Arboricultural strategies for climate change

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Introduction

While it is usually assumed that the impacts of climate change on street trees and urban forests will be deleterious, the real scenario will be more subtle. Some species will benefit from climate change and others will be disadvantaged. Some cities will be largely unaffected while others will experience major changes in the vegetation of public open space. It is an ill wind that blows nobody good and the winds of climate change will bring good and bad for tree managers.

All ecosystems will be affected by climate change that includes increases in global air temperatures, increases in atmospheric CO_2 concentrations, change in the patterns and amounts of annual precipitation, more frequent and intense storms and changes in the frequency and severity of wildfires (IPCC 2007).

It is difficult to predict the impact that change might have on species that constitute streetscapes and urban forests, but the most significant factors likely to impact on species making up urban forests are:

- increased temperatures
- changes to rainfall patterns
- greater storm intensities
- more severe droughts
- altered fire frequencies affecting peri-urban areas

The impacts of climate change on urban trees will not be uniform which will make decisions related to planning and managing urban forests difficult. However, understanding tree biology and physiology will allow active tree management. It may be possible to take advantage of some of the changes brought on by climate change to manage urban trees and forests so that they can cope more effectively and efficiently with likely changes. This paper presents a number of scenarios relevant to urban street trees and urban forests and strategies that might be useful to arborists as climate changes.

Urban arboricultural strategic management

Tree selection

Many trees that are widely planted in cities and regarded as great urban trees are renowned for their wide tolerance ranges. They have great environmental resilience and tolerance of a wide range of soil, rainfall and temperature conditions. In Australia, many of the common native urban trees come from populations that have wide and extensive natural distributions. Careful provenance selection and breeding using temperature and drought tolerance as criteria should ensure that there are suitable intraspecific selections to meet urban planting demands (Table 1).

Table 1: Simplified strategic management matrix for urban trees during climate change (Moore 2011)

Species Characteristics	Likely Impact of Climate Change	Management Strategy
Widely dispersed over a broad range	Low	Select propagation material from appropriate provenance
Higher temperature and drought tolerance	Low	Monitor performance and expand planting
Restricted range	High negative	Monitor performance and consider related species with tolerance of warmer, drier conditions
Prone to insect grazing as higher temperatures lead to increased insect numbers	High negative	Monitor insect number and use integrated pest management with extreme high wind and temperature days
Luxury water user with little capacity for stomatal control	High negative	May only be viable where irrigation is available
Possession of adaptations to high levels of environmental stress	Low	Make full use of available adaptations above and below ground and over time
General stress tolerators	Low	Monitor performance and expand planting
General stress avoiders	High negative	Monitor performance and plant only where favourable management conditions allow survival
Drought prone or reduced urban growth with limited water availability	High negative	Plant only in urban areas where irrigation is practical and efficient
Species prone to native mistletoe infection	Moderate positive	There may be reduced mistletoe numbers due to hot windy days, which could be an advantage in mistletoe management
Seed set reduced, especially if night temperatures rise	Moderate positive	May be an advantage when fruits or seeds are problematic in cities
Increased photosynthetic rate for many species if water is available	Moderate positive	May be an advantage with higher establishment, growth rate and denser canopy
Increased respiratory rate over a wide range of increased temperatures	Moderate positive	Enhanced tree establishment, growth and canopy density with efficient irrigation
Higher transpiration rate as temperatures rise	High negative	May only survive if irrigated
Frost sensitive when young	Moderate positive	Small, young trees may be grown without protection from frost

If species' ranges are limited, there is the option of selecting different species from within a genus. This is the case with the genera, *Eucalyptus* and *Acacia* within Australia, where there are large numbers of related ands often visually similar species occupying a broad range of habitats. For Australian species, studies on the provenances of *Lophostemon confertus* (Williams 1996) and *Tristaniopsis laurina* (Looker 2001) from different climate and soil conditions have been undertaken, which provide data for making urban selections for changed climates.

Street tree establishment

Warmer temperatures may allow more rapid tree growth if there is sufficient water available (Clark *et al.* 2011). In some cities this would allow easier and more rapid street tree establishment. Trees that may have been restricted in their planting due to frost sensitivity may be considered for planting or planted at an earlier age as the frequency of frosts and their intensity reduces (Table 1).

Furthermore, the warmer temperatures should see more rapid root growth so that when street trees are planted root systems should extend into the surrounding soil from the root plate and planting hole more rapidly. This should enhance overall tree growth allowing a more rapid and efficient tree establishment. This would be beneficial for street trees where rapid early growth and establishment is considered an advantage as trees make an impact on the streetscape more quickly.

To capitalize on these advantages, however, there must be attention to ensuring that there is sufficient water available so that growth is not restricted. There must also be action in relation to insect grazers. As temperatures increase the numbers of insects attacking street trees are likely to rise and the period over which they graze is likely to be longer. This could have a devastating effect of individual trees and urban forests (van Mantgem *et al*. 2009).

Street tree strategy, Eucalypts and Lignotubers

Lignotubers are swellings that develop at the base of the stems of most eucalypts and which occur either at or just below the soil surface. These 'woody tubers' have the same anatomical features as the tree stem (Jacobs 1955; Chattaway 1958; Bamber and Mullette 1978), and Carrodus and Blake (1970) found that the carbohydrate content of the stem and the lignotuber were not significantly different. Their real significance is as a reservoir of a large number of protected, dormant buds (Carrodus and Blake 1970). The basal burls of northern hemisphere trees would appear to be similar structures.

Lignotubers are vital adaptations for the survival and persistence of eucalypts under adverse growing conditions (Jacobs 1955; Chattaway 1958; Carrodus and Blake 1970). Regeneration of trees from lignotuberous shoots after damage due to wind, drought, salt, waterlogging, fire, grazing and insect attack enhances the eucalypts' resistance to, or recovery from, environmental stresses (Jacobs 1955).

Not all eucalypts possess lignotubers. There are species such as *E. regnans, E. fastigata* and *E. delegatensis* which do not possess lignotubers at any stage of their development. In other species such as *E. obliqua* and *E. camaldulensis*, some populations possess lignotubers while others do not (Table 2). In these situations, the populations growing in harsh, stressful environments usually have lignotubers and their counterparts in cooler, wetter, more temperate environments do not. This may be a useful characteristic in selecting eucalypts for future use in urban environments – lignotuberous species are likely to be hardier than non-lignotuberous species as climate warms and dries. Within a species, lignotuberous populations will tend to be hardier than their non-lignotuberous relatives.

Table 2: Some non-lignotuberous species and some which may or may not possess a lignotuber (Moore 1981).

Non-lignotuberous species	Species which may or may not be lignotuberous
E. regnans	*E. camaldulensis*
E. delegatensis	*E. obliqua*
E, grandis	
E. diversicolor	
E. gomphocephala	
E. nitens	
E. astringens	
E. pilularis	

Even when lignotuberous shoots are produced, survival is not guaranteed as many will subsequently die, but those which survive often grow at very rapid rates. If more than one lignotuberous shoot survives and develops, their point of attachment to the trunk may be compromised and so arboricultural intervention may be required. However, the existence of a lignotuber and a well-developed root system represent a substantial urban asset and they should be used where appropriate for rapid tree re-establishment.

Strange and unusual benefits of climate change

As with many environmental matters, climate change will have both positive and deleterious aspects. Biological homeostatic mechanisms mean that ecosystems and their components tend to counter change to remain in equilibrium. This usually means that there are predictable and unpredictable consequences when human beings significantly alter ecosystems. Thus while there is a justifiable focus on the negative effects of climate change there will be benefits, some of which will be strange, unusual and expected.

Elm leaf beetle deaths

Climate change may have diverse and unexpected effects on trees and urban forests (Kramer *et al*. 2000). Usually insect predation increases as temperatures rise due to large increases in insect population numbers in warmer weather. The increased insect grazing often outpaces increased tree growth in the warming climate leading to significant increases in tree mortality (van Mantgem *et al.* 2009).

In many parts of south-eastern Australia, elm leaf beetles have proved a significant pest affecting European elms since the mid 1990s. During the prolonged dry period they caused significant damage leaving entire tree canopies with shot hole symptoms and adding to the stress experienced by the trees. However, on the record hot day of February 7th 2009 in Victoria when temperatures rose to 46.4°C, under the canopies of many mature elm trees in Melbourne, large numbers of elm leaf beetles were found dead. The beetles had not survived the high temperatures and strong winds but the foliage had.

A favourable winter and spring followed and many trees showed recovery from the years of below average rainfall. Furthermore foliage was not decimated by elm leaf beetle grazing over the following summer. Continued good rainfall saw another fine spring and summer in 2010-11 with many trees showing even more impressive recovery from the long dry period with fuller canopies and greater leaf production. This resulted in a display of autumnal colour in 2011 that was widely commented upon (Webb 2011).

The killing of insect pests may have been more widespread in its occurrence than reports suggest and if this is so there may be the possibility of integrating elm leaf beetle control programs, such as banding and spraying with predictions of hot windy days. Such a strategic opportunity might prove both environmentally and economically beneficial.

The physiology of autumn colour

The autumnal colours have been brilliant in Victoria and for much of south-eastern Australia in 2011. In some ways it is a return to the autumn splendour of the past, but the additional colour has not been simply enhanced by a nostalgic view through rose coloured glasses. The added colour is real and understanding why gives us a glimpse not only of plant biology but what might happen as the climate warms (Webb 2011).

The colours are much brighter this year because the weather – excellent spring and summer rainfall – has allowed luxuriant foliage growth for the first time after the fourteen years during which we endured below average rainfall. The prolonged dry period resulted in a thinning of tree canopies and premature and sporadic leaf shedding. Trees, such as elms and planes, were subdued by the dry, warm weather, shedding leaves over summer as drought stress took its toll. When autumn came there were fewer leaves to shed and these were duller. So autumn crept almost unnoticed upon winter.

In 2011, prolific growth has seen trees retain a full canopy of bright green foliage over summer and into early autumn. Then colder autumn days triggered a full and rapid withdrawal of chlorophyll from leaves revealing the yellow and browns in a matter of days. Leaves have been shed simultaneously, quickly and in huge numbers. Furthermore, there have been many more fallen leaves rustling in the breeze, for walking and scuffing your way through and for raking and composting!

The mild spring and summer that allowed trees to retain their leaves also resulted in trees accumulating large amounts of sugar from extended photosynthetic activity. So much sugar was produced that some was converted to pigments such as anthocyanins which are stored in the vacuoles of leaf cells. These pigments can range in colour from pale yellows, through the various oranges, to the most wonderful deep crimsons and reds. When the temperatures drop, once again the removal of chlorophyll is triggered, but instead of the pale yellow and browns emerging, in species such as liquidambar, maples and claret ash, the hues are orange and red.

The long warm dry period may have provided a glimpse of what global climate change might have in store. There may be long dry periods in a warmer future but there will still be mild wet summers and cold autumnal days from time to time. When this occurs autumn colour will be back in all its glory, and it will be noticed. Perhaps for once we do know what we've got before it's gone, or at least before it becomes rarer as climate warms!

Tree physiology and mistletoe

Over the years of below average rainfall in south eastern Australia (1997-2010), a number of very old remnant native trees, particularly river red gums (*Eucalyptus camaldulensis*), died due to heavy infestation with mistletoes and the subsequent effects of drought. The mistletoes are native species too (mainly *Amyema* species or *Muellerina eucalyptoides*) and have their place in the ecology of plant communities, but mistletoe numbers seem to have increased due to spread by exotic birds and changed fire regimes.

Mistletoes are essentially water parasites on the host species, and the host branch beyond the point of mistletoe attachment often dies. Many of the old trees that died, or are in danger of dying, were carrying in excess of 40-50 individual mistletoe plants, which is excessive. These trees are often the last significant seed trees on the sites from which future generations of trees can be sourced.

The situation calls for sophisticated and professional management by those managing significant landscapes. Older trees should be surveyed to ascertain mistletoe numbers. Steps should then be taken to remove most, but not all of the mistletoe plants if infestations are considered to be excessive. A large native tree with a full canopy and good condition should cope with about 5 or 6 mistletoe plants. Any mistletoe in excess of this number should be removed by cutting the mistletoes at the base, but not cutting into the host tree. Such a balanced management approach should see sustainable management of both mistletoes and their hosts for future generations of Australians.

While it is usually assumed that the effects of climate change will be negative, and they may be, there will be some advantages. In Victoria, in February 2009 when temperatures rose to 46.4°C, an unexpected consequence of the high temperatures was the killing of many of the mistletoes affecting older eucalypts (Table 3). The foliage on the trees survived as it seemed to cope with the high temperatures and strong winds. Interestingly, similar mistletoe deaths have been observed in non-eucalypt species, including *Platanus x acerfolia* and several *Prunus* species. The effect of high winds and temperatures in killing mistletoes may thus have a broader impact on urban tree species.

For one *Eucalyptus camaldulensis* specimen, over 50 of the 60 mistletoes growing on it died and 2 years later the tree remains largely mistletoe-free. *E camaldulensis* is a luxury water user with very limited stomatal control (Pate and McComb 1981) and there is some evidence (Davidson, True and Pate 1989) that at least some of the mistletoes also have poor stomatal regulation. This would appear logical as there would be little advantage for a water and nutrient parasite to have stomatal control when it has first access to the hosts water and nutrient stream.

Table 3: Number of mistletoe growing on Euclayptus camaldulensis trees prior to, one month, and 30 months after the 46.4°C day of February 7, 2009.

Tree Type	# of Trees	# of living mistletoe per tree prior to 46.4°C day	Total # of living mistletoe	# of living mistletoe per tree 1 mth after 46.4°C day	Total # of dead mistletoe 1 mth after 46.4°C day	# of new mistletoe after Feb 7 2011	# of living mistletoe 30 mths after 46.4°C day
Young	**10**	2	20	0	20	0	0
Young	**10**	1	10	0	10	0	0
Young	**5**	3	15	0	15	0	0
Semi	**5**	6	30	0	30	1	1
Semi	**4**	5	20	0	20	3	3
Semi	**1**	4	4	0	4	1	1
Mat	**1**	60	60	10	50	0	5
Mat	**1**	12	12	2	10	0	2
Mat	**1**	20	20	4	16	0	4
Mat	**1**	6	6	0	6	0	0
Mat	**1**	4	4	1	3	1	2
Mat	**4**	5	20	2(8)	12	2	10
Mat	**2**	8	16	1(2)	14	1	3
TOTAL	**46**		237	27	210	9	31

Note: Mat are older large trees >20m height with dbh >40cm, Semi are semi-mature trees <15m height with 20<dbh<40cm and Young are trees <10m in height and with dbh<20cm.

However on days of extreme high temperature and wind it seemed that the mistletoe reached permanent wilting before at least some host species, resulting in the death of the parasite. The pattern of mistletoe death is consistent with this hypothesis as nearly all of the mistletoe on the extremities of the canopy died while those that survived seemed to be on older, larger branches within the canopy and closer to the trunk. Furthermore, after the death of the mistletoe, many of the host trees produced significant epicormic growth on the *ad axial* parts of branches close to the dead mistletoe.

Once again there is a strategic opportunity for urban tree managers to integrate climatic events with mistletoe control programs. It appears that hot windy days may have a role similar to fire in limiting mistletoe numbers, which could prove very useful especially in peri-urban areas where the occurrence of fire is rare or the risks of fire are too great.

Efficient water use on hot windy days

If water is available, most trees time their stomatal opening to coincide with sunrise. They anticipate the right level of light for photosynthesis to maximise both light and water use. Consequently, most tree species tend to photosynthesize most effectively and efficiently in the morning.

However, if water is limiting many, but not all, tree species will close their stomata, often sometime between around noon and 2pm. The trees then conserve water but may go into water deficit with a declining internal water potential, which can adversely affect growth and development. Thus the trees need to restore their internal osmotic balance by taking up water before the next morning. Many trees recharge their water deficits from the soil overnight and just before dawn they are back to normal internal water potential.

Therefore irrigation in the early morning allows trees to maintain photosynthetic activity before water becomes limiting. Thus with shallow spreading root systems typical of urban trees, early morning irrigation using drippers or leaky pipe under mulch is a logical strategy to maximise growth and foliage development. This should provide effective urban tree development and establishment while ensuring high levels of water use efficiency.

Trees can mitigate flood damage by slowing water flows

Under the climate change scenarios predicted for south-eastern Australia there will be more severe weather events more often with associated stronger winds and more intense rainfall. In many places there will be reduced annual rainfall but more intense summer rainfall, leading to major summer flooding events.

While it has long been appreciated that trees have a role in mitigating localised flooding in urban areas by holding and absorbing water during intense rainfall events (Moore 2006; Killicoat *et al.* 2002), it seems to have been forgotten that planting trees along waterways can reduce the rates of water flow during floods. A consequence of this is that trees may also spread the flood waters over a greater area, which may be problematic. However, if properly planned along urban waterways where mitigation basins are common, planting trees can slow the water and reduce the risks of soil erosion and infrastructure damage due to flooding.

Along Taylor's Creek, Keilor, trees planted in a revegetation scheme in the mid 1980s have slowed flood water, reducing erosion and stream side scouring. The waters are spread over a greater area but this is available and so does not result in damage. An unexpected consequence has been that litter is spread away from the creek and so does not enter the Maribyrnong River or Port Philip Bay. The economic benefits of both reduced erosion and easier local litter collection could be readily established.

Conclusion

Rising sea levels are not just the result of the melting of the polar icecaps, but also from the expansion of water as temperature increases. Most major Australian cites are at, or near, sea level as they are or were ports. This means that in many of these cities there is likely to be at least some inundation, even if it is locally restricted. There will be a need to redevelop and protect significant urban areas from these rising seas. This may provide an opportunity to develop new sustainable urban forests under conditions where they thrive.

It is worrying that at a time when urban trees and public open space are finally being recognised as the urban infrastructure assets that they are, that public and private open space and urban forests are being threatened and lost in all major Australian cities. In all cites, in-fill and high density developments are putting the benefits of open space for future generations at risk. This will impact on the capacity of cities and regions to counter at least some of the effects of global climate change, which will have a deleterious affect on human health, social structures and the economic components of our society as well as the environment.

It is frustrating that just when it is becoming clear that the future sustainability of our cities requires open space and urban forest canopy that they are being lost. There are significant opportunities for proactive urban tree management in Australian cities that must be captured if our cities are to cope with global climate change.

Acknowledgements

The author acknowledges the assistance of Ms E Moore, linguist, for her helpful comments on the manuscript.

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