Clean Air and Urban Landscapes Hub

National Environmental Science Programme

Benefits of Urban Green Space in the Australian Context

A synthesis review for the
Clean Air and Urban Landscapes Hub

Final report, August 2016

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This report was prepared to satisfy the 3.2 milestone (July 2016): '*Review existing urban greening research being undertaken nationally and internationally to identify priority research gaps relevant to the Australian context and avoid duplication*', and Output 1: '*A review of national and international published and grey literature identifying urban greening characteristics and their thresholds for a range of ecosystem service, human mental and physical health and psycho-social benefits*'.

The report will also contribute to the response to the *'Blueprint for a Green City'* agenda by outlining the key benefits provided by urban green spaces, and broader factors influencing the distribution of green spaces and the benefits they provide.

About the Clean Air and Urban Landscapes Hub

The Clean Air and Urban Landscapes Hub (CAUL) is a consortium of four universities: the University of Melbourne, RMIT University, the University of Western Australia and the University of Wollongong. The CAUL Hub is funded under the National Environmental Science Programme of the Australian Government's Department of the Environment. Our task is to undertake research to support environmental quality in our urban areas, especially in the areas of air quality, urban greening, liveability and biodiversity, and with a focus on applying research to develop practical solutions.

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1. Introduction

Dave Kendal, The University of Melbourne

What is urban green space?

Urban green space is all the vegetated areas that occur in cities. Green spaces can be found on public land (e.g. parks) and on private land (e.g. residential gardens). Urban green spaces are commonly categorised by land use, which distinguishes areas used for public recreation, biodiversity conservation, residential dwellings, commercial or industrial activities, and transport corridors. These spaces can also be categorised by land cover, such as planted trees, shrubs or lawn, or native vegetation.

Urban green spaces can cover a large proportion of Australian cities. For example, 41% of houses in Australian capital cities have a street tree, while 77% have a tree in their garden (Kirkpatrick et al., 2011). A study of Ballarat, Victoria found that 13% of the city was zoned as recreational or conservation parks, and a total of 28% of the city was covered in trees with a further 24% of the city covered in lawn (Kendal et al., 2012).

What are the benefits of urban green space?

Urban green spaces are widely understood as 'improving' cities by increasing amenity and providing places for both passive and active recreation. Since the 1970s, areas of green space in cities have also been set aside for conservation purposes e.g. to protect rare and threatened plants, animals and ecosystems. More recently, there has been extensive research into a wide range of effects that urban greens spaces have on urban environments, and the people, plants and animals that live in them. This research has been extensively reviewed in the academic literature demonstrating that urban green space contributes to:

- Reduced morbidity and improved physical health outcomes (Richard Mitchell & Popham, 2007; Sugiyama et al., 2008; J Maas et al., 2009; Hunter et al., 2015)
- Improved mental wellbeing (Bratman et al., 2012; Hartig et al., 2014; Cohen-Cline et al., 2015).
- Increased social cohesion (Maas et al., 2009; Fan et al., 2011; De Vries et al., 2013)
- The provision of important ecosystem services such as cooling and air pollution (Bolund & Hunhammar, 1999; Bowler et al., 2010)
- Maintaining biodiversity and the conservation of native species (Sadler et al, 2010)

Several large research projects have explored the benefits of urban greening in other countries:

- In Europe, the URGE project has explored the benefits and planning of urban green spaces (Venn & Niemela, 2004)
- In the United Kingdom, a series of projects run through the University of Sheffield have explored biodiversity and ecosystem services generated by different kinds of urban green spaces (e.g. Davies et al., 2011; Thompson et al., 2003)
- In the USA, several Long Term Ecological Research programs have been established in the cities of Phoenix, AZ and Baltimore, MD with a focus on urban ecology but a clear aim of integrating social science (Grimm et al., 2008; Redman et al., 2004)

A number of government and industry reports also review these benefits systematically and in great detail in particular green space and political contexts:

- Cecil Konijnendijk and others reviewed the benefits of urban parks for the International Federation of Parks and Recreation Administration (Konijnendijk et al., 2012)

- Tara Zupancic and others reviewed the effects of green space on two ecosystem services: cooling and air pollution reduction (Zupancic et al., 2015)

Included in these are some reports on the benefits of green space in Australia:

- Martin Ely and Sheryn Pitman reviewed the benefits of green infrastructure for the Botanic Gardens of Adelaide and Department of Environment, Water and Natural Resources, South Australia. (Ely & Pitman, 2013)
- Chris Ambrey and Chris Fleming reviewed the influence of public greenspace on the life satisfaction of people living in Australia's capital cities (Ambrey & Fleming, 2013)

How do these benefits relate to the Sustainable Development Goals?

The recently announced Sustainable Development Goals include a city-specific Goal 11 to 'Make cities inclusive, safe, resilient and sustainable' (United Nations, 2016). One of the targets for this goal is directly related to the provision of urban green space: 'By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities' (United Nations, 2016). The benefits provided by urban green spaces may also indirectly contribute to other Sustainable Development Goals such as Goal 3, 'Ensuring healthy lives and promote well-being for all at all ages' and Goal 15 'Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss'. The provision and management of urban green spaces will make an important contribution to Australia's ability to meet the Sustainable Development Goals.

What shapes the benefits provided by urban green spaces?

A number of studies have identified broader contextual variables that shape the provision of urban green space and the benefits it provides. Physical environmental variables such as climate and degree of urbanisation directly influence the composition, abundance and structure of urban green spaces. These factors also influence the level of benefits provided – for example the provision of cooling is more important in some places at some times of years, but less important in other places and at other times of year.

The social environment is also an important predictor of the provision of urban green space and the benefits it provides. Population density is an important limiting factor on the distribution of green spaces, and a predictor of the use of these spaces. Inequity in the provision of green spaces has led these to be less abundant and available in disadvantaged areas.

An important consideration in a changing environment is resilience (McPhearson et al., 2015). Maintaining healthy urban green spaces able to continue to provide benefits in contribute to the resilience of cities by ameliorating external shocks and changes. Green spaces themselves must also be managed to be resilient in the face of external change.

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2. Physical health benefits

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Overview

A substantial body of literature has emerged over the past two decades that has sought to assess the physical human health benefits of green infrastructure. The majority of these studies indicate that there is, in general, a positive relationship between greener environments, contact with nature, and physical health, however there is still a need for more systematic research to support conclusive findings.

A number of review papers have assessed the links between physical health benefits and green infrastructure/green space/contact with nature; these papers have indicated an array of benefits, although further research requires the use of more rigorous methodologies in order to deepen our understanding of the pathways and mediating influences (Lee & Maheswaran, 2011; Konijnendijk et al., 2013; Hartig et al., 2014; Lovell et al., 2014; Wolf & Robbins, 2015). An ongoing review of publications investigating the relationship between urban greening and human health and well-being has documented more than a dozen themes of services and benefits, supported by over 3000 scholarly publications (University of Washington, 2014).

Key findings

Physical activity

The dominant focus of research conducted within green space and physical health has been in the field of physical activity. Recent international reviews of research studies indicate that the majority of research supports a relationship between parks and open spaces and the facilitation of physical activity (Lee & Maheswaran, 2011; Konijnendijk et al., 2013; Wolf & Robbins, 2015). Most research suggests that the provision of attractive, open green spaces, such as parks, or recreational spaces, provide important places for individuals to engage in physical activity (e.g. Almanza et al. 2012, Cohen et al. 2007, Coombes et al. 2010, Pearce and Maddison, 2011). Additionally, adults who reside in the highest quartile urban green space are more likely to participate in leisure-time physical activity than those living in areas with the lowest quartile of urban green space (McMorris et al. 2015). The provision of green space to facilitate physical activity is particularly important for children, adolescents, and the elderly (Almanza et al., 2012, Janssen and Rosu, 2015, Moran et al., 2014). A small number of studies have found no association between green space and physical activity (Konijnendijk et al., 2012, Maas et al. 2008, Witten et al. 2008, Foster et al. 2009, Hillsdon et al. 2006, Ord et al., 2013).

Obesity

Higher levels of green space have been associated with lower levels of obesity (Bell et al. 2008, Neilson and Hansen, 2007); this is supported by a recent review of international studies (Lachowycz & Jones, 2011). However, other studies have found no or a weak association (Potwarka et al. 2008; Potestio et al. 2009).

Morbidity

Cause-specific morbidity has been examined by a small number of studies in order to assess its association between access to, and levels of green space. Maas et al. (2009) found that having 10% more green space within 1km radius than average was protective of particular diseases including chronic heart disease, upper respiratory tract infection, asthma, chronic obstructive pulmonary disease, migraine and serve headaches, vertigo, acute urinary tract infection and diabetes mellitus. In examining the association between access to, and use of, green spaces and risk of cardiovascular mortality and morbidity, Tamosiunas et al. (2014) found that the

prevalence of cardiovascular risk factors and the prevalence of diabetes mellitus were significantly lower in individuals who were regular park users. However, there has been mixed findings from research investigating the links between respiratory health and vegetation/canopy cover in urban areas; further evidence on links between the presence of trees and other green elements with respect to respiratory health is needed to establish net benefits (Wolf & Robbins, 2015).

Mortality

A small number of studies have examined the association between neighbourhood levels of green infrastructure and mortality risk. Mixed results have been found, with some studies finding evidence of an association (Takano et al. 2002; Hu et al. 2008; Villeneuve et al. 2012) and others not (Richardson et al. 2010a; Richardson et al. 2012).

Birth outcomes

There is some evidence of an association between green space and birth outcomes, including birth weight (Dadvand et al. 2012, Laurent et al. 2013, Hystad et al. 2014, Grazuleviciene et al. 2015). However, no association has been found between foetal growth and the presence of green spaces within an individual's neighbourhood (Markevych et al. 2014).

Healing and pain

A review of studies has indicated that access to natural elements, such as nature experiences and views, can assist physical healing and higher pain thresholds (Wolf & Robbins, 2015).

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3. Mental Health & Wellbeing

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Overview

Urban green spaces are consistently associated with a range of mental health benefits. Recent reviews indicate this long-standing body of research provides strong evidence of the benefits of green over built urban spaces (Bratman et al., 2012; Hartig et al., 2014). This research has potentially far reaching implications considering the epidemic of stress and mental ill health in Australia (Shanahan et al., 2016). Designing successful population-level greening interventions, however, requires a greater understanding of their efficacy; the precise mechanisms of this effect, the duration, frequency, and type of exposure that is required to confer benefits, and how these benefits play out across the lifespan (Bratman et al., 2012; Hartig et al., 2014).

Key findings

Green space

Hartig and colleagues (2014) in their annual review of nature and public health identified a number of different pathways through which green space influences health. Mental health benefits, in particular, occur through a 'stressor reduction' pathway. This pathway assigns a dual role for green spaces: reducing exposure to urban stressors (like noise) and their detrimental psychophysiological effects, and in additionally boosting capacity to deal with life stressors. This second role is proposed to occur via restoring the finite mental resources drawn on in daily life, for making decisions, and for regulating moods and behaviour (cf. Kaplan & Kaplan, 1989).

Bratman and colleagues (2012) in their review of nature and cognitive functioning, reported on studies showing benefits across a range of outcomes including concentration and memory, impulse inhibition, aggression, stress relief, mood, self-esteem, and childhood developmental behaviours (i.e. Barton & Pretty, 2005; Berman et al., 2012; Kuo & Sullivan, 2001; Kuo & Taylor, 2004; Lee et al., 2015; Ulrich et al., 1991). These have been explored after seconds, hours, days, and years of nature exposure using real or simulated views through the window, or physical interactions with green space (Bratman et al., 2012). And across a range of contexts including work, home, school, and clinical settings (i.e. Dadvand et al., 2015; Kaplan, 2001; Nieuwenhuis et al., 2014). For example, there is evidence that green space could be used for people suffering depression (Berman et al., 2012), with recent cancer diagnoses (Cimprich & Ronin, 2003), and children with ADHD behaviours (Kuo & Taylor, 2004).

Biodiversity

The majority of existing research compares the benefits of green versus built urban spaces with little consideration of the variation in quality across these broad classifications. So, researchers argue, there is a great need for better understanding the types and characteristics of green space that drive these benefits (Bratman et al., 2012; Hartig et al., 2014; Lovell et al., 2014). Addressing this question, Lovell and colleagues (2014) recently conducted a meta-analysis of studies on biodiversity and human health, deciding that the evidence for these relationships is equivocal. Claims for a direct relationship between biodiversity and mental health seem tenuous, with little explanation of why such a relationship should exist and how it might function. More recent research is beginning to shed light on this, however, revealing an indirect role for biodiversity in mental health outcomes, operating through perceptions of the restorative potential of environments (Carrus et al., 2015; Marselle et al., 2016).

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4. Social Cohesion

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Overview

There is a small but growing body of evidence that access to green space improves various measures of social cohesion including community and neighbourhood connection, and reduced levels of crime.

Key Findings

A large study in the Netherlands found that people with less green space (excluding street trees and residential gardens) within 1 km of their homes felt they were more lonely and less social support (Jolanda Maas et al., 2009). A related study found that social cohesion partially mediated the positive effect of streetscape vegetation on self-reported health – i.e. people with more streetscape vegetation felt their neighbourhood was more cohesive (e.g. "People around here are willing to help their neighbours"), and this was related to improved health (Groenewegen et al., 2012; De Vries et al., 2013). Green space quality and size have also been shown to be linked A mixed methods study in the UK found that social ties were improved by high quality local parks (Kaźmierczak, 2013). People with a larger area of park within a walkable ½ mile (0.8 km) had higher levels of social support (Fan et al., 2011).

Urban green space has also been linked to positive indicators of functioning societies, such as reduced fear and both property and violent crime (Kuo & Sullivan, 2001). This has been linked to green space enhancing people's ability to restore attention and maintain self-discipline (Faber Taylor et al., 2002). Parks have also been shown to be inclusive spaces that promote social interactions (Peters et al., 2010). Participation in urban greening programs can also improve societal functioning by empowering the communities that participate (Westphal, 2003).

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5. Preference for urban green spaces

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Overview

The aesthetics of urban green spaces are important. People's preference for landscape is a well-researched field of enquiry with established theory and extensive supporting empirical evidence. This research shows that people prefer vegetated urban areas over built areas, and provides some insight into preferred characteristics of green spaces. People's preferences help mediate some of the health and wellbeing benefits of urban green spaces (Lee et al., 2014). However, this research also shows that different people have different preferences, and that a diverse 'portfolio of places' is needed to satisfy the broader community (Swanwick, 2009).

Key Findings

There is a well-established body of literature exploring how people perceive urban green spaces. A large body of literature in environmental psychology shows that people consistently prefer natural scenes in cities to scenes including built elements (Kaplan & Kaplan, 1989). People's landscape preferences operate at three levels: evolutionary, cultural and individual (Bourassa, 1991). At an evolutionary level, people are thought to prefer landscapes that would make good habitat for humans (e.g. Orians & Heerwagen, 1992). At a cultural level, people prefer landscapes with cues that conform to social or cultural norms. These preferences can be based on ethnic grouping e.g. people with an English background can prefer landscapes with shade trees while people from a Mediterranean background can prefer landscapes with edible plants and fruit trees (e.g. Fraser & Kenney, 2000). They can also be based on social norms; people's preference for messy, biodiverse landscapes can be improved by adding a neat 'frame' such as a fence or maintained edge that show the landscape is being cared for (Nassauer, 1995). At an individual level, people can prefer landscapes they are familiar with, that have particular meaning, or suit their personality (van den Berg et al., 2006; 2010).

More recent research has shown that different kinds of people prefer different kinds of green spaces. For example, landscape preferences are based in values (Ives & Kendal, 2013); people with ecocentric value orientations prefer wild landscapes, while people with more human-centred values prefer more managed landscapes (Kaltenborn & Bjerke, 2002). The provision of information that is consistent with people's values can be used to change people's preferences (Straka et al., 2016). As people learn about the environmental benefits of particular landscapes or landscape elements, they can shift from seeing landscapes using a scenic aesthetic to one that uses an ecological aesthetic (Gobster, 1999). An important implication for land managers from this research is that experts tend to have very different preferences for urban green spaces that members of the general public (e.g. Hofmann, 2013).

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6. Biodiversity and the conservation of native species

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Overview

While there are extensive and systematic reviews of the benefits of urban green spaces for people's health and wellbeing, there has been relatively little systematic review of the benefits of urban green spaces for non-human organisms. This is largely due to a research focus on the ecology of particular species, which have relatively narrow geographic ranges making cross-city generalisations difficult.

Nonetheless, a few patterns have been observed widely that show some benefits of urban green space for biodiversity and the conservation of native species. Species richness can be much higher in urban green spaces than in native vegetation outside cities (Kendal et al., 2012). Urban areas provide important habitat for some native species such as flying foxes (e.g. Williams et al., 2006), and urban green space can provide important habitat for threatened species (Ives et al., 2016).

Key findings

Biodiversity

There are two ways in which urban greens spaces contribute to biodiversity: 1) the vegetation and structures that make up green spaces can contribute directly to species and habitat diversity and 2) green spaces can provide habitat for other organisms.

Species richness can be very high in urban green spaces, and much higher than surrounding native ecosystems. Parks have a high species diversity of plants and animals, particularly exotic species (Nielsen et al., 2014). Residential gardens have very high species diversity of plants (Smith et al., 2006). In Australia residential gardens have much higher levels of species diversity than native vegetation (Kendal et al., 2012).

While some species such as the Peregrine falcon are able to use the built environment as habitat (Chace and Walsh, 2006), many species are dependent on green spaces to survive in cities. In one of the few systematic reviews of the effects of green space on biodiversity Sadler et al. (2010) identified that local habitat structure is very important for many taxonomic groups. As a result of increased availability of some resources and reduced predation, some animal species can become very abundant in urban green spaces, and occur at much higher densities than they do outside cities (Shochat et al., 2006; Williams et al., 2006).

Conservation of native species

Urban green spaces are important for the conservation of native species generally (Aronson et al., 2014) and for many threatened species, which are overrepresented in Australian cities (Ives et al., 2016). While some species are disadvantaged by urbanisation, urban areas can provide abundant food resources for some kinds of Australian animals. For example, Grey-headed Flying Foxes (*Pteropus poliocephalus*) have become abundant in Melbourne at least in part due to the year round availability of food in planted green spaces (Williams et al, 2006). Similarly, some species of nectivorous birds are more abundant in cities due to the increased availability of nectar in green spaces (Shukuroglou & McCarthy, 2006). Urban areas can also provide suitable shelter (e.g. nesting) habitat for some species (Weaving et al., 2016)

Some studies from the UK suggest that the identity of plant species (e.g. native vs exotic) in urban green spaces is not an important determinant of some kinds of biodiversity, such as

insect species richness and abundance (e.g. Smith et al., 2006). However, a number of Australian studies have drawn clear relationships between the use of native plants in urban green spaces, and the diversity and abundance of Australian animals. In particular, several studies have shown that native bird species benefit from the presence of native plants in streets, parks and gardens (e.g Young et al., 2007; Ikin et al., 2013), and both birds and bats benefit from the presence of native plant species (Threlfall et al., 2016).

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7. Ecosystem Services: Cooling and Air quality

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Overview

'Ecosystem services' are defined as "the benefits human populations derive, directly or indirectly from ecosystem functions" and that maintain or improve their well-being (Costanza et al. 1997). From the 17 major categories of ecosystems services identified by Costanza et al. (1997), Bolund & Hunhammar (1999) highlighted six were most relevant in urban areas – air filtering, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational/cultural values, while several other were potentially relevant, including food production and erosion control. Here, we focus on two ecosystem services provided by urban green spaces that are most relevant in Australian cities: cooling and air quality.

Key findings

A systematic review of the effects of urban green space on air cooling in urban areas found that parks are on average 0.9 °C cooler than their surroundings during the day, that larger parks tend to be cooler than smaller parks (Bowler et al., 2010). The proportion of sealed surface and vegetation cover was related to the differences in temperature between parks and their surroundings – parks with high proportions of impervious surfaces could be warmer than the surrounding landscape. Air temperature beneath both individual and clusters of trees was lower than temperatures in an open area, at least during the day.

Another systematic review of cooling and air quality (Zupancic et al., 2015) suggests that closely spaced and connected smaller green spaces can provide greater cooling effects to adjacent urban areas than large individual parks with open grass areas. The density and spatial configuration of an urban forest — the sum of all urban trees, shrubs, lawns and pervious soils located in an urban setting — clearly affect land surface temperatures in the city and that these elements are critical for improving urban air quality. In general, the research suggested that balancing urban forest density, particularly in areas with low green space density, would greatly improve both local and city-wide urban air quality.

Zupancic et al. (2015) found that various plant species provide heat and pollution-mitigating capacities, and compact multi-layering of diverse plant species can help improve overall resiliency to drought, heat and pollution. Among plant types, trees have an exceptional ability to capture and filter multiple air pollutants, including ground-level ozone, sulphur dioxide, nitrogen oxides and particulate matter. Trees are also significantly associated with improved thermal comfort and relief from heat stress at the street level and neighbourhood scale, particularly during hot seasons and times of day. The study also highlighted growing evidence of disproportionate heat- and air-pollution-related health burdens associated with unequal distribution of green space in urban neighbourhoods. Two main negative impacts were identified associated with urban greening: 1) increased BVOC emissions and 2) increased localized air pollution in street canyons. The authors conclude with recommendations that include improving the quantity, quality and connectivity of green spaces; prioritizing green strategies for vulnerable urban areas; and integrating greening policies with broader health and land-use planning policies.

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8. Ecosystem Disservices

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Overview

While there are many benefits to human wellbeing and to biodiversity provided by urban green spaces, they can also have some negative consequences. Much of the literature on the benefits of urban green spaces tends to overlook the disservices that can accompany these spaces (Lyytimäki et al., 2009; von Döhren & Haase, 2015). Ecosystem disservices can be thought of as those outcomes of green spaces that can reduce people's health and wellbeing, or negatively affect biodiversity.

Disservices can be generated directly by green spaces (e.g. bushfire), or indirectly as an outcome of management (or lack of it), e.g. negative aesthetics. Some disservices may be reduced with appropriate management and design. However, there is a risk that the desire to avoid disservices will lead to reduced provision of green space elements such as trees. This could have overall negative consequences as the loss of benefits may far outweigh the avoidance of negative consequences of disservices.

Key findings

Key ecosystem disservices that can be generated by urban green spaces have been categorised as having ecological impacts, economic impacts, health impacts, psychological impacts or general impacts on human wellbeing (von Döhren & Haase, 2015). Individual disservices are diverse and can have impacts in multiple categories. Reported disservices include (drawn from Lyytimäki et al., 2008; 2009; Lyytimäki, 2014; Conway & Yip, 2016; Dunn, 2010; Dobbs, Kendal, et al., 2014; von Döhren & Haase, 2015):

- Damage to infrastructure (e.g. tree roots)
- Unwanted shading (e.g. roof solar panels, winter sun)
- Falling leaves creating mess or hazard
- Falling fruit attracting pests or creating hazards
- Source/harbour for invasive species
- Attracting unwanted animals
- Transmission of zoonotic diseases
- Allergies from pollen
- Falling trees and tree limbs
- Perceived lack of safety (especially for women)
- Animal noise
- Animal and plant smells (e.g. algae)
- Animal excrement (particularly bird and dog)
- Poisonous plants and animals
- Fear and disgust towards wild or semi-wild animals
- Bushfire
- Floods
- Conservation actions (e.g. threatened species protection) restricting human-centred activities e.g. recreation, or reducing landscape amenity
- Decrease in air quality e.g. emission of volatile organic compounds (VO)
- Maintenance costs
- Trees blocking views
- Traffic hazards and sightline obstruction
- Displacement of endemic species

Literature

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9. Thresholds and correlates of benefits from green space

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Overview

There is relatively little research providing evidence for thresholds and correlates of greenspace characteristics with green space benefits. This small body of research suggests that distance to green space is important predictor of use of that space, that short exposures to green space can have some psychological benefits, and that longer exposures can lead to improved mental health and physical health outcomes. Building evidence of greenspace correlates and thresholds would help in choosing evidence-based targets and shaping urban green space policy.

Key findings

Human health and wellbeing

Distance from parks, and size of park, have been shown to influences physical activity. Accessibility (as indicated by distance) is a strong predictor of use of public open space, and size and attractiveness are also contributing factors (Giles-Corti et al., 2005)

Street tree canopy has been shown to be linearly (but weakly) related to decreases in self-reported stress (Jiang et al, 2016). A correlative study showed that increasing tree canopy was related to decreasing crime rates in Baltimore, USA (Troy et al., 2012).

The frequency and duration of green space experiences influence the provision of benefits. Just 40 seconds viewing of green grassy flowering meadow can boost attention (Lee et al., 2015). While longer visits to parks are associated with lower rates of depression and high blood pressure (Shanahan et al., 2016).

Ecosystem Services

There is a relatively linear relationship between tree canopy cover and the removal of particulate matter (Tallis et al., 2011). About 80% of the cooling effect of green space is determined by the shade cast by the canopy of trees (Shashua-Bar et al., 2009). The carbon sequestration of urban green space is mostly related to tree biomass (Davies et al., 2011).

Biodiversity

Different characteristics of green space are important for different kinds of organisms. Larger parks tend to support more bird species (Donnelly & Marzluff, 2006) and large patches of habitat are needed for some species of wildlife (Tyrväinen et al., 2005)**.** Larger conservation reserves can also have fewer local extinctions of native woodland plant species (Ramalho et al., 2014). However, patch or reserve size are not important for some kinds of organisms. Species and ecosystems that operate at smaller scales may not necessarily need large reserves to conserve species. For example, invertebrates in Sydney (Gibb & Hochuli, 2002), and native grassland species in Melbourne (Williams et al, 2005) are able to persist in small reserves.

The vegetation structure in green space is very important for some species. Increasing understory vegetation leads to more bird species, and increasing tree density leads to higher bat activity (Threlfall et al., 2016). A number of studies have identified the importance of large, hollow bearing trees for native biodiversity in Australian cities (Stagoll et al., 2012; Threlfall et al., 2016).

Recent research suggests that the identity (native vs exotic) of vegetation may be more important in Australia than has been demonstrated overseas. Several studies have shown that

native bird and bat species benefit from the presence of native plants in streets, parks and gardens (e.g Young et al., 2007; Ikin et al., 2013; Threlfall et al., 2016).

Habitat heterogeneity is a major driver of species diversity, and parks that have more diverse habitat are likely to contain more species. As local habitat structure is very important for many taxonomic groups (Sadler et al. 2010), the design and management of urban green space is very important for biodiversity. As different kinds of organisms respond differently to particular landscape attributes, there cannot be a single prescription for open space that will improve all kinds of biodiversity. Instead different kinds of urban green space are needed to provide heterogeneity in habitat to promote different kinds of biodiversity.

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10. Green space targets

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Overview

A wide range of criteria and indicators are used to set targets for urban green spaces. These are often related to the goals of the greening programs – health focussed programs tend to focus on accessibility and amount of green spaces (often limited to parks), while ecosystem service (e.g. cooling) focussed programs tend to focus on canopy cover, which is more directly related to cooling effects.

Key findings

The World Health Organisation has recommended that cities should provide a minimum of 9 m^2 of green space per person. However, city green space is largely related to city area rather than population, meaning that per-capita green space declines in compact cities (Fuller & Gaston, 2009), and the function, quality and access to green space is more important than a simple per-capita metric (Ngom et al., 2016). Other health related targets tend to focus on the accessibility of green spaces, such as minimum walkable distance to parks.

'Million tree' programs have been widely used in the USA as high-profile mayoral initiatives (Pincetl, 2009; Young, 2011). These can benefit from creative involvement of the community and corporate partnerships to fund and steward the programs, but have been criticised for not addressing long term management and being overtly associated with a political champion (e.g. mayor) that can lead to their unravelling when that champion loses office.

Tree canopy cover is one of the most widely adopted target for green space, as it is relatively easy to calculate and related to some of the benefits provided by green space (Ward & Johnson, 2007; Walton et al., 2008; Kenney et al., 2011). Some high profile examples of tree canopy targets include the City of Melbourne setting a target to double its tree canopy to 40%, and Singapore achieving an increase in green cover from 36% to 47% while increasing population by 68% between 1986 and 2007.

Diversity targets are extremely important in managing vegetation in cities to create resilient green spaces. Reliance on one or a few species can leave green spaces vulnerable to the effect of environmental change and pests and diseases. For example, a large proportion of the urban forest of many cities in the USA and Europe were wiped out due the Dutch Elm Disease in the 1960s and 1970s. In response, diversity targets are used in the urban forest at the species, genus and family levels to manage this diversity (Santamour, 1990). Recent research suggests these targets should be varied with climate, natural history and social factors (Kendal et al., 2014).

Like taxonomic diversity, age-class diversity is also an important characteristic influencing the resilience of urban green spaces and the urban forest in particular. Where a large proportion of trees are of a similar age, they can decline together leading to dramatic changes in the provision of ecosystem services. (Kenney et al., 2011)

As well as targets based on measurements of green space, there is a growing interest in including social criteria and indicators in green space management (Kenney, 2011) and NRM management more broadly (Montreal Process Implementation Group for Australia, 2013). Suggested social criteria include awareness of green space, community participation in green space management, public agency cooperation and private landholder involvement (e.g. Kenney, 2011)

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11. Resilience

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Overview

Resilience is the capacity of a socio-ecological system to cope with sudden shocks (e.g. floods) and global environmental change (e.g. climate change, urban densification) (Brian Walker & Salt, 2006; McPhearson et al., 2015). There are two ways that resilience is important in urban green spaces; the resilience provided urban green spaces to the social-ecological system they occur in, and resilience of the urban green spaces themselves (*sensu* McPhearson et al., 2015, Dobbs *et al.*, in press).

Key Findings

Urban green spaces contribute to the resilience of cities by ameliorating the effects of sudden shocks such as heat waves, and storms (Gill et al., 2007). Urban green spaces contribute significantly to cooling and can reduce temperature extremes by many degrees. The permeable surfaces in urban green spaces can also slow the runoff of stormwater during storm events, reducing floods. Urban green spaces also contribute to mitigating and adapting to global environmental change such as urban heat and climate change. For example, increasing tree canopy cover can help to mitigate the effects of climate change by sequestering carbon (Dobbs et al., 2014), and adapt to urban heat by increasing the provision of shade and cooling in cities (Gill et al., 2007).

The resilience of urban greenspaces themselves are also important to ensure the provision of benefits despite external shocks and global environmental change (McPhearson et al., 2015). For example, the loss of many urban trees in North America and Europe to Dutch Elm Disease in the 1960s and 1970s is likely to have had a similarly catastrophic effect on the provision of benefits by the urban forest. Two key concepts underpinning the resilience of urban green spaces are redundancy and response diversity (Biggs et al., 2012). Redundancy reduces the effects of catastrophic loss of any particular species or landscape element, and can be increased by the use of different species or elements that provide the same benefit (Biggs et al., 2012). Response diversity occurs when different species or landscape elements respond in different ways to the same external changes, and increases the likelihood of the system continuing to supply benefits in the face of this change (Elmquist *et al.*, 2003).

Increased diversity in the composition, traits, structure and age of species and the materials and design of infrastructure increases the resilience of the urban social-ecological system, as diverse green spaces and landscape elements are more likely to be able to mitigate and adapt to a broader range of external change (Kendal et al., 2014).

A particularly important external driver of change in urban systems across much of Australia is urban heat (Norton et al., 2015). Urban green spaces can help adapt cities to increasing temperatures through the provision of shade and cooling. However, these increasing temperatures also threaten the survival of some plants and endurance of some infrastructure that provide these services. Selecting plants and materials that can are adapted to future urban climates and continue to provide the benefits of cooling are critical to the resilience of Australia's cities and their green spaces.

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12. The physical environment shaping the benefits provided by urban green spaces

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Overview

Australia is a large country, and its cities occur across temperate, tropical and arid climate zones. The level of urbanisation of these cities and towns vary enormously. These physical environmental differences lead to green spaces that vary in composition, structure and quantity across Australian cities, that provide different kinds and levels of benefits their human and non-human inhabitants. As Australian cities become warmer and more intensely urbanised, the structure and composition of their urban green spaces will change.

Key findings

Climate

Temperature is a very strong driver of the distribution of plants (Woodward & Williams, 1987). Urban forest cover tends to be similar to that found in surrounding ecosystems (Dwyer et al., 2000). Climate has been shown to be a very strong predictor of tree species composition in urban green spaces (Kendal et al., 2012a) and a useful predictor of diversity in the urban forest (Kendal et al., 2014). Increases in urban temperatures due to urban heat are leading to large changes in the composition and structure of urban forests, which are likely to be compounded by the effects of climate change (Kendal & Baumann, 2016).

The ecosystem service and wellbeing benefits provided by urban green spaces are also likely to vary with temperature (Roy et al., 2012). For example, shade trees can significantly reduce energy use in cities with hot summers via a reduction in the use of air conditioners (Akbari et al., 2001). Similar increases in benefits for human health and wellbeing may flow in hotter cities (Madureira et al., 2015).

Other climate variables such as rainfall can be locally important in some places. For example, cities with Mediterranean climates (with long dry summers) tend to have different species growing than cities with more uniform rainfall patterns.

Level of urbanisation

The level of urbanisation influences a number of environmental parameters that influence the structure and function of urban green spaces (Grimm, Faeth, et al., 2008; Grimm, Foster, et al., 2008). Highly urban areas tend to be warmer than surrounding areas due to urban heat effects, soils tend to be drier as rainfall is captured and piped into stormwater systems rather than allowed to infiltrate through soils, and the chemical composition of the environment varies due to pollution and nutrient deposition. These factors affect different species in different ways, and lead to changes in the species composition and structure of urban green spaces.

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13. The social context shaping the benefits provided by urban green spaces

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Overview

A number of social factor, including population density, culture, socioeconomic status, social values, age and gender have been demonstrated to influence the way people think about and use urban green spaces. As these social factors vary in space and time, an understanding of how communities are structured currently and how they are predicted to change into the future is needed to plan, design and manage urban green spaces that satisfy the diverse needs of the community in different cities across Australia.

Key findings

Population Density

Population density has been shown to be an important limiting factor on the distribution of green cover (Iverson & Cook, 2000) and a driver of fragmentation of green space (Tian et al., 2011). High population densities lead to changes in the built form that generally lead to more impervious surfaces, and less impermeable surfaces where plants can grow. These physical limitations may be able to be overcome with a policy focus on increasing green cover and green space. For example, the high density city of Singapore has been able to increase green cover from 36% to 47% while increasing population through the implementation of strong greening policy. Limited space on the ground also leads to an increase in green interventions encapsulated within the built environment, such as green roofs and facades (Tian & Jim, 2011).

Green spaces in areas with a high population density also tend to be more intensively used by people. Population density is also a useful predictor of the global provision of some ecosystem services from the urban forest, including recreation potential and carbon sequestration (Dobbs et al., 2014)

Socioeconomic inequality

Socioeconomic status is an important driver of urban greening in public landscapes in Australia and around the world (Iverson & Cook, 2000; Luck et al., 2009). Some research from the USA suggests that this is the result of a 'luxury effect', where people with the 'economic wherewithal' are able to move to areas with more vegetation, or plant more vegetation themselves (e.g. Martin et al., 2004). However, there is a growing body of evidence showing that this phenomena is being driven by top-down processes where advantaged sections of the community have the capacity to influence the provision of public goods (e.g. street trees) for private gain (Heynen & Lindsey, 2003; Kendal et al., 2012b).

There are potentially large benefits in greening disadvantaged areas. For example, health inequalities have been shown to be smaller in green areas (R Mitchell & Popham, 2008). Trees and green spaces may provide proportionally greater benefits in disadvantaged areas. In Australia, a number of studies have identified education level rather than income as a better predictor of the distribution of urban greenery (Luck et al., 2009; Kendal et al., 2012b). This reinforces the idea that factors other than personal economic ones are important in people's thinking about urban green spaces.

Gender

Few studies have explored the importance of gender in the provision of benefits by urban green spaces. Richardson & Mitchell (2010) showed that cardiovascular disease and respiratory disease mortality rates decreased with increasing green space for men but not women. A number of studies have shown that perceptions of safety are gendered (e.g. women tend to feel less safe) and influenced by landscape design (Jorgensen et al., 2002); it is likely that this leads to differential use of green spaces based on gender. The motivations for women and men to engage with green space also differ, and this can lead to differences in the benefits provide by green spaces (Currie et al., 2016). For example, women were more motivated to be involved in conservation programs than men, who more just looking 'for something to do'.

Social Values

There are a variety of ways that green spaces are important to people (Burgess et al., 1988). Recent research suggests that social values (e.g. altrisum, biospherism) are an important factors shaping the decisions people make about the world around them. In post-industrial societies such as Australia there has been a shift in values over several generations away from more utilitarian values for nature, towards more ecocentric values including the conservation of species (e.g. Xu & Bengston, 1997, Manfredo et al., 2015). These value shifts are likely to change the way people expect green spaces to be designed and managed in cities in the future.

Culture

Relatively few studies have explored the importance of culture in shaping people's experience of public green spaces (as opposed to private green spaces). A study from Turkey found some small differences such as an emphasis on passive recreation compared with western green space users (Özgüner, 2011). In practice, the design of green spaces are changing to meet the perceived needs of changing ethnic groups, such as provision of areas for large community gatherings. Further research is needed to support this decision-making.

Age

Older people have different needs for urban green spaces than younger people (e.g. Arnberger & Eder, 2011). The design and planning of urban green space can have significant effects on the health and wellbeing outcomes for an ageing population. Having walkable access to urban green spaces has been shown to increase longevity of senior citizens (Takano et al., 2002)

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14. Governance and policy shaping urban green space

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Overview

Urban green space policies are created and implemented within a multi-level governance context (Lawrence et al. 2013), encompassing different levels of government, as well as different policy domains within each government level. In Australia, federal, state and local governments all directly influence green space policies and have roles in their planning and implementation. Policy domains include urban strategy, land use planning, environment and sustainability, open space and recreation, transport, health and community welfare, and emergency management. Green space governance, policy and implementation therefore necessitate vertical and horizontal integration, and governance efforts that involve non-government stakeholders, including utilities, developers, private landowners and community groups.

Key findings

Whilst there is substantial and growing research demonstrating the multiple functions and contributions of green space, the conceptualisation of urban green space (urban forest, street trees, parks and waterways, and so on) as part of urban infrastructure, 'green infrastructure', is a much more recent approach (Benedict and McMahon 2006; Tzoulas et al. 2007). Urban sustainability and liveability challenges are requiring new approaches, including rethinking the functions of urban infrastructures, and reconceptualising how green infrastructure contributes to essential urban functions (Frantzeskaki et al. 2016; Davison and Kirkpatrick 2014). Given the complexities of urban systems and the relatively immature status of green infrastructure as a component of these systems (Matthews et al. 2015), a range of policy mechanisms are required to support the inclusion, retention and maximisation of green space in cities, as well as addressing both public and private land tenure.

Policy mechanisms can be categorised into four types (Maddison and Denniss 2009): information and engagement; incentives and encouragement (to promote innovation and best practice); government provision; and regulation and legislation (to define minimum standards) (Table 1). Whilst regulatory mechanisms are often the focus for both researchers and policy-makers, other types of policy mechanisms make significant contributions to green space outcomes, and reinforce community and leadership support for stronger measures (City of Melbourne 2012; 202020 Vision 2015). In addition, linking green space policies with other measures that integrate green infrastructure functions, such as water sensitive urban design, heatwave mitigation, public space amenity and design, and urban ecology and biodiversity strategies can contribute to building broad-based support both within and beyond government (for example Mayor of London 2012; US EPA 2010; Kabisch et al. 2016).

Table 1: Urban green space policy mechanisms

Policy mechanism	Policy instruments			
	Advocacy	Incentive	Government provision	Regulation
Community information, engagement, participation: community workshops, plantings, site visits and other activities	✓			
Guidelines and toolkits: urban greening; green roofs and walls, urban agriculture	✓			
Incentives during the planning process: • increased floor area ratios with increased green space provision • 'green door' fast tracking of approvals for those which incorporate urban greenery features (e.g. green roofs, walls, open space, etc.) • Waiving planning fees • Exempt certain works related to urban greenery		✓		
Stormwater fee discount with increased pervious surfaces		✓		
Grants, rebates, financing for installation of urban greenery features		✓		
Leadership, including demonstration urban greenery treatments			✓	
Creation of pocket parks from street closures or realignment			✓	
Opportunistic public works (utilities/ easements management)			✓	
Integrated government decision-making on urban infrastructure and land use planning: consider urban heat island effect and mitigation			✓	
Integrated government decision-making: ensure existing regulations do not pose a barrier for urban greenery implementation and innovation			✓	
Metropolitan Open Space Strategy: use socio-economic vulnerability and public activity exposure data to prioritise actions			✓	
Water sensitive urban design treatments integrated with street tree plantings			✓	✓
Developer contributions for public open space				✓
Regulations, mandated for particular types of development, using Green Star model (Green Star Communities rating tool; ENV 3 UHI)				✓
Planning scheme overlays for 'hot spots' (based on thermal data): require specific heat mitigation treatments using greenery for private development				✓
Protection of public trees: penalties for damage				✓
Data collection, monitoring, evaluation of urban greenery indicators	✓		✓	
Research and implementation partnerships: universities, peak bodies	✓		✓	
Awards, recognition programs	✓	✓	✓	

Sources: City of Melbourne; City of Sydney; State of Victoria; Inner Melbourne Action Plan; Victorian Department of Environment, Land Water and Planning; US EPA; Green Building Council of Australia.

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