2003:14). This trait is equal to the leaf width for regular shaped simple leaves and the leaflet width for compound leaves. For lobed leaves, the leaf width was estimated from photos relative to overall leaf length. The relationship between each trait and the mean temperature of occurrence was determined with linear regressions, using the *lm* function in R v2.13 (R. Development Core Team 2010).

RESULTS

Potential changes driven by increasing temperatures

A total of 11 taxa commonly planted in Melbourne are also commonly planted in cities that are on average more than 1.5°C cooler than Melbourne (Table 1), such as New York (12.4°C), Prague (8.1°C) and Chicago (9.4°C). These taxa are all currently recommended for planting in USDA plant hardiness zones colder than Melbourne. These taxa varied across different suburbs. Three of the four taxa with the lowest mean temperature of occurrence were on the Melbourne City Council species list. Only one species, Pin Oak (*Quercus palustris*), was on all three lists (greater Melbourne, City of Melbourne and the Hume City Council).

All 11 taxa identified as at risk in a warmer climate are deciduous, while trees from similar or warmer climates are mostly evergreen (Figure 1). None of the 11 taxa identified as at risk in a warmer climate are native to Australia (Figure 2). There was a significant ($P<0.001$, $R^2=0.17$) negative relationship between leaf width and mean temperature of occurrence (Figure 3). The regression model suggests that average tree leaf width reduces from 35 mm to 22 mm as a temperature increases from 15°C to 18°C. Note that no cool climate conifers (which have very narrow foliage) were recorded in the list of Melbourne's most common street tree taxa. There was also a non-significant ($P=0.17$) trend suggesting that trees from warmer cities may be slightly smaller than those from cooler cities.

Table 1 – Street tree species commonly occurring in cooler cities than Melbourne

Species	Mean annual temperature of occurrence (°C)	USDA plant hardiness zone range	Where recorded in Melbourne		
			Greater Melbourne	Melbourne City Council	City of Hume
Norway Maple (*Acer platanoides*)	9.9	4-7		✓	
Silver Birch(*Betula pendula*)	10.8	3-6B	✓		
American Elm (*Ulmus americana*)	11.2	2-9		✓	
Pin Oak (*Quercus palustris*)	11.5	4-8	✓	✓	✓
Plane Tree (*Platanus* spp.)	11.6	5-9	✓		
Elm (*Ulmus* spp.)	11.7	5-8	✓		
Maple (*Acer* spp.)	12.4	4-8		✓	
Flowering Cherry (*Prunus* spp.)	12.5	4-8	✓		
Ash (*Fraxinus* spp.)	12.9	5-8B	✓		✓
Black Locust (*Robinia pseudoacacia*)	13.0	4-8			✓
Ornamental Pear (*Pyrus calleryana*)	13.2	5-9	✓		

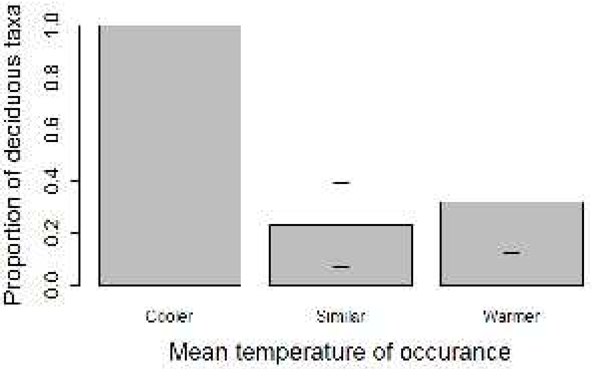

Figure 1 – The proportion of deciduous taxa with a mean temperature of occurrence cooler (below 13.5°C), similar to (13.5°C to 16.5°C) and warmer (above 16.5°C) than Melbourne.

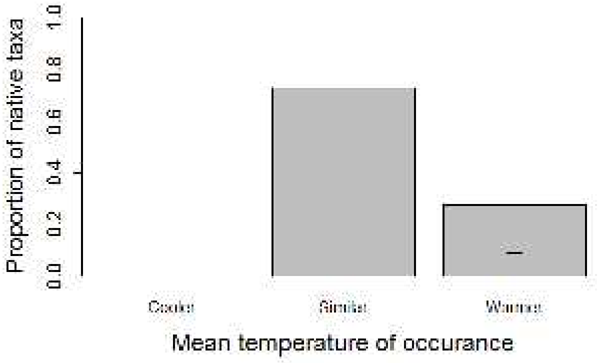

Figure 2 – The proportion of native taxa with a mean temperature of occurrence cooler (below 13.5°C), similar to (13.5°C to 16.5°C) and warmer (above 16.5°C) than Melbourne.

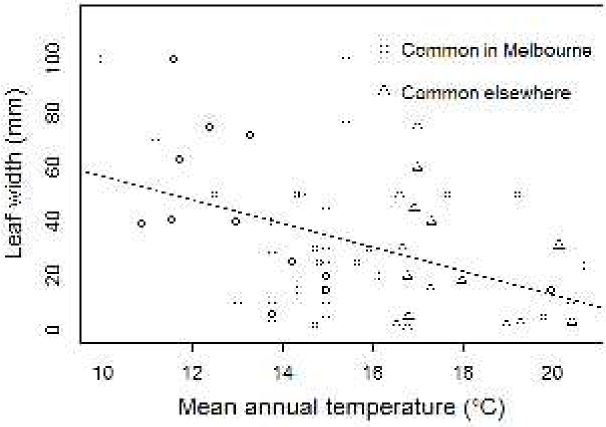

Figure 3 – A linear regression of leaf width of tree species against the mean annual temperature of cities in which they have been recorded

DISCUSSION

The results show that there are a number of common street tree taxa in Melbourne that are mostly cultivated in cities cooler than Melbourne, and that may be at risk of becoming less successful in a climate that is warming as a consequence of climate change. These taxa are more likely to be deciduous trees with broader leaves and originate from countries other than Australia. There are also a number of taxa that are mostly cultivated in cities warmer than Melbourne, and these may perform better in Melbourne in a warmer climate. These tend to be evergreen trees with narrower leaves, and are more likely to be native to Australia.

The impact of these changes is likely to be distributed unequally, with some places, such as the City of Melbourne municipal area, which has a higher proportion of cooler-climate trees, being at greater risk than others, such as the City of Hume which has many more native street trees. In other suburbs, risk may be related to fashions in street tree species selection in Melbourne. Broad leafed, European, deciduous trees were popular in the late 19th and early 20th century, and consequently are more common in older suburbs, while native species have become more popular since the 1960s and are more common in new suburbs (Spencer, 1986).

Implications for humans

A number of benefits provided by trees, such as rainfall interception, pollution reduction and shading, are related to leaf area (McPherson et al. 1997). If some trees with large leaves were replaced by trees with smaller leaves, the provision of these benefits would be likely to be reduced. There is also potentially a feedback between leaf width and temperature, as trees with narrower leaves provide less shade, resulting in more heat absorption by impervious surfaces, in turn resulting in higher local temperatures (the Urban Heat Island effect). Replacing some deciduous taxa with evergreen taxa would also result in seasonal variation in the provision of these benefits; rainfall interception, pollution reduction and shade would be increased in winter and reduced in summer. While winter rainfall interception is a benefit in Melbourne, the provision of shade in winter is usually not considered a benefit as it leads to the reduced solar performance of buildings. Reduced shade in summer may also lead to increased mortality and morbidity through heat stress (Harlan et al. 2006).

Street trees can also contribute to a city's sense of place (Dwyer et al. 1991). This is true of Melbourne, where the urban trees of western Europe are an important component of popular representations of the city: "large deciduous shade trees are the most beloved in our urban environment" (Kizilos 2008). Debate about threats and challenges to the character of Melbourne's urban forest are a regular feature of news and opinion in the cities media e.g. (Dowling 2011; Ramadge 2007). While central Melbourne is dominated by large, European deciduous street trees, there have been some very public debates over whether this should be changed in favour of more native trees. A 1992 proposal to plant large deciduous trees (London Planes – *Platanus* × *acerifolia*) along Swanston St, a prominent boulevard through the centre of Melbourne, resulted in a great deal of debate over whether Melbourne was a European or Australian city (Cerwonka 2004).

Of course one of the reasons so many large, European deciduous trees have been planted in Melbourne is its colonial heritage. It has been argued that European colonisation of temperate lands around the world was followed by a 'portmanteau' of biological life in crops, stock, weeds, pests and ornamental plants (Crosby 1986), and that the appearance of colonial cities was transformed through the cultivation of European plants in gardens, parks and streetscapes (Ignatieva & Stewart 2009). The results of the present study suggest that while Melbourne as a whole has already largely moved away from western European street trees, perhaps due to the already large temperature difference between Melbourne and western Europe, this trend is likely to continue and perhaps increase as a result of climate change. In some places in Melbourne such as the City of Hume, street trees are already dominated by native trees and narrow leaved exotic trees from warmer climates (e.g. Desert Ash, *Fraxinus angustifolia*, which originates from the Mediterranean and North Africa). These areas may see changes in particular street tree species over time as a result of climate change, but the overall traits of deciduousness, nativeness and canopy texture are at less risk of change. In contrast, suburbs that are dominated by street trees that are exotic, deciduous and have coarse foliage are at greater risk of significant changes in these traits, and the people living in these areas more vulnerable to changes potentially affecting their connection to place. As one of these places is the City of Melbourne with its iconic parks and streets, this may be true of Melbourne's overall identity as a European city.

These changes to plant traits may also affect peoples' preferences for street trees. Research on people's preference for Melbourne's street trees show that leaf width and nativeness are both important predictors of preference (Williams, 2002). Melbourne residents generally preferred coarse foliaged deciduous trees. However, different groups of residents had somewhat different preference. For example, those residents with a degree level education had higher preference for native trees (Williams, 2002). Different sections of the community may be unequally affected by a change in the composition of Melbourne's street trees. Some people may prefer a shift to the use of more native trees, while others may not prefer a shift from coarse to finer foliaged species.

Implications for non-human animals

Changes to the composition of Melbourne's street trees also have implications for non-human animals. Street trees have been identified as driver of recent increases in the population of Grey headed flying foxes (*Pteropus poliocephalus*) in Melbourne as additional food resources are provided by non-local street tree taxa (van der Ree, McDonnell, Temby, Nelson, & Whittingham, 2006; Williams et al., 2006). Of the 20 non-local street tree species that provided additional food resources, 80% were taxa native to warmer parts of Australia that overlap with the range of *P. poliocephalus*, while only 10% were cooler climate species (Williams et al., 2006). Street trees could provide an even greater food resource for *P. poliocephalus* if more street tree species from warmer parts of Australia are planted in Melbourne in the future in response to climate change. Similarly, Rainbow Lorikeets (*Trichoglossus haematodus*) preferentially use native street tree species (Fitzsimons et al. 2003) and populations in Melbourne have increased dramatically as a result of increased planting of native street tree species (Shukuroglou & McCarthy 2006). Populations of Rainbow Lorikeets in Melbourne may continue to increase if more native street tree species are cultivated in the future.

More broadly, changes in the composition of Melbourne' street tree flora as a result of climate change may also lead to changes in the composition of other fauna species. Streets with native street trees support more birds species and foraging guilds than streets with exotic trees (White et al. 2005), suggesting that the taxonomic and functional diversity of birds may increase if more native street tree species and fewer exotic species are cultivated. There may also be changes favouring specific functional groups. More insectivorous birds use the London Plane Tree (*Platanus* × *acerifolia*) than native trees such as River Redgum (*Eucalyptus* *camaldulensis*) or Crimson Bottlebrush (*Callistemon citrinus*) (Young, Daniels, & Johnston, 2007), and a shift from planting exotic to native street tree species may favour nectivorous birds at the expense of insectivores. Similarly, exotic birds rarely use native plant species and a shift to more native street tree species may favour native bird species over exotic species (Daniels & Kirkpatrick, 2006).

Mechanisms driving changes to the species composition of street trees

The changes suggested by this research are not prescriptive, and it is difficult to make predictions about the viability of specific taxa from the data used in this analysis. The decisions made by arborists, landscape architects and landscapes planners about which species to plant as street trees are complex and based on both physical and social factors. However, changes to the composition of street trees can occur very quickly. In the late 19th century, the composition of Melbourne's street trees changed dramatically from conifers and native trees (such as Blue Gums, *Eucalyptus globulus*) to the European deciduous trees that are so familiar today (Spencer, 1986). These changes were the result of both mature trees failing and changes to key decision makers and policy leading to changes in the species used in new plantings (Spencer, 1986).

Similarly today, areas of Melbourne have a very mature street tree canopy, and severe heat waves (such as occurred in February 2009) placed severe stress on many of these mature street trees. These events are predicted to increase with climate change and may lead to premature decline and failing of some trees. Many local councils have been reviewing their recommended street tree species in response to climate change and long drought through the 2000s (e.g. City of Port Phillip, 2010). These factors may combine to again lead to rapid changes in the composition of Melbourne's street trees.

CONCLUSION

It seems likely that Melbourne's street tree population will change in response to climate change. This study suggests that exotic, broad leaf deciduous trees may be at greater risk in future climates, while native, evergreen trees with narrower leaves may become more successful. This may lead to the reduction in some of the benefits related to leaf area, such as the provision of shade, rainfall interception and pollution reduction and an increase in environmental disservices such as the Urban Heat Island effect. The impact of this is likely to vary by suburb, as some older areas of Melbourne have a higher proportion of broad leaf deciduous trees, while others in newer areas have more native, evergreen and fine textured species. The impact will also vary for different people, as some people prefer native species while other prefer exotic broad leaf deciduous trees. It is likely that impacts on some non-human native animals will be positive as the availability of suitable food resources may increase if more native species are planted. However, some exotic bird species that do not use native trees as a food resource may be disadvantaged by these changes.

The changes suggested by this study are not prescriptive for individual species, and understanding the impacts of climate change on particular tree species will require further research and careful observation of responses in different places across Melbourne. Balancing the impact of climate change driven shifts in Melbourne's street tree population on humans and non-human animals will require careful planning.

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