

# URBAN ECOLOGY: THEORY, POLICY AND PRACTICE IN NEW SOUTH WALES, AUSTRALIA

## DESKTOP REVIEW



THE NATIONAL  
GREEN INFRASTRUCTURE  
NETWORK

Cover pictures: first on the left Centennial Park Wetland, Sydney; below, Royal Spoonbill (*Platalea regia*) in reconstructed saltmarsh in Annandale, Sydney; top right, One Central Park, Sydney; Long-billed Corellas (*Cacatua tenuirostris*) in Centennial Park, Sydney; reptile habitat feature among bioretention swales in Orphan School Creek, Sydney.

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## EXECUTIVE SUMMARY

### The case for change

Australia is one of the most urbanised countries in the world, with more than 75% of the population living in one of 20 major cities. There has been a trend toward living in cities in Australia for more than a century, and it is predicted to continue.

Urban ecosystems and the ecosystem services provided by nature contribute to community health and wellbeing and the economic sustainability of cities, but urbanisation can also cause ecological decline and change. Terrestrial and aquatic systems are affected by land clearing, the construction of housing and infrastructure, and the way in which cities are managed and maintained. Urbanisation has resulted in the local extinction of many species and ecological communities, but it has also favoured some adaptive species, which thrive in urban habitats.

The urban population and rate of development continue to grow in NSW's three major urban centres, Sydney, Wollongong and Newcastle, both vertically, with infill development and high-density residential towers, and horizontally, with new subdivisions at the expanding urban edge. By 2034, the NSW Government expects Sydney to be home to an additional 1.6 million people, including 900,000 in western Sydney (NSW Department of Planning and Environment, 2014). Wollongong (incorporating the Illawarra-Shoalhaven region) is predicted to grow by 60,400 people by 2036, and the greater Newcastle region will be home to an additional 862,350 people.

The urban planning strategies of the NSW Government have focused on housing supply and employment targets, and many bushland and riparian areas have been cleared or otherwise affected by development. Cities are highly modified environments and represent a coupled human and natural system, and ecological impacts are not unexpected. Decision-making processes are, however, often at odds with the guiding objectives of state environmental and planning laws, which are framed around ecologically sustainable development.

Recent changes in laws and policies are contributing to and exacerbating declines in the ecological health of cities in NSW. Examples include fast-track development assessments that forego rigorous merit-based processes, reductions in buffer widths along riparian corridors to provide more land for development, enabling tree and vegetation clearing without consent in bushfire-prone areas, and the application of 'switching-off' mechanisms to certain developments that disable environmental assessment processes. There is political and industry reluctance to impose or strengthen environmental controls that exist in other jurisdictions in Australia and internationally. The narrow and silo-style decision-making approach often taken by governments, industry and communities is another contributing factor in the decline of urban ecological health.

In NSW, the land-use decision-making framework is routinely compromised and purposely deterred from prioritising urban ecology. There is a lack of understanding of the co-benefits that ecologically rich urban areas provide the people and economy of NSW, and such co-benefits therefore remain outside planning and development decision-making systems. As outlined in this report, however, substantial, realistic and deliverable actions can be undertaken to arrest the ecological decline in urban areas, enhance the quality of life of residents, and ensure that Sydney, Wollongong and Newcastle become global leaders in urban ecology.

## The purpose of this report

The aim of this report is to provide the evidence base for embedding urban ecology into laws, policies, strategic investment decisions and actions that inform and have a positive impact on the three major cities in NSW. The report draws on academic, peer-reviewed literature and 'grey' literature such as reports, conference presentations, newspaper articles and government laws, policies and reports. Three thematic areas of literature are examined:

- Urban biodiversity and ecology
- Policy and legislative frameworks
- Built environment and urban landscape design.

Case studies are presented to demonstrate best practices in applying urban ecological thinking, both within Australia and internationally. In parallel with the literature review, workshops with industry, government and community groups helped in identifying how these groups define and implement urban ecology projects and what they consider to be the barriers to and opportunities for embedding urban ecology into decision-making and practice within and between our cities.

This report informs the *Blueprint for Living Cities: policy to practice*, a document designed to demonstrate to the NSW Environmental Trust, state government departments and agencies, local governments, industry and the community how to change from a business-as-usual approach to realistic, ecologically based city planning and practice. It positions urban ecology as a foundation for the identity and betterment of NSW cities.

## The nine major findings

1. **Urban biodiversity and ecosystems are being lost in our cities.** Land clearing, habitat fragmentation, the declining size of remaining habitats, invasive species, and changes in microclimate, lighting, hydrology, nutrient availability and artificial structures (e.g. roads and drains) all affect the quantity and quality of habitats and thus the ecology of cities. Sydney, Wollongong and Newcastle are comparatively new and still-growing cities. Past and current pressures are likely to incur a future 'extinction debt', in which non-viable populations and habitats become locally extinct. This points to the importance of what should be the dual objectives of urban ecology in cities: to protect and conserve what exists (which does not include trading the protection of one habitat for another); and to reduce the individual and collective ecological pressures through adequate and enforced standards.
2. **Strategic planning reform** is required to protect existing habitats and create or re-establish habitats and corridors. Habitats and habitat corridors should be mapped at the local to metropolitan scales and strategies implemented to support their long-term viability. Opportunities to create novel urban ecosystems require support from state and local governments; such habitats can help in linking core habitats and providing ecological function and ecosystem services, and they should build on an agreed urban 'vision'. Strategic reform should be vertically integrated, and state and local governments and the community – not the development sector – should set priorities.
3. **Cities are heterogeneous** in land use, density, form and function, and there is high variability in institutional and community values and practices. This heterogeneity affects habitat quality and quantity and therefore the responses of species to and within the urban matrix. There can be great variability even within a single land-use type, and this affects species richness. Actions to

improve urban ecology in cities must consider spatial and temporal scales, reflect political, business and community priorities, and be driven by values derived from both top-down (state) and bottom-up (community) processes.

4. **The natural environment is not considered to contribute to a city's wellbeing or economic outcomes.** Addressing this lack of understanding requires incorporating the co-benefits of urban ecology into decision-making processes. Cities have traditionally been planned and developed on the basis of housing affordability and employment generation, despite abundant research demonstrating that the services provided by the natural environment have significant economic and social value from both anthropocentric and intrinsic perspectives. The creation and direction of the Greater Sydney Commission to plan Sydney on three pillars – productivity, liveability and sustainability – should provide a foundation for a more integrated decision-making approach. This new direction will be tested in the development direction and controls set for the growth areas in western Sydney.
5. **Performance-based development application and assessment tools are required** to support urban ecological outcomes at the lot-to-precinct scale. Environmental planning instruments, such as state environmental planning policies, can be developed and applied to advance the sustainability of cities, including through urban ecology. Such tools can be spatially specific (e.g. connecting green grids and linking to regional parks), offer flexibility (e.g. in the choice of plantings and setting limits on house-to-land development ratios), and support diverse and appropriate habitat form and function that is species- and community-relevant. Performance-based tools can be used to set quantifiable monitoring and evaluation frameworks. To date, however, monitoring and evaluation have lacked consistency as well as relevance to the incremental planning decisions affecting cities, and they have proved inadequate for measuring the environmental impacts of such decisions.
6. **The enforcement of laws and policies** needs to be prioritised and embedded within institutional- and community-change programs. There exists a strong foundation of local plans and policies that support lot-to-precinct-based landscaping and urban ecological outcomes. Many controls set by local government and contained in development control plans are not legally enforceable, however. Other local government and state agency plans and policies, such as biodiversity plans and strategies, tree preservation and protection rules, and best practice guidelines, have no statutory effect. There is a disconnection between such local plans, policies, best-practice guidelines and development conditions and their enforcement. This problem is exacerbated by changes in the planning and approval system towards more code-based development and exempt forms of development, in which environmental and landscaping controls are given little or no attention. Outside the development approval structure, the day-to-day management practices of property owners, including public agencies, need greater scrutiny to ensure compliance with existing laws. Monitoring and evaluation programs linked to consent conditions for governments, public agencies and major public development projects are required to increase the institutional importance and value given to urban ecology and to change business-as-usual practice.
7. **“Our cities are green enough.”** There is a perception that NSW cities are already ‘green’, and this contributes to a values-based conflict, in which urban ecology is afforded insufficient importance to warrant changes to policy and practice. Sydney, Wollongong and Newcastle are bounded by national parks, have significant pockets of bushland, and are defined by their coastal outlooks and waterways. Paradoxically, these natural attributes both support the urban

ecology of our cities and contribute to complacency in government, industry and the community on the extent of habitat clearing and consequent ecological decline. Resolving this value conflict is complex: efforts must go far beyond the conventional (business-as-usual) approach of providing more or new education and awareness programs. There is a need for a whole-of-government review of policy and practice to identify and resolve contradictions in laws, policies and practices that have detrimental effects on urban ecology in our cities. Building on local government strategic plans, local community planning needs to be guided by overarching objectives that value urban ecology to the same extent as jobs and housing targets. Local community plans must have enforceable provisions to support urban ecological outcomes that cannot be overridden by lot-based and subdivision-based development decisions or the priorities of public agencies.

8. **Public open space** is an underused opportunity for enhancing urban ecology in cities. The traditional metrics for the provision of open space (e.g. area per capita) are no longer relevant and have been unable to ensure the reservation of sufficient areas of land for either active or passive uses or for ecological outcomes. There is a need to develop locally based open-space standards that relate to current and forecast urban population size and density and which also consider and provide for improved urban ecological outcomes. Such standards need to be tailored to new subdivisions in greenfield locations as well as to infill development, and they need to be supported by mechanisms linked to land dedication and acquisition and strategic rezoning.
9. **Environmental services and disservices.** Urban ecology and its associated natural areas and green infrastructure can provide valuable services and increase resilience to extreme weather events and climate change, but they can also provide disservices. There is a policy tension, for example, in landscape management for bushfire protection at the urban interface, where tree removal and understorey clearing can be at odds with the provision of habitat. Governments have failed to determine acceptable tradeoffs in many such cases, leading to the polarisation of views and policy perceptions. This requires attention to ensure satisfactory outcomes in policy and practice.

## Key recommendations

### State level

1. Set an overarching target in an apex policy to promote the implementation of urban ecology
2. Establish a monitoring program to evaluate the change in condition of ecological assets and green infrastructure and use this to assess the efficacy of plans and policies
3. Review urban biodiversity governance structures and systems

### Regional level

4. Identify, protect and conserve remnant ecosystems, including riparian and coastal ecosystems and habitats
5. Develop a performance-based design and construction rating tool that supports and advances urban ecological outcomes
6. Monitor the habitat quality of remnants and identify and address regional-level impacts

### Metropolitan level

7. Prioritise a compact city development pattern rather than lower-density greenfields as a way of minimising habitat loss
8. Undertake a systematic, spatially explicit mapping program to identify opportunities for green and blue corridors at multiple scales to connect existing and newly created habitats
9. Create green corridors with minimum width requirements that connect patches of habitat and encourage species movement. As a general guideline, at least 50 m is required as it is known that narrower corridors are vulnerable to weeds and introduced ants (Ives et al. 2011).
10. Develop a spatial information biodiversity layer that identifies the extent and condition of habitats
11. Use road, rail and infrastructure easements and corridors as green corridors
12. Establish a metropolitan-wide policy to support the design, construction and maintenance of green infrastructure
13. Designate buffer zones around key remnant bushland areas and green and blue corridors
14. Where possible, include and restore riparian vegetation in planned green corridors and networks
15. Develop and implement a policy to put power lines underground to reduce conflict between tree canopies and power lines

### District level

16. Establish and enforce planning controls that support urban ecology, such as a performance-based rating tool
17. Enhance existing degraded remnant ecosystems in urban areas
18. Integrate water-sensitive urban design in master planning for new subdivisions
19. Reduce the total amount of impervious area and the connectedness of impervious surfaces
20. Implement bush revegetation and restoration programs with set benchmarks that address the original causes of decline, and actively monitor them to enable the assessment of outcomes. Appropriate benchmarks can be determined by following the approach of the Biodiversity Assessment Method (BAM – Office of Environment & Heritage). Benchmarks should include

variables describing composition (e.g. native species richness), structure (e.g. % native mid-storey cover) and function (e.g. leaf litter depth), and target values for these benchmarks can be determined from reference sites of the appropriate vegetation type that are considered to be in a near natural state.

21. Implement green infrastructure, including green roofs, with high habitat complexity and resources that encourage biodiversity

### **Local level**

22. Ensure that local government community strategic plans and operational and delivery programs allocate resources to achieve positive urban ecological outcomes
23. Support participatory planning processes to set local planning controls that encourage liveability and urban ecological outcomes
24. Require all local councils to establish and implement urban forest strategies
25. Establish and enforce planning controls that support urban ecology
26. Develop incentive mechanisms to promote and maximise urban ecological outcomes as part of local policy and development assessment
27. Prioritise compliance and regulation programs in councils to ensure compliance with development approval conditions and local environmental policies
28. Create novel ecosystems that benefit local biodiversity, support ecosystem services and promote human health and wellbeing
29. Establish and implement green roof and green wall policies for infill and compact development sites
30. Establish community education and awareness programs to raise the importance and value of urban ecology in cities
31. Plan open spaces to capture the ecosystem services and ecological benefits of informal green spaces
32. Support design and maintenance guidelines that enable the creation of habitat complexity in informal green spaces
33. Revise local street design and building set-back controls to support canopy planting and complement lot-based landscape outcomes
34. Develop local park design and maintenance guidelines that support urban ecology and sustainability principles
35. Support ecological engineering projects that replace grey (conventional) infrastructure
36. Implement soft/ecological engineering practices for shoreline protection and coastal revetment structures
37. Encourage the establishment of community gardens and bushcare type programs specifically for parks
38. Establish best-practice demonstration projects on publically owned land
39. Make use of interpretative features (including signage) to inform the public of the ecological reasons behind management decisions

### **Lot level**

40. Establish maximum built-lot coverage requirements to ensure sufficient area for landscaping and pervious surfaces
41. Establish deep-soil requirements to support canopy plantings on private land

42. Retain large, mature, hollow-bearing trees
43. Encourage the planting of native gardens that include structural complexity and the provision of habitat resources
44. Ensure lot-based stormwater and water-sensitive urban design controls to minimise pollution and hydraulic impacts on local streams
45. Reduce noise impacts on environmentally sensitive areas through vegetation buffers
46. Reduce light pollution in environmentally sensitive areas through the use of narrow-spectrum bulbs, down lights, shields, embedded lights and motion-activated lighting
47. Encourage the introduction of parklets with a minimum 75% vegetation area.

## Summary of Technical Chapters

### BIODIVERSITY CONFERS URBAN RESILIENCE AND HUMAN HEALTH AND WELL-BEING

Healthy ecosystems provide ecosystem functions that benefit urban environments and communities. Such functions, often referred to as 'ecosystem services', include the role of vegetation in cleansing the air, stormwater management, climate regulation and carbon sequestration. Healthy urban ecosystems also provide economic benefits, promote human health and wellbeing, and generate aesthetic and visual benefits.

The valuation of ecosystem services for urban health and wellbeing is important for ensuring that governments understand the economic benefits that vegetation and biodiversity bring to a city. Costanza *et al.* (2014) calculated that, worldwide, the value of changes in land use and resultant habitat loss between 2007 and 2011 was USD 20 trillion/year; it has also been suggested that, whatever value is conferred on a given ecosystem, it will be an underestimate because ecosystems provide more benefits than can accurately be valued economically (Vucetich *et al.*, 2015). In addition to the financial benefits of maintaining healthy ecosystems, researchers have pointed to the inherent value of natural spaces and biodiversity; there are strong arguments that biodiversity should be maintained for its intrinsic value.

People and nature are inexorably linked, but urban ecosystems may also provide disservices to cities and their populations (Lyytimäkia *et al.*, 2008). Potential disservices include physical attacks or bites from wildlife; allergies; discomfort caused by close proximity to certain undesirable species; damage to property and other assets (such as trees falling on houses); and disease transmission (Soulsbury & White, 2015).

### URBAN BIODIVERSITY AND ECOSYSTEMS ARE BEING LOST AT AN ALARMING RATE

Biodiversity is vulnerable in the face of increasing urban development due to the decline in the quality and quantity of urban ecosystems. Many cities are carrying 'extinction debts', with non-viable populations of organisms persisting in areas where they will eventually become locally extinct (Hahs *et al.*, 2009).

Australian cities have recorded large changes in their biota. In Adelaide, for example, 132 native species are no longer present in the city, and 648 new species have been added. The increase has been driven mainly by increases in plant richness of introduced species in urban areas; for birds, the number of species now locally extinct (21) has been offset by colonisation by other species (20) (Tait *et al.*, 2005). This same pattern was observed for small mammals in Melbourne, where only 29 of the 54 historically (pre-European settlement) present mammals are likely to still occur; most of the extinctions have been

of small, ground-dwelling marsupials (van der Ree & McCarthy, 2005). In Sydney, a comparison of current and historic bird compositions (as determined from museum specimens) showed dramatic changes in assemblage composition and structure, with larger birds (e.g. parrots and carnivorous species) becoming more abundant and smaller birds, especially insectivorous birds, decreasing (Major & Parsons, 2010).

The process of urbanisation causes multiple changes to abiotic and biotic conditions, and these changes can have large ramifications for ecosystem quality, biodiversity and ecosystem function. Abiotic changes include factors such as changes in microclimate, lighting, hydrology, nutrient availability, and the addition of artificial structures that hinder species movement. Biotic changes include habitat loss, habitat quality and the spread of invasive species.

The loss of habitat reduces the area available to support populations, resulting in decreases in species richness. In cities, habitat clearing for development transforms large tracts of continuous ecosystems into smaller fragments of remnant habitat (Grimm *et al.*, 2008b). For example, extensive clearing of the Sydney Basin has reduced habitat to small, isolated patches surrounded by a matrix of other urban land uses. Smaller patches of habitat in urban areas support fewer species than larger patches, as demonstrated for multiple Australia taxa (Drinnan, 2005; Palmer *et al.*, 2008; Kang *et al.*, 2015), and may affect the long-term survival of individual species and groups of species. As the size of remnant vegetation patches decreases in cities due to development pressure and land clearing, local extinctions of species that require larger, connected core habitats are inevitable, thus reducing the overall species diversity of a city (Marzluff, 2005).

Landscape fragmentation can mean a loss of wildlife movement between patches of remnant habitat. For some species, the urban matrix is inhospitable and constitutes a barrier to movement. Populations become genetically isolated, leading to decreased genetic diversity and potentially a reduced ability of populations to 'bounce back' from environmental perturbations. For other species, the urban matrix may represent lower-quality habitat that nonetheless is adequate to sustain movement between patches. Species for which the urban matrix is inhospitable will be outcompeted by species able to survive in new urban landscapes.

Urban ecosystems can be crucial for the conservation of threatened species and endangered ecological communities. Given the diversity of the urban matrix, it has the potential to provide niche habitats and to protect these through (for example) conservation agreements. This role should not be underestimated, and it points to the value and need to integrate urban ecology in cities as an intrinsic right and a liveability proposition.

## HOW WE GROW OUR CITIES HAS A BIG IMPACT ON BIODIVERSITY AND ECOSYSTEMS

Traditionally, people have settled in places that are nice to live in, and these places not surprisingly also represent good habitat for many other species; hence, human settlements occur in many highly biodiverse areas (Cincotta *et al.*, 2000; Luck, 2007). How we choose to grow our cities can have a big impact on the extent to which biodiversity and ecosystems are supported.

The urban matrix is a heterogeneous landscape comprising a mosaic of land uses that differ in their capacity to support biodiversity. This heterogeneity changes how species respond to the urban matrix, depending on the quality of habitat within patches (Godefroid & Koedam, 2007). There can be considerable variability in species richness, even within a single land-use type. In Brisbane, for example, bird species richness was found to be higher in suburbs that retained much of their original vegetation compared with planted suburbs, and planted suburbs had higher bird species richness than suburbs

without vegetation. The ability of landscapes to support biodiversity depends, in large part, on the management, planning and policy regime.

Some urban planning choices can have detrimental effects on biodiversity and ecosystems. In Sydney Harbour, for example, the armouring of coastlines with artificial structures such as seawalls to minimise shoreline erosion and protect coastal infrastructure has led to a reduction in the extent of saltmarshes, mud flats and natural rocky shores, and many of the remaining natural ecosystems are isolated from each other. Artificial structures effectively fragment coastlines and lead to differences in species assemblages and diversity in separated habitat fragments (Goodsell, 2009). Additionally, urban drainage systems are often highly modified, with small streams commonly removed or diverted by development and modifications made to rivers, canals, wetlands and other water bodies (Grimm *et al.*, 2008b). Changes in the engineering of urban hydrology can have large impacts on populations and species richness at a local to regional scales.

Planning decisions can also decrease fragmentation and ensure larger patches. Strips of continuous vegetation between habitat patches, for example, can facilitate the movement of some species (Tewksbury *et al.*, 2002; Angold *et al.*, 2006). Retained small stands of remnant vegetation, and even single trees between remnant fragments, can act as ‘habitat stepping stones’, enabling species to traverse through the urban matrix. Large, mature native trees have been shown to have higher value for biodiversity conservation than smaller, younger trees. In Brisbane, for example, the number of remnant trees on vegetated streets was positively correlated with bird species richness and abundance in new high-density suburban housing developments (Barth *et al.*, 2015).

Deciding what should be prioritised in planning (e.g. compact urban design or suburban development, or concentrated pocket parks versus forested areas for nature play) is essential for designing future urban ecosystems. The full range of available green infrastructure, such as green roofs, green walls, urban agriculture, and other more commonly considered green spaces such as parks, should be used in developing corridors and patch frameworks that enable species to persist in the urban matrix and ecosystems to continue functioning.

## EFFECTIVE URBAN POLICY EMBRACES THE VALUE THAT URBAN ECOLOGY CAN BRING

The incorporation of urban ecology into laws and policies presents a number of opportunities. Biodiversity conservation is often framed in the context of ‘protect, conserve or preserve’. The *Threatened Species Conservation Act 1995* (NSW) confers additional importance on species and communities deemed threatened or endangered over other remnant bushland sites. Despite this long-standing legal approach to protecting endangered habitats, there is strong evidence, both in Australia and internationally, to suggest that the ecology of urban environments continues to decline. It is necessary, therefore, to shift the current debate from environmental protection towards an environmental management approach (Taylor, 2005).

Generally, there is no deliberate alignment of Commonwealth and NSW laws on urban ecology, with each jurisdiction managing its own list of threatened species and populations. In 2015, the NSW Government identified 30 key reform areas, including 12 ‘Premier priorities’, as part of its NSW: Making it Happen policy announcement (NSW Government, 2016). None of these key reform areas includes consideration of urban ecological values. The present State Plan lacks specificity on biodiversity and the protection of natural environmental assets. Therefore, no apex policy with consideration of the environment is informing state government decision-making.

There are many examples of policies, projects and initiatives that could contribute to or promote urban ecology, such as the following:

- The *Biodiversity Conservation Act 2015* (repealing the *Threatened Species Conservation Act 1995*) (NSW Government, 1995) is concerned with the conservation of threatened species, populations and ecological communities of animals and plants. The Act sets out a number of specific objects related to the conservation of biodiversity and the promotion of ecologically sustainable development. Analysis of available threatened species records shows a high number of threatened species in urban areas across NSW, particularly in and around Sydney, which is also where development pressure is greatest.
- In 2013, the NSW Government launched the Saving Our Species program as a means for prioritising expenditure linked to the protection of species and populations listed in the *Threatened Species Conservation Act 1995* (NSW Government, 1995). The objective of the Saving Our Species program is to ‘maximise the number of threatened species that are secure in the wild in NSW for 100 years, recognising that species can only survive if managed for the long term’.
- The *Native Vegetation Act 2003* is important for promoting urban ecological outcomes. Many of Australia’s endemic species rely on remnant native vegetation, and the Act ensures the protection of these patches. The preservation of larger ecosystems, especially near urban areas, is essential for maintaining healthy, viable populations of certain native species.

NSW is well placed to preserve remnant patches of vegetation. National Vegetation Information System data show that significant areas of remnant vegetation remain in the coastal area of the Sydney Basin, including Wollongong and Newcastle. Vegetation maps illustrate the importance of connecting patches of remnant vegetation to sustain species requiring larger territories (e.g. by creating wildlife corridors). In part, this is acknowledged in Sydney’s Green Grid, as advocated by the Greater Sydney Commission in district plans.

For NSW, major challenges in achieving urban ecological outcomes include:

- The lack of a strong vertical policy framework between federal and state governments.
- The lack of a strong vertical and horizontal policy framework within the NSW Government.
- The absence of regulatory and non-regulatory measures to support the implementation of urban ecology enhancement.
- The ongoing, excessive clearing of vegetation due to inadequate protection via a regulatory framework.
- Incomplete development design and construction rating tools that promote urban greening.
- Poor green asset<sup>1</sup> management and maintenance practices.
- Pressure on land in urbanised areas, particularly in greenfield developments.
- Mechanisms that weigh economic outcomes above other values in the development assessment process for infrastructure delivery.
- The lack of an adequate knowledge base on the multiple benefits of green spaces in urban environments.

## MISMATCHES IN PLANNING/POLICY AND ECOSYSTEM PROCESSES CAN BE AN IMPEDIMENT

Urban planning needs to consider complex ecological and social processes operating in different periods and at different scales within a region in order to protect and encourage the establishment of urban ecosystems (Faehnle *et al.*, 2015). The large spatial extent of urbanisation and its impacts on the

<sup>1</sup> Green assets are vegetated infrastructure or green spaces that are owned by public or private entities and have social, environmental or economic value.

connectedness of ecosystems in landscapes means that, for many conservation actions, landscape-scale approaches are necessary. Often, planning decisions and assessments of development impacts on biodiversity are made at a small spatial scale or are based on only a few species. This can lead to the accumulation of impacts at larger scales, leading to the degradation of ecosystems through the incremental loss of habitat, reductions in habitat quality, and the introduction of multiple stressors.

At the scales of district planning (e.g. as undertaken by the Greater Sydney Commission and the Department of Planning) and local planning (e.g. as undertaken by local governments), the protection of existing habitats and the creation or re-establishment of green corridors can link and connect habitats. Strategic planning at the neighbourhood or suburb scale must connect with planning at the bioregional scale to incorporate vegetation corridors that connect habitats. The Rouse Hill Town Centre Master Plan, prepared by Oculus for the Lend Lease/GPT Group, is an example of urban planning that integrates green infrastructure and water-sensitive urban design throughout the urban fabric. The Master Plan for the 120-ha site preserves and enhances Caddies Creek (which runs through the centre of the site), establishes a network of street-tree corridors, and creates 'patches' of green and open spaces for ecological and social outcomes.

Although disturbance is a natural and regularly occurring dynamic of ecological systems, the frequency and intensity of some disturbances (for example, those caused by high-velocity water flows into streams or by human or vehicle movements through habitat corridors), and their spatial and temporal extent, are high in urban environments. Often, the time required for an ecosystem to return to a pre-disturbance state is much greater than the duration of the disturbance. For example, abrupt habitat removal will have an immediate impact on a population or species, but recovery, if achieved, will likely be measured over decades or even centuries.

Given this, poor planning and policy decisions, as well as the actions of individuals and institutions, can result in 'legacy impacts' on biodiversity. In general, the greater the impact, the longer it will take an ecosystem to recover. Ultimately, this can create a time lag between the implementation of an urban ecology renewal intervention and the recovery of the ecosystem. For example, it might take many decades for trees planted to replace removed large trees that once provided nesting hollows or canopy connectivity for birds and arboreal mammals to grow large enough to provide similar habitat (Le Roux *et al.*, 2014). Lag time, therefore, is an important factor to consider in developing metrics and targets for urban ecological transformation. Crucially, the evaluation of intervention impacts will often exceed political and organisational planning cycles.

Spatial and temporal dimensions (particularly the effects of cumulative disturbance) have not been adequately integrated into assessments of the impacts of urban development on ecosystems (e.g. Folke *et al.*, 2005; Borgström *et al.*, 2006; Andersson *et al.*, 2014). Spatial information technologies, such as biodiversity overlays, may provide valuable tools for urban planning (e.g. Scott *et al.*, 2002), as well as for communicating the importance of, and potential for, maintaining viable wildlife populations in urban environments.

## **Developing a blueprint to plan and protect our urban ecology**

This report provides the evidence base for the next phase of the Urban Ecology Renewal Investigation: the development of a 'blueprint' for the NSW Environmental Trust. The blueprint recommends a suite of practical recommendations for strategic investments in the design of an urban ecology renewal program.

The collaborative approach established in this initial phase of the project, which brought together ecologists, planners, sustainability experts and landscape architects, also informed the development of the blueprint, which:

- Articulates and defines how urban ecology can be embedded in a whole-of-government-and-industry approach to urban planning, renewal and development.
- Identifies specific and strategic opportunities for Environmental Trust investment and a prioritised set of actions and recommendations for multiple stakeholders.
- Identifies how to achieve the greatest gains for urban ecosystems and biodiversity.
- Directs and influences a broad policy and legislative framework that encourages ongoing investment and action in enhancing and protecting urban ecosystems.
- Articulates the modifications and improvements required to maximise urban ecological outcomes and change business-as-usual approaches.

# 1 INTRODUCTION

## 1.1 Context and rationale

Over half the world's population (54%) lives in urban areas, and this urbanisation trend is set to continue, with a further 2.5 billion people projected to reside in towns and cities by 2050 (UN, 2014). To accommodate this population growth, urban land cover is expected to triple by 2030, with nearly 60% of this additional land yet to be allocated (Fragkias *et al.*, 2013). Ecologists (Rees, 1997) and urban planners (Moudon, 1997) acknowledge that cities have become the 'primary habitat' of humans. The American landscape architect, Richard Forman, even suggested that the species has become *Homo sapiens urbanus* (Forman, 2014). Not surprisingly, the twenty-first century has been labelled the 'century of the city' (Peirce *et al.*, 2008).

Based on the extent to which the world has been transformed by human action, Steffen *et al.* (2007) argued that the Earth has now entered a new geological epoch, the Anthropocene, in which humans have become the dominant driver of change to the Earth system. Building on this research, Rockström *et al.* (2009) identified nine 'planetary boundaries' that they consider define the safe operating space for humanity with respect to the functioning of the Earth system. They estimated that three of these planetary boundaries – climate change, rate of biodiversity loss, and changes to the global nitrogen cycle – have already been crossed, raising concerns about the potential for catastrophic impacts on human wellbeing. In this study, we address the loss of biodiversity in cities and impacts on urban ecosystem services.

It has been well understood for more than a decade that human actions have had a profound impact on biodiversity (Vitousek *et al.*, 1997). The Millennium Ecosystem Assessment (MEA, 2005) provided the first major global assessment of the condition and trends in the world's ecosystems and the services they provide, although it failed to address the urban context. Given current trajectories of global urbanisation, biodiversity and urban ecosystem services are expected to continue to decline (Eigenbrod *et al.*, 2011). This was confirmed by the Cities and Biodiversity Outlook (Elmqvist *et al.*, 2013), an initiative linked to the Convention on Biological Diversity, which provided a global assessment of the links between urbanisation, biodiversity and ecosystem services.

There are many drivers of biodiversity loss in cities, including climate change, habitat removal, increased disturbance, invasive species, and the pollution of land, air and waterways (**Figure 1.1**). These impacts are the outcome of a combination of past and present laws and priorities of government, the practices of industry, and the ways in which urban residents collectively interact with and value the natural environment. An urban transformation is required to arrest this trend of biodiversity loss, involving the following: a substantial shift in focus towards liveability, sustainability and resilience; an industry that is more sensitive to the impacts of urban development; governments that drive priorities and coordinates and ensure the implementation of their laws, policies and plans; and communities that understand and place greater value on nature. To this end, urban ecology is an increasingly significant field of research for understanding how urban processes are affecting the natural environment, and vice versa.

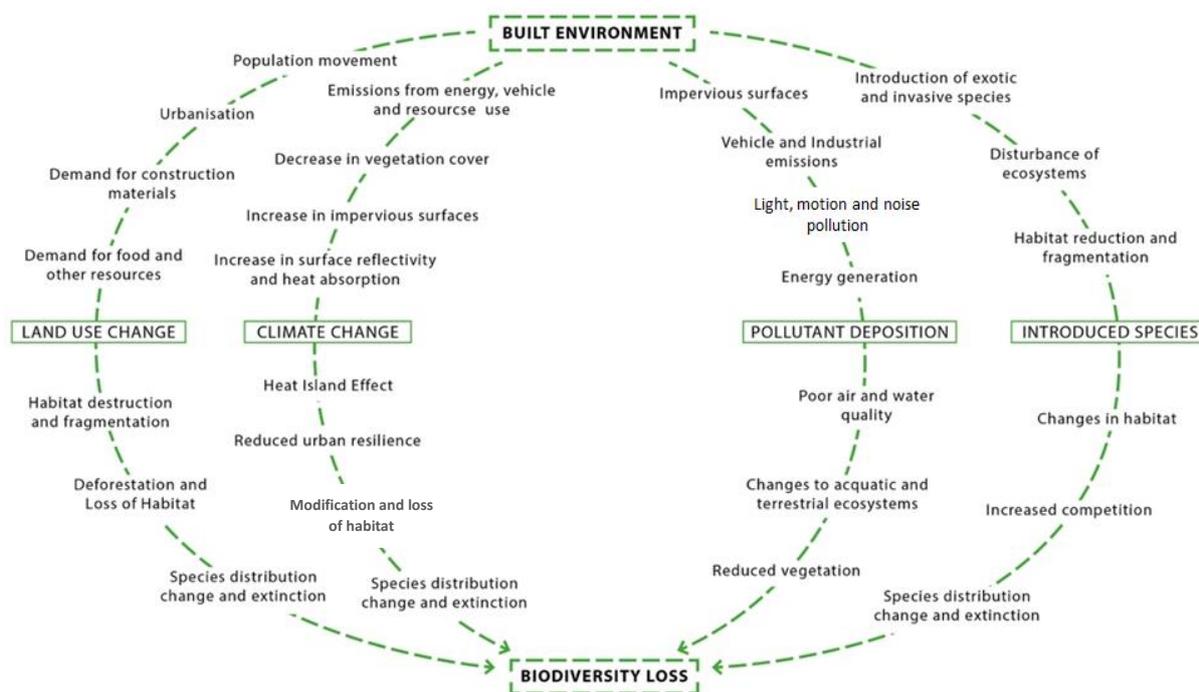


Figure 1.1. Built environment drivers of biodiversity loss. Source: modified from Zari (2014).

## 1.2 What is urban ecology?

Urban ecology is the study of all living organisms (people, plants and animals) located in urban environments (Parris, 2016). Its definition and context for this report are presented in detail in Chapter 2, but in general it is concerned with the distribution, abundance and behaviour of organisms and their interactions with the environment. Urban ecology is focused on biodiversity and ecosystem services, with an emphasis on how these vary across space and time, considering the influence of environmental impacts and urbanisation processes (Wu, 2014). Urban ecology enables an understanding of the cumulative impacts caused by changes to land with the corollary of projecting the requirements to retain and restore ecological values in cities – whether in the most dense or most sprawled urban centres, greenfield developments, or urban transformation projects.

### The theory of urban ecology

Theory provides a lens through which to understand urban ecology. For decades, practitioners and academics have sought to understand the relationship between ecology and the built environment. Several classic works form the theoretical basis of the field of urban ecology in relation to the built environment. The first of these was Ian McHarg in his 1969 book *Design with Nature*. Works by Spirn (1984), Forman and Godron (1986), and Hough (1989) built on this foundation.

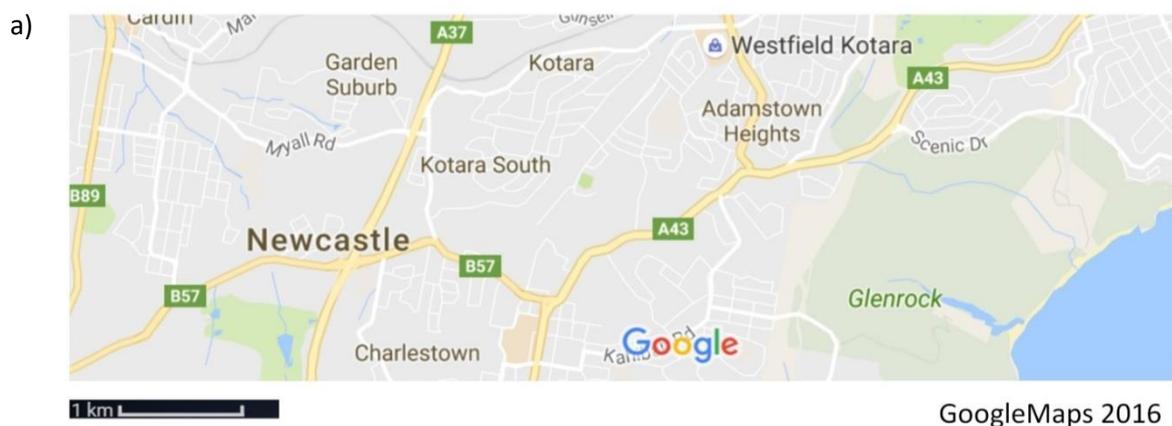
Recent literature on urban ecology discusses the concepts of ecology ‘in’, ‘of’ and ‘for’ cities, which proved useful in this report for unpacking contemporary urban ecology (Pickett, 2012; Wu *et al.*, 2013; Wu, 2014; McPhearson *et al.*, 2016). Ecology *in* cities is considered to form the early foundations of the field of urban ecology. It applies ecological approaches from natural and rural ecosystems to inform the investigation of ‘green patches’ in urban areas (McPhearson *et al.*, 2016). Ecology *in* cities focuses primarily on non-human organisms in the urban environment (Wu, 2014) and has a similar scope and methodology to studies of ecological systems in non-urban areas (Cadenasso *et al.*, 2006). It includes

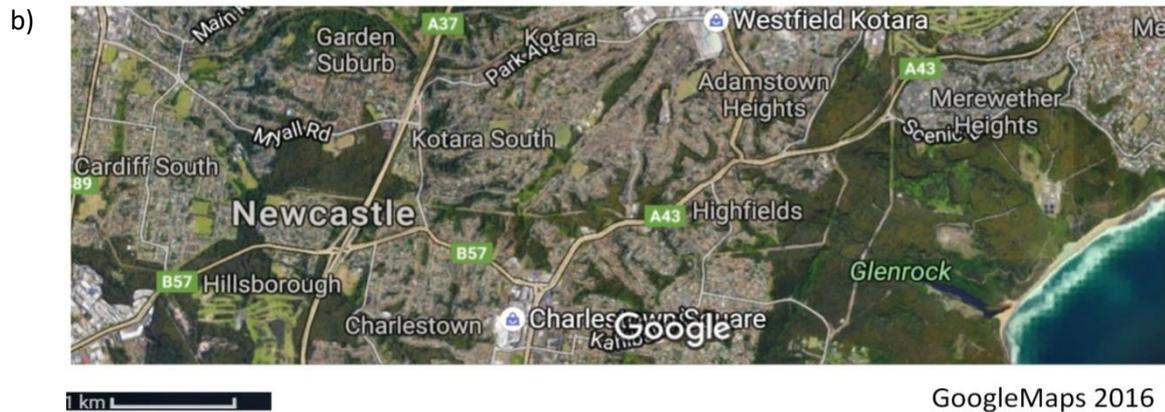
key ecological questions, such as how urbanisation affects the ecology of organisms in urban habitats (McDonnell 2011).

Ecology *of* cities incorporates ecology *in* cities, but it is a broader concept that conceptualises the city itself as an ecosystem (Wu, 2014; McPhearson *et al.*, 2016). Although the term ecology *of* cities has emerged in the last 15 years, the concept dates to the 1960s and the idea of urban metabolism (Wolman, 1965). Ecology *of* cities addresses the full range of habitats in metropolitan systems, not just green spaces, which are the focus of ecology *in* cities (Cadenasso *et al.*, 2006). Ecology *of* cities models urban ecosystems differently from traditional methods, acknowledges the role of humans, and considers time and scale. Ecology *of* cities is a systems science that integrates approaches from many disciplines to view cities as complex and dynamic systems, including social and technological considerations (McPhearson *et al.*, 2016).

A third conceptual framework has developed recently. Ecology *for* cities expands the interdisciplinary nature of ecology *of* cities to create a more holistic science of cities, pushing the boundaries of the field (McPhearson *et al.*, 2016). Ecology *for* cities argues that a synthesis of approaches from a wide range of disciplines is necessary to advance the field of urban ecology and provide a basis for human interventions. Ecology *for* cities underpins the application of urban ecology to urban policy, planning, design and management.

The urban matrix is the milieu of ecology *for* cities. Although it is tempting (and sometimes useful) to view urban landscapes as simple binary divisions between 'green' and 'grey', where 'green' is natural habitat for biodiversity and 'grey' (the built environment) is non-habitat, this is clearly an oversimplification. An urban landscape is a gradient of urbanisation, spanning areas of 'dark grey' through to 'deep green', arranged in complex and fragmented patterns created by myriad local urban development decisions (**Figure 1.2**). Different species respond differently to the urbanisation gradient (McDonnell & Hahs, 2008), with some tolerant of highly urbanised areas and others able to persist only in those areas least affected by urban development. Given that natural habitat is often fragmented and urban development is relatively consolidated, the connectivity of green spaces becomes an important way in which cities can minimise biodiversity loss. In essence, the grey landscape must become increasingly green.





**Figure 1.2.** The urban matrix of Kotara, Newcastle. The area is not a simple binary of habitable green and blue areas surrounded by a matrix of inhospitable grey, yellow and orange developed areas (a). Rather, the surrounding matrix provides habitats of varying degrees of suitability for different species, as demonstrated by satellite images (b). Images from Google Maps, 2016.

### Urban ecology in practice

Improving our understanding of urban ecology and incorporating this information in urban planning, policy and management decisions will benefit all species in urban areas (Parris, 2016), including humans. There is considerable interest in Australia and internationally in the ‘greening’ of cities as a way of promoting urban biodiversity and ecosystem services. Importantly, a considerable proportion of greening initiatives focus on amenity, landscapes and aesthetics rather than ecological function. Nature in cities can provide urban residents with many ecosystem services, such as local climate regulation, pollination, pest control, pollutant reduction, and improved health and wellbeing (Tzoulas *et al.*, 2007; Taylor & Hochuli, 2015). For example, vegetation in parks and gardens can remove thousands of tonnes of particulate matter from the air, reduce stormwater runoff, and cool cities by 1–2 °C (Demuzere *et al.*, 2014). Views of vegetation have been shown to improve workplace productivity (Lee *et al.*, 2015), and areas with high plant and animal diversity can have positive impacts on psychological wellbeing (Luck *et al.*, 2011). Urban areas are important for biodiversity conservation, often containing significant populations of native plants and animals, including some considered rare or threatened (Ives *et al.*, 2016). Devising ways to protect and enhance biodiversity in cities through urban ecology will provide benefits for society.

Increased attention is being paid to urban ecology research in Australia, with the Australian Government investing AUD 8.88 million over five years to establish the Clean Air and Urban Landscapes Hub in the National Environmental Science Programme. Research in the Hub focuses on air quality, urban ecology, urban planning, urban design, public health and green infrastructure (CAUL, 2015). This research will support other Australian Government initiatives, such as the 20 Million Trees Programme, the aim of which is to work with the community to plant 20 million trees by 2020, creating green corridors and urban forests. The 2020 Vision also aims to encourage and engage industry by delivering a variety of hubs, such as the Water Sensitive Urban Design Online Learning Centre, and support tools, such as the Which-Plant-Where Database, which will look specifically at the biodiversity functions of plants.

Australian states and territories have also been active. The NSW Government has developed technical guidelines for urban green cover (OEH, 2015), which provide best-practice advice on greening urban areas to minimise the impacts of increasing urban temperatures. Similar initiatives are underway in Victoria, funded through the Victorian Centre for Climate Change Adaptation Research, demonstrating

the benefit of green cover in urban areas, also with a particular focus on mitigating the urban heat island (UHI) effect (Norton *et al.*, 2013).

There are many examples across Australia of local governments implementing strategies aimed at increasing the uptake of green infrastructure and incorporating urban ecology into planning and management, such as through urban forest, open space and biodiversity strategies. Capital city councils across Australia, including the City of Sydney and the City of Melbourne, have developed such policy initiatives, and there are also some leading suburban councils. Nevertheless, these initiatives are ad hoc, limiting their scope and impact, and some have been implemented poorly.

In addition to top-down policy approaches, some local governments have implemented programs to engage residents in urban ecology, which is especially important because many urban council areas encompass large areas of privately owned land. Community-led initiatives include backyard biodiversity programs (e.g. the City of Boroondara and the Knox City Council in Victoria) and citizen science projects, such as the Citizen Forester Program and the Urban Bioblitz in the City of Melbourne.

### 1.3 Project background

The Urban Ecology Renewal Investigation (UERI) project was commissioned by the NSW Environmental Trust to develop the evidence base and business case for embedding urban ecology into decision-making frameworks in the major cities of NSW. The NSW Environmental Trust defined ‘major cities’ as those with a population of more than 100,000 people<sup>2</sup>, which, in NSW, encompasses Sydney, Wollongong and Newcastle. The UERI project is founded on the premise that increased urbanisation is changing the shape and composition of NSW cities, putting considerable pressure on biodiversity, water resources, and human health and wellbeing. Given the current trajectory of urban intensification and the expansion of major cities in NSW, further losses in the number and diversity of species and habitats can be expected in the absence of effective action.

The objective of this report is to improve knowledge and understanding of the gaps and opportunities that exist to improve urban ecological outcomes in the Greater Sydney Region, providing a sound case and generating a set of recommendations supported by evidence for embedding urban ecology principles and knowledge into decision-making and practice. Urban ecology can be considered at the scale of a land parcel or ‘lot’, through to the metropolitan and regional planning scales (**Figure 1.3**), and it recognises the contributions of natural areas, ranging from large designated national parks to small areas of landscaping in backyards and streetscapes. Urban ecology should also consider a range of temporal scales, from the immediate (e.g. the immediate shelter, food and habitat needs of short-lived insects) through to the many decades that it might take to establish complex and resilient ecosystems at the landscape scale.

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<sup>2</sup> Most of the findings of this report are applicable to urban centres of any size and can be used as a means to minimise and pre-empt the impacts of urbanisation.

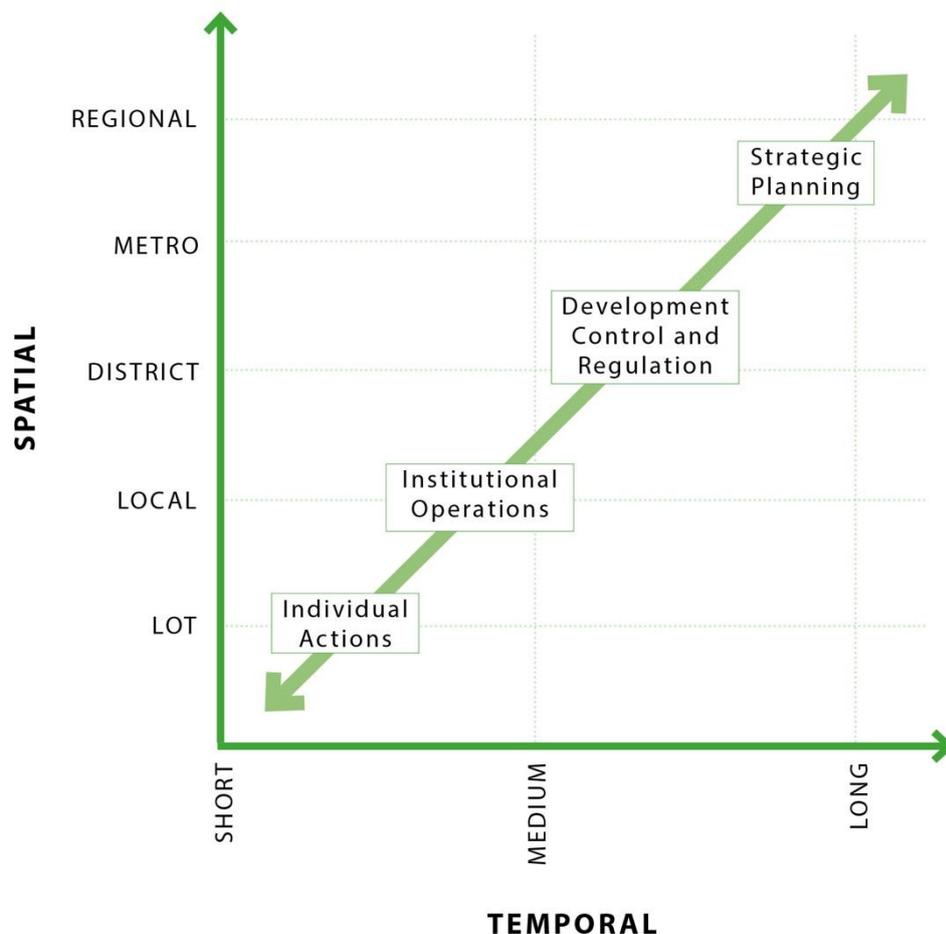


Figure 1.3. Temporal and spatial scale interactions. Source: After Borgström *et al.* (2006).

Sydney is Australia’s most populated city. Census data indicate that, in 2011, Sydney was home to 4.3 million people. By 2031, the population is expected to have grown by 1.6 million, with 900,000 of these new residents living in western Sydney. *A Plan for Growing Sydney* (NSW Government-DPE, 2014) provides an outline of where and how the city will expand and increase in density in the coming 20 years. The Greater Sydney Commission (GSC) will prepare district-level plans to inform the preparation of local plans developed by councils. Similar, vertically aligned strategies exist for the Illawarra-Shoalhaven region, incorporating Wollongong (NSW Government-DPE, 2015c), and the Hunter region, including Newcastle (NSW Government-DPE 2015b). These plans will be integrated with major infrastructure planning proposed by the NSW Government in 2014 and revised in 2015, with funding prioritised for public transport, roads, freight, water, education, sport and culture, and energy projects (NSW Government, 2015).

Under these plans, it is envisaged that new housing in Sydney will be delivered through a combination of infill of existing urban areas (urban renewal) and new master-planned communities (greenfield development). Ongoing urban growth will change the look and structure of the city; without a new approach to planning and development that incorporates the benefits of urban ecology, there will be considerable detrimental impacts on biodiversity and urban ecosystem services. Urban planning and design professionals tasked with identifying where and how to accommodate future urban growth will require new, innovative solutions to maintain the social, economic and environmental benefits of ecosystem services.

Strategic planning needs to move from a short-term approach, such as that generated by political cycles, to one that considers the longer-term requirements of natural systems (such as the time required for environmental regeneration or for trees to reach maturity). Cross-scale interactions are also important: local decisions should be framed within the broader context of district- and regional-level planning and priorities. Institutional and governance systems need greater coordination, and they should be aligned with a set of agreed central priorities that recognise the fundamental importance of the natural environment for the effective functioning of our cities.

Urban ecosystem services are directly affected by land-use policy and planning decisions (Colding, 2011), yet knowledge of these effects is patchy and insufficient (Gómez-Baggethus & Barton, 2013). Solutions may be characterised as either incremental changes to the current infrastructural, institution or social systems, or as ‘transformational’ in the development of new systems or ways of doing business (Geels, 2002). Past efforts to reform planning systems and policy frameworks for environmental protection in NSW (Ives *et al.*, 2013) suggest a greater acceptance of incremental change (Ruming & Davies, 2014), and even this is not guaranteed (MacDonald, 2015). Transition theory suggests that new approaches typically experience difficulty in breaking through existing regulatory processes, industry and community practices, and maintenance regimes. The emergence of new approaches relies on integration or co-evolution at multiple levels. At the micro level, innovation and experimentation is needed, such as by trialling green walls and pocket parks. At the meso level, a patchwork of sociotechnical regimes must exist to support policy development and reform.

Cities are sources of creativity and innovation and engines of economic growth, and their population concentrations afford a range of opportunities and economies of scale. Cities are major drivers of global change, and they are increasingly seen as a key part of solutions to global problems. On climate change, for example, cities have proved far more nimble and ready to take action than nation states, which may rely more on international agreements (Rosenzweig *et al.*, 2010). For the same reasons, cities have the opportunity to assume leadership roles in arresting biodiversity decline.

## **1.4 Project methodology**

The UERI project team is composed of academic and scientific institutions under the umbrella of the National Green Infrastructure Network. The team comprises members from Macquarie University, the University of New South Wales, the University of Sydney, the University of Technology Sydney, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Given the broad scope of the project, the NSW Environmental Trust established an advisory group to help steer the project and ensure its relevance to government and industry. The UERI project team has expertise in three thematic areas for focused investigation: urban biodiversity; built environment; and urban planning and policy.

The project is being delivered in four stages: 1) planning; 2) consultation and research; 3) blueprint development; and 4) final deliverables. The project involves cross-sectoral collaboration and is validated by peer and stakeholder review. The consultation and research stage has involved a review of the science, current practice, cutting-edge developments, industry investment and stakeholder perceptions. The aim of the consultation and research stage is to provide the evidence base for embedding the concepts and principles of urban ecology into the process of urban renewal and development in the major cities of NSW. The review summarises peer-reviewed literature and government and industry reports on the status of urban ecology in cities and how it can be integrated into urban renewal and development. The review supports those who want to ‘dig deeper’ into the theory, justification and drivers of urban ecology and the use and management of natural systems in urban environments. It will

also assist the understanding of those people involved in developing policy controls and guidelines (government) and those preparing detailed specifications (industry).

This report presents the outcomes of our review. It is designed to be read in conjunction with information gathered through a consultation process involving government, industry and other stakeholders. Together, the review and the consultation process inform the development of a blueprint of what a healthy and ecologically viable metropolitan landscape could look like in 50 years and how it can be achieved. The blueprint presents a set of guiding principles and enabling recommendations to inform urban planning and development. The blueprint will be of value to the NSW Environmental Trust as part of its delivery of statutory objectives and to other organisations, industry and the community.

We recognise that urban ecology is only one aspect of the sustainability of cities, and it is a relatively new scientific discipline (Collins *et al.*, 2000). Interdisciplinary approaches are needed to fully understand cities and to plan effectively for their sustainable future. Our approach shines a light on many 'locked-in' path dependencies that exist in the planning system, operational and infrastructure systems, and other institutional and social norms, belief systems and vested interests (Rip & Kemp, 1998; Geels, 2010). We identify the need to challenge the *status quo* and to adopt innovation as a means for transforming our cities. Such a transformation is required to challenge and circumvent the present piecemeal approach that is failing our biodiversity and to develop a more integrated system-wide approach (May *et al.*, 2010).

## **1.5 Structure of the report**

Responding to the challenges outlined above, this report focuses on three areas: the state of knowledge on urban biodiversity; the existing legal and policy structures in NSW that affect how cities integrate ecosystem services in strategic planning and development assessment processes; and the ways in which urban ecosystems and the built environment can be integrated.

The report has seven chapters. Chapter 2 summarises the key terms used in this report. Chapter 3 describes the core ecological concepts and the various changes that have occurred to biodiversity as a result of urbanisation. Chapter 4 outlines the existing legal and policy frameworks in NSW related to urban biodiversity and urban ecosystems and highlights approaches adopted in other Australian states and internationally on urban biodiversity management. Chapter 5 explores the relationship between urban ecology and the built environment. Chapter 6 presents case studies of urban ecology projects and discusses these from the perspectives of biodiversity, the built environment and policies and laws. Chapter 7 enumerates key principles for advancing urban ecology in the major cities of NSW, drawing on the evidence presented in the report. The literature reviewed in chapters 3–5 forms the bulk of the report. A more detailed summary of these key chapters is provided below.

### **Chapter 3 – Urban biodiversity and ecology**

This chapter defines the key concepts of urban ecology, as established in the literature, and describes the major values of urban biodiversity and ecosystems, including the ecosystem services (and disservices) they provide. Topics such as the significance of the built environment as habitat and the role of connectivity in improving the resilience of urban ecosystems are reviewed, along with crucial knowledge gaps and opportunities for improving urban ecosystems.

### **Chapter 4 – Planning and policy**

This chapter identifies the interactions between policies, urban ecosystems and the built environment. Literature on how planning systems benefit and constrain ecological values is examined in detail,

knowledge gaps are identified, and opportunities for intervention to support the renewal of urban ecosystems are explored.

## **Chapter 5 – Built environment and landscape design**

This chapter reviews literature addressing the values that make for healthy, liveable cities and the social and economic considerations that affect policies, urban biodiversity and the built environment. The chapter reviews topics specific to the built environment, such as the UHI effect, and emerging technologies and best practices in urban design. Crucial knowledge gaps are identified, as well as opportunities to leverage developments in the built environment and landscape design for the renewal of urban ecosystems.

## 2 KEY CONCEPTS AND DEFINITIONS

### 2.1 Key concepts

Many of the terms used in this report have multiple meanings, with definitions varying depending on the profession, discipline and background of the authors. The following terms are defined as per their usage in this report.

#### Urban

Natural science assigns a broad range of meanings to 'urban', generally focusing on the presence of human constructions (Mcintyre *et al.*, 2000). Social science defines 'urban' in various ways, including on the basis of population density, points of interest, structural divisions and cultural features (Mcintyre *et al.*, 2000). Given that the social sciences emerged from the study of human systems, definitions and methods from this field can help ecologists integrate social variables into their research.

Urban areas are anthropogenic landscapes that cover a range of land-use types, including residential, industrial, recreational, natural and business areas centred around cities and towns. Collectively, this mosaic of land-use types creates an urban matrix. Natural areas (e.g. remnant patches, water bodies) found within the boundary of urban areas are considered part of the urban landscape and are integral to defining the urban matrix. Aquatic environments adjacent to or within the boundary of an urban matrix are also considered part of the urban area. Ecosystems differ in their level of urbanisation, from peri-urban, to suburban, to urban. This urbanisation continuum is often defined as the urban–rural gradient.

The definition of urban depends on many variables. Gómez-Baggethun and Barton (2013, p. 236) noted that 'definitions of urban areas and their boundaries vary between countries and regions depending on land use type, total population, population density, distance between dwellings, and percentage employment outside the primary sector'. Different definitions focus on different aspects of urban systems. According to Wu (2014), the two key factors are high human population density and an extensive impervious surface area.

Given all these variables, the United Nations does not subscribe to a single definition of urban; rather, it adopts national definitions. The European Union (EU) and the Organisation for Economic Co-operation and Development (OECD) attempted to classify different types of urban area, identifying three urban categories – densely populated areas (cities), intermediate-density areas (towns and suburbs), and thinly populated areas (rural areas) – using a population grid methodology (Dijkstra & Poelman, 2014).

Building on the more established social science literature, McIntyre *et al.* (2000) noted that no definition of urban was necessarily more correct than any other; what was important was that demographic, economic, political, perceptive, cultural, geophysical and biological criteria were integrated to provide a complete and useful definition. **For the purposes of this review, 'urban' is defined as 'where the built infrastructure covers a large proportion of the land surface, or those in which people live at high densities'** (Pickett *et al.*, 2001, p. 129).

#### Ecology

Ecology is the scientific study of the interactions between organisms and their environment and how those interactions influence distribution and abundance (Krebs, 1972). Ultimately, therefore, ecology is concerned with pattern (the arrangement of organisms in space and time) and process (the transformation and movement of energy and matter due to organismal interactions). Ecology is an interdisciplinary science that integrates biology with earth and social sciences. Traditionally, ecologists

have focused their research on 'natural' systems (McDonnell, 1997). Therefore, the foundations of our understanding of ecosystems come primarily from areas with low human activity.

### Urban ecology

For most of the twentieth century, ecologists did not engage with the urban context (Grimm *et al.*, 2008a). This changed, however, as scientists, planners, engineers and landscape architects began to collaborate, although the field of urban ecology is still relatively young (Cadenasso *et al.*, 2006).

Urban ecology 'integrates the theory and methods of both natural and social sciences to study the patterns and processes of urban ecosystems' (Grimm *et al.*, 2008a, p. 756). Urban ecosystems integrate natural, built and socioeconomic systems. They represent both physical and conceptual spaces in which dynamic interactions between these three systems occur. Urban ecosystems are places where people live in high densities, or where built infrastructure covers much of the land (Pickett *et al.*, 2001). A comprehensive understanding of urban ecosystems must include an understanding of how less densely populated areas also affect and influence reciprocal flows between densely and sparsely settled areas (Pickett *et al.*, 2001).

Urban ecology is a multidisciplinary field that provides many tools for advancing the potential of sustainability and resilience in cities (McPhearson *et al.*, 2016). Diverse conceptual approaches to urban ecology exist, reflecting the numerous and overlapping ways in which urban ecosystems are understood and studied (McPhearson *et al.*, 2016). Although this gives urban ecology great depth and breadth, it also makes it difficult to define.

Urban ecology has been defined differently in different disciplines (Wu, 2014). In urban design and planning literature, for example, urban ecology has focused on the design of environmental amenities for people in cities and on reducing the environmental impacts of urban regions (Pickett *et al.*, 2011). The term urban ecology has been given a number of definitions, but these have largely failed to achieve a global consensus (Pickett *et al.*, 2008; Wu, 2014; McPhearson *et al.*, 2016). Definitions include: 'the scientific study of the processes determining the abundance and distribution of organisms, of the interactions between organisms, of the interactions between organisms and the environment, and of the flows of energy and materials through ecosystems ... within urban systems' (Gaston, 2010); the 'investigation of living organisms in relation to their environment in towns and cities' (Sukopp, 2008, p. 373); and 'the relationship between the spatial pattern of urbanization and ecological processes' (Luck & Wu, 2002).

Wu (2014) described how varying concepts and perspectives of urban ecology today fall into two main categories: 'ecology *in* cities', which focuses on non-human organisms in urban environments; and 'ecology *of* cities', which considers a city or urban area as an ecosystem. Wu (2014) proposed that recent developments in urban studies warranted a third category: 'sustainability *of* cities', where cities are envisioned as socioecological systems.

Wu (2014) attempted to integrate the three perspectives into a broad definition in which 'urban ecology may be defined as the study of spatiotemporal patterns, environmental impacts, and sustainability of urbanization with emphasis on biodiversity, ecosystem processes, and ecosystem services'. This can be stated as follows: urban ecology studies the environmental state (i.e. biodiversity and ecosystem services and processes) and the impacts of urbanisation on it, considering the relative sustainability of these patterns over different temporal and spatial scales.

For this report we define urban ecology as the study of the ecology of all living organisms (people, plants and animals) in urban environments (Parris, 2016). It includes the study of the distribution, abundance and behaviour of organisms and their interactions with their environment, and it

encompasses the study of the spatiotemporal patterns, environmental impacts and sustainability of urbanisation, with an emphasis on biodiversity, ecosystem processes and ecosystem services (Wu 2014).

This report uses this integrated, holistic, definition of urban ecology to discuss the processes and practices that could be used to enhance urban ecosystems for both humans and non-humans.

### **The built environment**

Although the term 'built environment' has been used frequently in the literature since the mid-1970s (Moffatt & Kohler, 2008), there is no widely accepted definition. Broadly, it is the intersection between nature and culture, a 'complex social-ecological system where multiple-related metabolisms interact at different scales' (Moffatt & Kohler, 2008, p. 248).

For the purpose of this review, the built environment comprises 'urban design, land use, and the transportation system ... encompassing patterns of human activity within the physical environment' (Handy *et al.*, 2002, p. 65).

### **Green infrastructure**

Green infrastructure is an adaptable term used to describe an array of products, technologies and practices that use natural systems – or designed systems that mimic natural processes – to enhance environmental sustainability and human habitability (quality of life).

Originally, the term green infrastructure was associated with parklands, forests, wetlands, greenbelts and floodways in and around cities that provided improved quality of life or ecosystem services such as water filtration and flood control (Foster *et al.*, 2011). The three most common approaches to green infrastructure focus on the role of ecosystem services, green engineering and linked green spaces (Pitman & Ely, 2015). Green infrastructure is most often used as a way of integrating urban ecology into the built environment.

The term blue infrastructure describes water-based products, technologies and practices that integrate natural systems to enhance environmental sustainability and habitability (see definition below). In this document, the term green infrastructure includes both green and blue infrastructure.

## 2.2 Definitions

The key words and terms used in this report are defined below.<sup>3</sup>

**Abiotic:** Non-living components of an ecosystem.

**Assemblage:** The collection of organisms that co-occur in a particular area at a particular time. The term is often used interchangeably with ‘ecological community’ (Fauth *et al.*, 1996).

**Assemblage composition:** Both the identity and relative abundances of the organisms that occur in an area at a given time. Different taxonomic levels (e.g. species, genera, families and phyla) may be used to classify the composition of an assemblage. It is appropriate, therefore, to refer to ‘species composition’ or ‘family composition’.

**Biotic:** Living components of an ecosystem.

**Biodiversity:** ‘The variability among living organisms, including terrestrial, marine, and other aquatic ecosystems. Biodiversity includes diversity within species, between species, and between ecosystems’ (TEEB, 2010). This report’s definition of biodiversity covers more than just species diversity, incorporating the compositional, structural and functional elements of natural systems (Franklin, 1988; Noss, 1990, p. 357). That is, biodiversity consists of the identity and variety of organisms (composition), the physical arrangement (pattern) of organisms (structure), and the processes resulting from interactions between organisms (function). These three attributes can be categorised at four levels of hierarchical organisation: genetic, population/species, community/ecosystem, and regional/landscape (Franklin, 1988; Noss, 1990, pp. 358-361).

**Blue infrastructure:** This term originally referred to engineering solutions related to the management of urban rain, stormwater, drinking and wastewater, and related proprietary systems, but is now broader than that. Blue infrastructure incorporates blue spaces such as constructed wetlands, streams, lakes, ponds, artificial swales and stormwater retention ponds (Elmqvist *et al.*, 2015), as well as built infrastructure in aquatic environments (e.g. seawalls). It is sometimes referred to as blue-green infrastructure when green elements are present (e.g. water-sensitive urban design – WSUD).

**Built environment:** Comprising ‘urban design, land use, and the transportation system ... encompassing patterns of human activity within the physical environment’ (Handy *et al.*, 2002).

**Climate change:** Refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (Intergovernmental Panel on Climate Change).

**Connectivity:** Structures in a landscape that allow the flow of biotic or abiotic components. Connectivity can be at the scale of the ecosystem (e.g. nutrient, hydrological and energy flows between ecosystems), at the population/species level (e.g. movements of animals, plants and other organisms, including dispersal) and at the genetic level (e.g. the movement of alleles between individuals).

**Ecological resilience:** Refers to the capacity for an ecosystem to recover from a disturbance by returning to its original composition, structure and function.

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<sup>3</sup> Certain other terms are defined in the text.

**Ecology:** The scientific study of the interactions between organisms and their environment and the patterns of distribution and abundance resulting from these interactions.

**Eco-engineering:** The incorporation of structures, materials or design elements into traditional engineering structures for the purposes of maintaining, protecting or enhancing biodiversity or other ecological functions. These eco-engineering elements are based on ecological principles and need to be monitored and evaluated to assess their effectiveness.

**Ecosystem:** The interacting biological (biotic) community of a given physical (abiotic) environment.

**Ecosystem disservices:** Ecosystem functions that have effects that are harmful to human wellbeing (von Döhren & Haase, 2015).

**Ecosystem functions:** The numerous processes that arise as an outcome of species interactions, such as water filtration, plant biomass production and nutrient cycling. Many of these processes are of direct benefit to human societies and are thus referred to specifically as ecosystem services.

**Ecosystem services:** The benefits for humans that are derived from the functioning of natural ecosystems. The Millennium Ecosystem Assessment (2005) separates ecosystem services into four categories: provisioning services (e.g. food, water and natural resource production), regulating services (e.g. water and air filtration, and climate and flood regulation), supporting services (e.g. nutrient cycling and the provision of habitat) and cultural provision (e.g. recreational and health, spiritual, educational and aesthetic benefits). Ecosystem services are 'specific results of ecosystem functions or aspects of ecosystems utilised actively or passively, directly or indirectly, to sustain or enhance human and non-human life' (Escobedo *et al.*, 2011).

**Endemic species:** A species only found in a specific area due to specialised habitat requirements or historical barriers to dispersal.

**Fragmentation:** The process that converts a relatively large area of contiguous habitat into a number of smaller patches that are isolated from each other within a matrix that is largely unsuitable for many species.

**Green infrastructure:** An adaptable term used to describe an array of products, technologies and practices that use natural systems – or designed systems that mimic natural processes – to enhance environmental sustainability and human habitability (quality of life). In this report, 'green infrastructure' includes green and blue infrastructure.

**Green roofs:** Roofs with a vegetative surface and substrate (Washburn *et al.*, 2016). There are two types of green roofs: intensive and extensive. Intensive green roofs typically have a depth of 300mm or greater and can provide useable open space for recreation and other opportunities. Extensive green roofs have a thin growing media, typically with a depth of 150mm.

**Green space:** 'Parks, sporting fields, bushland, [riparian areas of] creeks, rivers and bays, plazas, community gardens, bikeways and paths, ... as well as attractive and safe streets and 'green' links between these various elements ... [and may include] communal space around apartment buildings [as well as] cemeteries, rock walls, street verges and medians, school grounds, rooftop parks, and stormwater channels, and [unpaved] parking lots and open air, publicly accessible shopping malls' (Roy *et al.*, 2012).

**Green wall:** A general term encompassing a variety of vertical greening techniques (Madre *et al.*, 2015).

**Grey infrastructure:** The opposite of green infrastructure. In urban landscapes, it is all impervious or concrete infrastructure such as transport, housing and water-supply infrastructure, including roadways, car parking facilities, pavements, buildings and 'drainage and water treatment systems such as pipes, tanks, or underground storage facilities' (Keeley *et al.*, 2013).

**Grey literature:** Research or material that is either unpublished or has been published in non-commercial form, including reports, conference presentations, consultants' reports, newspaper articles and government policies.

**Human health:** Commonly defined using the World Health Organisation (WHO) definition, in which health is 'a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity' (WHO, 2006).

**Habitat quality:** The quality of a habitat is species-dependent and can be defined as both the density of individuals an area can support and the ability of the habitat to allow individuals of that species to survive and reproduce (Vanhorne, 1983). When viewed on a management scale, the overall habitat quality is the capacity of a habitat to support multiple species with viable populations.

**Indigenous/native species:** A species that occurs naturally in a region, in contrast to an introduced/exotic species that has been transported to a region, either deliberately or accidentally, by humans.

**Keystone species:** A species whose influence on the composition, structure or function of an ecosystem is greater than expected given its abundance (Power *et al.*, 1996). The removal of such a species can be expected to result in significant changes to local biodiversity.

**Landscape ecology:** The study of the spatial arrangement of habitat and disturbances (including human impacts) and how spatial patterns affect ecosystem function (Clark, 2010).

**Liveability:** A broad term encompassing all the things that contribute to quality of life and make a city enjoyable to live in (Water, 2014). It is a combination of the affordability, community, amenity, accessibility and employability of an area (McCrinkle, 2016).

**Local provenance:** Organisms of the same species selected from the same local geographic region and adapted to the same habitat. Usually used in the context of selecting plants for ecological restoration.

**Novel ecosystems:** Ecosystems that are composed of new combinations or relative proportions of species that have not previously occurred in an area. These novel ecosystems arise when the species pool changes in an area due to introductions of new species into an area (on purpose or accidentally), when environmental conditions change (e.g. the addition of nutrients or increased light), or when the response of a species to particular environmental conditions change through adaptation to those conditions. Despite their novelty, these ecosystems can still often contribute to ecosystem functioning and provide ecosystem services (Hobbs *et al.*, 2006).

**Riparian zone:** The transition between terrestrial and aquatic environments, incorporating multidimensional interactions, including terrestrial and aquatic ecosystems, groundwater and canopy vegetation (Ilhardt *et al.*, 2000).

**Species abundance:** The total number of organisms belonging to one species that occur in an area at a given time.

**Species richness:** The total number of species found in an area at a given time.

**Umbrella species:** A species whose conservation (through reserving habitat) confers protection on a large number of naturally co-occurring species (Roberge & Angelstam, 2004). Umbrella species generally have broad public appeal and require relatively large amounts of habitat to support a viable population.

**Urban:** Areas in which the built infrastructure covers a large proportion of the land surface, or areas in which people live at high densities (Pickett *et al.*, 2001).

**Urban ecology:** The investigation of the ecology of all living organisms (people, plants and animals) in urban environments (Sukopp, 2008; Parris, 2016). The scientific discipline that studies the abiotic and biotic components of ecosystems situated in urban areas (such as the distribution, abundance or behaviour of organisms and spatiotemporal patterns, environmental impacts, or sustainability of urbanisation) and the interaction between these components (Wu 2014).

**Urban ecosystem:** The abiotic and interdependent biotic components of an environment and their interactions within an urban area.

**Urban ecosystem services:** ‘Those services that are either directly produced by ecological structures within urban areas, or peri-urban regions’ (Luederitz *et al.*, 2015, p. 98).

**Urban forest:** The ‘sum of all urban trees, shrubs, lawns, and pervious soils ... located in highly altered and extremely complex ecosystems where humans are the main drivers of their types, amounts, and distribution’ (Escobedo *et al.*, 2011, p. 2078).

**Urban greening:** The practice of greening urban areas using all forms of vegetation, including street trees, open parks and gardens, green walls, green roofs and lawns.

**Urban heat island (UHI):** A condition in which human-made heat is trapped in the thermal mass of the built environment and results in urban areas being significantly hotter compared to their peri-urban and rural surroundings (Sharifi & Lehmann, 2014).

**Urban resilience:** ‘The ability of an urban system – and all its constituent socioecological and socio-technical networks across temporal and spatial scales – to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.’ (Meerow *et al.*, 2016, p. 45).

**Urban stream syndrome:** The degradation of urban waterways (Meyer *et al.*, 2005) as a result of: modified hydrologic conditions; alterations to stream channel morphology and function (most notably through piping and associated catchment imperviousness); increased water temperature and light (as riparian vegetation is cleared); increased barriers affecting the movement of aquatic and other riparian organisms; increased toxicants (derived from urban surfaces); changes to dissolved oxygen and pH, and increased ionic concentrations; or the increased availability of nutrients.

**Water-sensitive urban design (WSUD):** Typically, the ‘capturing of stormwater for local use, which then limits the deterioration of creeks, streams and receiving waters associated with the influx of sediment, oil, litter and other pollutants from roads, drains and gutters’ (Floyd *et al.*, 2014, p. 2). In the United Kingdom, WSUD is known as ‘sustainable urban drainage systems’; in the United States it is known as ‘low impact development’; and in China it is known as ‘sponge cities’. Arguably, other design approaches that enhance the health of waterways and their ecological communities can be considered as WSUD.

**Wellbeing:** The Millennium Ecosystem Assessment defines wellbeing as ‘material security, personal freedoms, good social relations and physical health’ (Tzoulas *et al.*, 2007).



### 3 URBAN BIODIVERSITY AND ECOLOGY

#### DESKTOP REVIEW OF LITERATURE

Prepared by:

UERI Biodiversity and Urban Ecology Team

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### 3.1 Key points

- Biodiversity is important to conserve in cities because it provides ecosystem services, including health and wellbeing benefits, and is crucial for the conservation of threatened species and ecological communities.
- The primary driver of biodiversity loss in cities is the loss of habitat and the subsequent decline in remaining habitat.
- Urbanisation causes changes in both abiotic conditions (e.g. microclimate, lighting, noise, hydrology, biogeochemistry, the introduction of artificial structures, and disturbance patterns) and biotic interactions (due to changes in the occurrence and abundance of organisms) that can affect biodiversity in cities.
- Understanding ecological concepts, including species area curves, island biogeography and connectivity, fragmentation and edge effects can help explain patterns of biodiversity loss in cities and support recommendations for conservation actions.
- Spatially explicit planning at the local to regional scales is necessary for the conservation of biodiversity in cities. Spatial planning should:
  - Retain remnant habitat, which is crucial for the conservation of urban-avoider species. Maintaining large, good-quality remnant habitats should be the primary conservation action for maintaining biodiversity in cities.
  - Include green corridors to enhance dispersal between remnant patches.
  - Prioritise compact development, with large green spaces retained in high-density residential areas. 'Spared' green spaces should overlap with areas of high ecological value.
- Reduce the amount of effective impervious surface cover in catchments by minimising impervious surface cover, unsealing urban soils, and decreasing the connectedness of impervious surfaces to waterways (e.g. through WSUD).
- Minimise the placement of artificial structures in marine environments in areas where they will impede the migration of native species or enhance the proliferation and spread of non-indigenous species.
- Increase the amount of habitat available for urban biodiversity by improving the suitability of the urban matrix (urban land that surround patches of remnant habitat). This can be done by:
  - Increasing the density of native trees and retaining large (>80cm diameter at breast height) mature trees (native or non-weedy exotics) throughout landscapes.
  - Using native vegetation to increase the structural complexity of ground-storey and mid-storey layers and reducing the intensity of management practices (e.g. mowing and the removal of logs, branches and leaf litter) that can reduce structural complexity.
  - Increasing the provision of habitat resources that are limited in urban areas, such as tree hollows.

- Improve stream and estuarine conditions through carefully planned and ecologically sensitive WSUD and by restoring riparian vegetation and enhancing in-stream habitat to support aquatic diversity.
- Provide good-quality water bodies, including wetlands, which can be constructed to serve both WSUD and biodiversity conservation purposes.
- Design artificial marine structures to support diverse and functional native ecological communities and retrofit existing structures with habitat-enhancing features.
- Reduce the amount of ecological light and noise pollution, and disturbances associated with human traffic, which can affect fauna by altering their behaviour and physiology.
- Incorporate principles for improving the suitability of the urban matrix into multiple types of green space, such as parks, golf courses, residential gardens, informal green spaces and vegetated aspects of the built environment.
- Evaluate the impacts on biodiversity of local and landscape-scale spatial management decisions through ongoing monitoring to determine whether decisions are effective. If not, adapt management practices and follow up with additional monitoring.

## 3.2 Purpose

Urbanisation reduces biodiversity due to habitat loss and subsequent declines in habitat quality, the modification of environmental conditions, and changes to the types of species that occur in urban areas.

This chapter has two main aims:

- 1. To describe ecological changes that occur due to urbanisation and demonstrate the impact of these changes on biodiversity, using evidence from the scientific literature.**
- 2. To recommend conservation actions and design interventions that can be undertaken to support or enhance biodiversity in cities. These recommendations are based on scientific evidence and underpinned by core ecological principles.**

Although conflicts, policies, planning and built environment considerations are mentioned where appropriate, the principal goal of this chapter is to review the ecological evidence and recommend principles, which, according to the evidence, will protect or enhance biodiversity in cities. The intersection of ecological objectives with other considerations is discussed in more detail in chapters 4 and 5 and in the stakeholder consultation document *What We Heard: documenting the stakeholder workshops*.

Peer-reviewed scientific evidence is used, where available, in this chapter, based on a global review of papers and Australian examples, particularly from Sydney and surrounding areas. An Australian perspective is taken because, although there are many similarities between cities, not all cities are the same. Climate, age, development pattern, distribution of remnant habitat, co-occurring stressors and traits of key organisms can all affect the responses of biodiversity to urbanisation. An effect that occurs in one city may not be a reliable indicator of what will happen in another. Although this review incorporates evidence from the literature spanning a wide variety of organisms, examples are biased towards terrestrial organisms and, within that group, birds. This bias reflects the urban ecology literature, with relatively few papers on marine urban ecology and almost half the number of research papers on the responses of terrestrial animals to urbanisation compared with those on birds (Beninde *et al.*, 2015).

The impacts of urbanisation extend across terrestrial, freshwater and marine ecosystems. Consequently, this report integrates terrestrial, freshwater and marine perspectives for both its main aims. Although some impacts and solutions are ecosystem-specific, many responses and subsequent conservation actions span the three types of ecosystem.

The chapter has five main sections. The first (section 3.3) introduces core ecological principles that can guide best-practice management decisions and conservation actions. Section 3.4 sets out the arguments for why conserving biodiversity in cities is important for the provision of ecosystem services, and the role cities can play in conservation. Section 3.5 describes patterns of change in landscapes as a result of urbanisation and the resultant impacts on biodiversity. Much of the literature in urban ecology describes patterns of changes in biodiversity in response to urbanisation. These patterns highlight variables that are, or might be, the cause of biodiversity changes in urban areas. Identifying factors that cause changes to urban biodiversity allows management decisions and conservation actions to design landscapes or implement measures to mitigate or minimise the impacts of these variables on biodiversity. Section 3.6 provides examples of conservation actions and design interventions that have been shown to, or, based on sound ecological principles, are likely to, improve biodiversity in urban

areas. Section 3.7 collates the recommendations made elsewhere in the chapter and highlights the need for ongoing adaptive management when implementing these recommendations in the future.

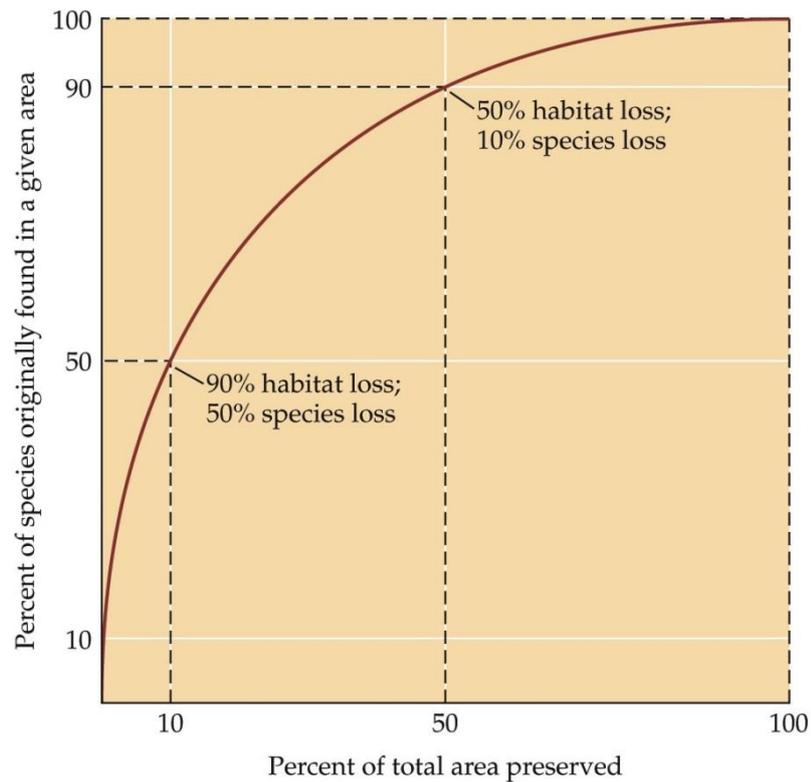
### 3.3 Ecological concepts

This section describes some fundamental ecological concepts in ecology derived through decades of sound ecological research across multiple ecosystems to provide a framework for explaining the response of biodiversity to the habitat loss, changes in connectivity and subsequent decline in habitat quality that occur due to urbanisation. These ecological concepts additionally provide support for recommendations on conservation actions to support or enhance biodiversity in urban areas.

#### Habitat area and the species–area relationship

A key principle in ecology is that larger areas of habitat support more species. As area increases, the number of species increases (Arrhenius, 1921) in what is known as the species–area relationship (SAR). The SAR is supported very strongly by evidence from around the world and from many environments and groups of organisms (Drakare *et al.*, 2006). In general, larger areas will support more habitat diversity and more individual organisms, and this means that more species will be supported. From a conservation perspective, therefore, habitat loss leads to species loss, and the way to prevent species loss is to retain (or restore) as large an area of habitat as possible.

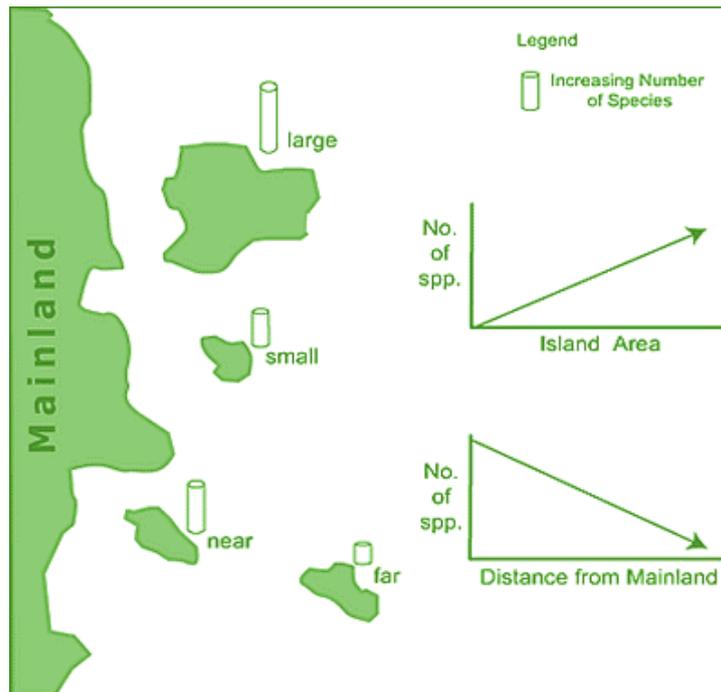
The positive SAR relationship is not linear, however (**Figure 3.1**). For example, using the most commonly observed form of the SAR, a loss of 90% of available habitat can be expected to lead to a loss of 50% of the original species (Primack, 2010). Species loss can be greater than that predicted from the SAR, however, due to factors additional to habitat loss. For example, the island of Singapore has lost more than 95% of its forest cover in the past two centuries, leading to a prediction based on the SAR of a 70% loss of native bird species when, in fact, the observed extinction rate is over 90% (Castelletta *et al.*, 2005).



**Figure 3.1.** The predicted effects of different amounts of habitat loss on the percentage of species that are retained in an area based on the species–area relationship, the curve demonstrating the typical non-linear positive relationship. The consequence of the curved relationship is that when the same amount of area is cleared from a small patch, its impact on species decline is much greater than if that amount of area was cleared from a larger patch. For urban areas, where remnant habitat is often already small in area, subsequent clearing of land can have large impacts on species loss. Source: Primack (2010).

### Island biogeography and connectivity

Much of the original research on the SAR was conducted on islands, with larger islands observed to support more species than smaller islands. Another important observation was that, given two islands of the same size, the island that was more distant (isolated) from a source of potential colonists supported fewer species than an island closer to a source of colonists (less isolated) (Lomolino, 1984) (**Figure 3.2**). These two factors in combination (area and isolation) provide a powerful means of predicting the total number of species (species richness) of an island, and they gave rise to the development of the equilibrium theory of island biogeography (MacArthur & Wilson, 1963). This theory states that the species richness of an island is an equilibrium that balances rates of local extinction (species loss) and colonisation (species gain), and that these rates are determined by island area and isolation, respectively.



**Figure 3.2.** Schematic demonstrating the island biogeography theory. The shaded areas are habitable land, surrounded by inhospitable ocean (unshaded). The number of species found on each island (represented by the height of the column) is based on both the size of the island and the distance of that island from the mainland (source population). Large islands will support more species, as will islands closer to the mainland. When applied to urban ecology, the 'mainland' is representative of large continuous habitat, while the 'islands' are representative of remnant habitat, surrounded by inhospitable 'oceans' of urban development. The degree to which the surrounding urban matrix is inhospitable varies among species and the degree of urbanisation of the matrix. Source: [www.labiotheque.org/2011/07/biodiversity-on-islands-ii-island.html](http://www.labiotheque.org/2011/07/biodiversity-on-islands-ii-island.html)

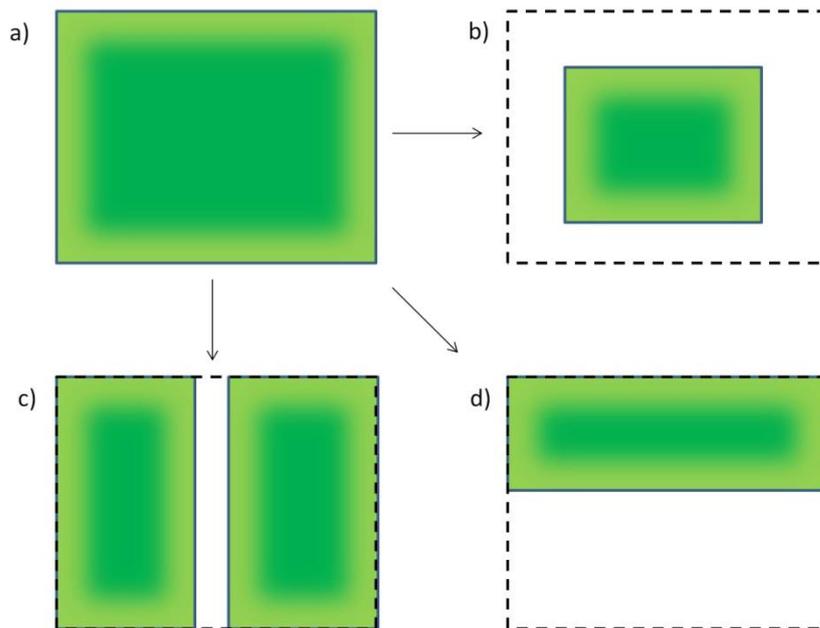
The idea of 'islands' can be interpreted quite broadly to include any type of habitat that occurs patchily across a landscape, seascape or cityscape. The intervening 'ocean', commonly referred to as the surrounding matrix, is essentially habitat that is inhospitable to a given organism but which must be traversed if the organism is to move from one habitable patch to another. In urban areas, the matrix of developed areas could be considered an ocean, if those developed areas are unable to support viable populations of organisms. What constitutes a 'patch' or 'island' varies considerably depending on the types of organisms involved and the nature of the surrounding matrix. For some insects in a highly urbanised landscape, for example, green roofs (rooftop gardens) can be viewed as islands of suitable habitat in a hostile ocean of concrete, steel and glass. In this case, island biogeography theory applies, and it can be predicted that insect diversity on green roofs will depend greatly on the area of vegetated surface and the distance (in vertical and horizontal dimensions) of that garden from other green spaces (Berthon *et al.*, 2016).

In the application of island biogeography theory to biodiversity conservation, 'connectivity' becomes the essential principle. Connectivity can be thought of as the extent to which a landscape/seascape/cityscape permits the movement of organisms and genes (Taylor *et al.*, 1993). Connectivity is determined, therefore, by the total area of suitable habitat, the proximity of habitat patches to each other, and the capacity of the intervening matrix to permit the transit of individuals or genes.

### Habitat fragmentation and edge effects

Habitat loss and degradation reduces connectivity in a process usually referred to as habitat fragmentation (Fahrig, 2003). The loss of connectivity can have profound effects on biodiversity, often exceeding that expected from the loss of habitat area alone (Castelletta *et al.*, 2005). The exchange of individuals and genes is essential for maintaining relatively large local populations, which offsets the risk of local extinction (O'Grady *et al.*, 2004). When connectivity is lost, local extinctions are often the result (Laurance, 2008).

Habitat fragmentation produces increasingly smaller and isolated patches with increasingly large edge-



**Figure 3.3.** Effects of habitat loss on edge effects. Edge effects are represented by light-green areas around the perimeter of a patch, while core habitat is represented by darker green areas in the centre of the patch. **a)** shows the patch of land before habitat loss, and **b-d)** represent three types of land-clearing scenarios typical of urban areas. The dotted line represents the original area of the patch. **Scenario b)** represents land clearing that changes the size but not the shape of the patch – the smaller patch has a higher edge-to-area ratio than the larger original patch. **Scenario c)** represents land clearing for the introduction of linear infrastructure (e.g. a railway, road, or power lines) – the area of habitat remains large in this scenario but the amount of edge area increases. **Scenario d)** represents land clearing that changes both the amount of habitat available and the shape of the patch. The resultant long narrow habitat fragment has a very high edge-to-area ratio. The effects of changes to edge-to-area ratios is dependent on the type of species. Some species are disturbance or edge specialists and are found mainly in the light-green areas, and other species are core-dependent (or interior specialists) and are found only in the dark-green areas. Land clearing reduces the area available for core-dependent species. Source: F. van den Berg.

to-area ratios (Fahrig, 2003) (**Figure 3.3**). Such patches are especially vulnerable to edge effects that reduce habitat quality in the vicinity of edges due to relatively abrupt changes in the physical and biological conditions prevailing in the surrounding matrix (Laurance, 2008). Edge effects include changes in the availability of light and moisture, the strength of wind or currents (in aquatic environments), and exposure to transient predators, which often negatively affect native species richness and ecosystem

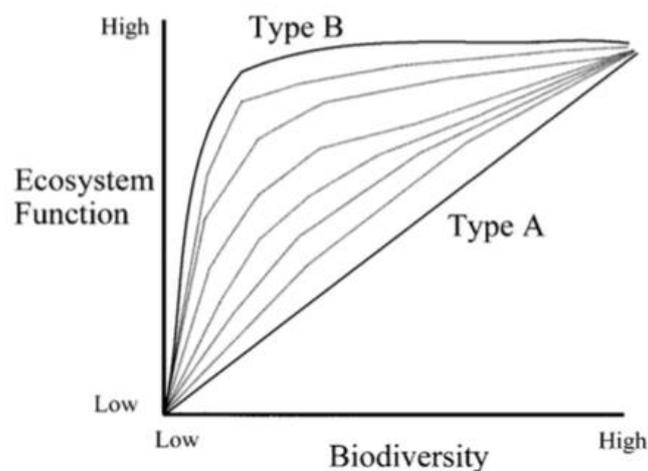
services (Laurance, 2008). Ecological edges are often also much more vulnerable to invasion by introduced and opportunistic species (Ives *et al.*, 2011).

Habitat fragmentation does not create a simple binary system of entirely suitable habitat patches within an entirely unsuitable matrix. The nature of the matrix surrounding the patches is often a crucial element, therefore, in determining the impact of fragmentation and edge effects (Laurance, 2008; Ives *et al.*, 2013; Ruffell *et al.*, 2016). In the many cases in which restoration of the original habitat is simply not possible, modifying the matrix to improve overall connectivity is the principal available means for achieving better biodiversity outcomes.

### 3.4 Benefits of urban ecosystems and biodiversity

#### Ecosystem function

An inevitable outcome of a diverse community of species interacting with each other and the physical environment is ecosystem function. The term 'ecosystem function' refers to the numerous processes that are the outcomes of a myriad of species interactions, such as water filtration, plant biomass production and nutrient cycling. Many of these processes are of direct benefit to human societies and are thus referred to as ecosystem services. The relationship between ecosystem function and biodiversity is complex: most ecosystems show curvilinear relationships (a type B relationship in **Figure 3.4**) in which many species appear 'redundant', making little or no contribution to ecosystem processes (Schwartz *et al.*, 2000). For example, Ossola *et al.* (2016) found that the removal of leaf litter promoted by soil detritivores (e.g. millipedes and pill bugs) in Melbourne's green spaces was enhanced by species richness but only up to 4–5 species (i.e. six or more species had no additional effect on leaf litter removal).



**Figure 3.4.** Relationship between biodiversity and ecosystem function. In a type A relationship, all species contribute equally to ecosystem function. In a type B relationship, ecosystem function is effectively provided by a relatively small proportion of the species, leaving many redundant species that are too rare to make a substantive contribution. Source: Schwartz *et al.* (2000).

Ecosystem redundancy is an unfortunate term because it implies that redundant species have no value. In fact, high redundancy provides a reservoir of latent species that can step in and contribute ecosystem function if the primary contributors become locally extinct. In other words, redundancy provides resilience to an ecosystem so that it may continue to provide function when disturbed (Naeem & Li, 1997; Naeem, 1998). This is analogous to structural redundancy in engineering, in which crucial

components (such as the supporting chains of a suspension bridge) are duplicated to enhance reliability and avoid catastrophic failure. It follows that local ecological communities driven to low species richness by human disturbances have little ecosystem redundancy and are therefore vulnerable to further disturbance and the catastrophic loss of function (Srivastava & Vellend, 2005).

### **Ecosystem services/disservices**

Maintaining urban ecosystems and the biodiversity they support in urban environments is essential because of the high number of ecosystem services they can provide. Ecosystem services are the benefits that humans obtain from ecosystems: air and water filtration, bank and shoreline stability, flood mitigation, carbon storage, microclimate moderation, noise reduction, decomposition, pollination, the regulation of pest species, nutrient cycling, seed dispersal, water infiltration, food production, health and wellbeing benefits, cultural values, aesthetic values, recreation, and tourism (Elmqvist *et al.*, 2004; Millennium Ecosystem Assessment, 2005; see also section 5.7). Evaporation from surfaces and transpiration from vegetation can cool surrounding areas, which can decrease exposure to heat stress on extreme weather days and during heatwaves. In Phoenix, Arizona, United States of America (US), for example, surfaces shaded by vegetation were cooled by almost 25 °C on summer days with low humidity (Jenerette *et al.*, 2011). Understanding the potential of ecosystem services, and the incorporation of this knowledge in urban design, can produce more liveable cities (Litvak *et al.*, 2014; Norton *et al.*, 2015). The City of Melbourne has a goal of increasing canopy cover citywide by 40% to mitigate increased urban temperatures due to the UHI effect and climate change (City of Melbourne, 2014). This microclimate moderation ecosystem service will become increasingly important in cities because the magnitude and number of heatwaves and extreme (heat) temperature events are predicted to increase in Australia due to climate change (Alexander & Arblaster, 2009).

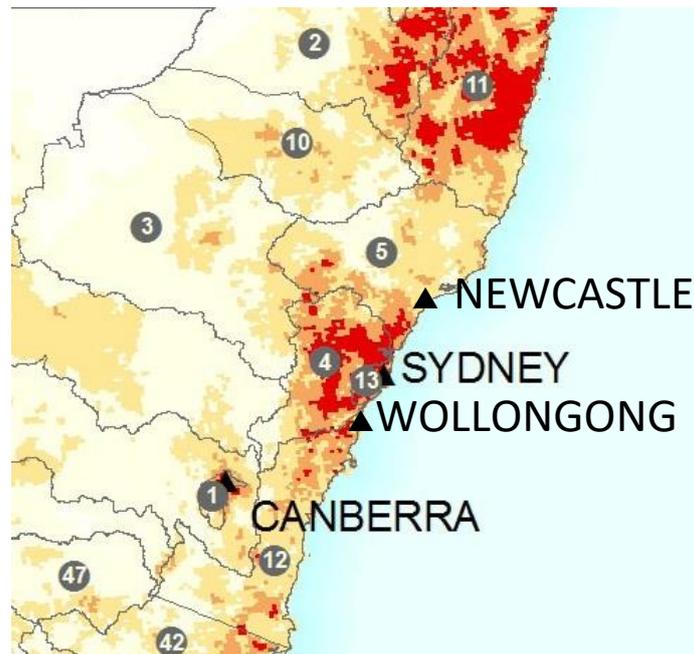
In 2011, ecosystem services were estimated to be worth an equivalent of USD 125 trillion/year globally (Costanza *et al.*, 2014). Although there are often philosophical issues in monetising services associated with ecosystems, applying a financial value to these ecosystem services enables the estimation of the financial losses incurred due to habitat loss and land-use change. Costanza *et al.* (2014) calculated that changes in land use between 2007 and 2011 and resultant habitat loss were equivalent to USD 20 trillion/year. Regardless of the financial benefits of maintaining healthy ecosystems, philosophical papers point to the inherent intrinsic value of natural spaces and biodiversity (Vucetich *et al.*, 2015). The argument is that green spaces and biodiversity provide benefits that cannot be measured financially and should be maintained for the sake of their intrinsic value.

Ecosystems can also provide disservices (Lyytimäkia *et al.*, 2008), such as physical attacks or bites by wildlife, allergies, discomfort caused by close proximity to certain undesirable species, damage to property or other assets, the risk of human injury, and the transmission of disease (Soulsbury & White, 2015). The number and types of direct human–wildlife conflicts might increase with increased biodiversity in urban areas. It is important that such disservices are identified and minimised through effective planning (Soulsbury & White, 2015). The tradeoffs in maintaining biodiversity and reducing ecological disservices in Sydney, Wollongong and Newcastle are discussed in more detail in the *What We Heard: documenting the stakeholder workshops* document.

### **The role of cities in conservation**

Traditionally, people have settled in places that are nice to live in – with pleasant climates, fertile soils, reliable water sources, good conditions for growing food, abundant fisheries, and safe harbours for shipping. Not surprisingly, such places also provide good habitat for many other species, and human settlements, therefore, can occur in highly biodiverse areas (Cincotta *et al.*, 2000; Luck, 2007). Although urban green spaces and remnant vegetation are often thought to be degraded, there is evidence that

they can provide adequate resources for vulnerable species (e.g. powerful owls in Melbourne: Isaac *et al.*, 2008), support high numbers of threatened species (Schwartz *et al.*, 2002; Ives *et al.*, 2016) and, therefore, play key roles in conservation (**Figure 3.5**). In a review of the number of threatened species of flora and fauna in urban centres in Australia (>10,000 people), Ives *et al.* (2016) found more threatened species supported in urban areas than in non-urban areas of equivalent area, with more than 30% of nationally listed species occurring in cities. Cities were especially important for plant species, with many of their ranges overlapping substantially with urbanised areas, and low redundancy between cities, due to the narrow distributions of endangered vegetation communities. Ives *et al.* (2016) highlighted the importance of maintaining and planning high-quality habitat for such threatened species in urban areas, as well as for the ecosystem services the green spaces provide.



**Figure 3.5.** Map of numbers of threatened species. Pixels in red show areas with the highest conservation significance due to the high numbers of threatened species. The high conservation potential of Sydney, Newcastle and Wollongong is indicated by the aggregation of red pixels surrounding these areas. The circled numbers indicated the Natural Resource Management (NRM) regions (relevant to Sydney, Newcastle and Wollongong are regions: 4 the Hawkesbury-Neapean NRM region; 5 the Hunter-Central Rivers NRM region; 12 the Southern Rivers NRM region; and 13 the Sydney Metro NRM region). Source: Excerpt of map from the Environmental Resource Information Network, Department of Environment, Water & Heritage, Australian Government.

Maintaining biodiversity in cities can promote conservation actions and Earth stewardship (Chapin *et al.*, 2011). People are likely to increase their connection with nature if they undertake environmental conservation efforts such as volunteering for nature-based agencies like Landcare or Streamwatch, engaging with domestic gardening and urban agriculture, and exercising their political voice for environmental purposes. For an increasingly urbanised population, interactions with nature may primarily or wholly occur in city contexts (Dunn *et al.*, 2006). For this reason, Dunn *et al.* (2006) argued that future conservation actions are dependent on contact with nature in cities, even if urban nature may not reflect the historical assemblages of a region, and they concluded that it is crucial that children living in urban areas have adequate access to urban nature.

### 3.5 Impacts on biodiversity from urbanisation

The process of urbanisation has multiple impacts in landscapes, such as habitat loss and the subsequent decline in habitat quality; changes to abiotic conditions (e.g. microclimate, lighting, hydrology, nutrient availability, exposure to contaminants and the introduction of artificial structures); and changes in the biotic environment (due to the effects of urbanisation on the occurrence and abundance of species).

Not all species respond similarly to the same types of changes, and the direction and magnitude of species responses are taxon-specific. Additionally, not all the impacts of urbanisation occur in isolation, and interactions between variables can drive biotic responses to urbanisation.

This section highlights biotic responses to some of the changes that occur due to urbanisation.

Understanding how organisms respond to urbanisation can help scientists, planners and managers work together to minimise the impacts of urbanisation on biodiversity.

#### Reductions in remnant habitat due to changes in land use and fragmentation

##### Reduction in habitat

In cities, habitat clearing for development transforms large tracts of continuous ecosystems into smaller fragments of remnant habitat (Grimm *et al.*, 2008). For example, extensive clearing of the Sydney Basin has reduced habitats to small patches surrounded by an urban matrix of other urban land uses (**Figure 3.6**). In marine habitats, dredging for shipping channels can cause the direct destruction of bottom habitats (Short & Wyllie-Echeverria, 1996; Orth *et al.*, 2006) and may lead to the loss of aquatic plants by causing sediment re-suspensions that block light (Short & Wyllie-Echeverria, 1996). Smaller patches of habitat in urban areas support fewer species than larger patches, as demonstrated for multiple Australian taxa (Drinnan, 2005; Palmer *et al.*, 2008; Kang *et al.*, 2015), as well as for taxa worldwide in a recent global review by Beninde *et al.* (2015) of the responses of biodiversity to urbanisation.

a)



b)

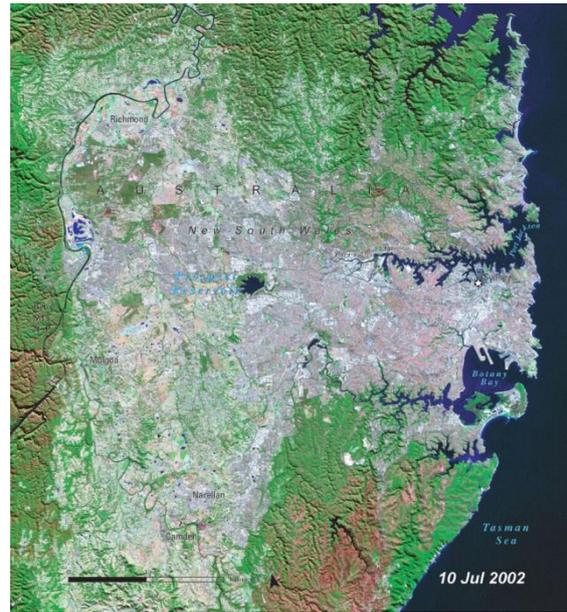


Figure 3.6. Satellite images of the Sydney Basin in a) 1975 and b) 2002 demonstrating extensive land clearing and the resultant fragmentation of remnant vegetation, especially in western and southwestern Sydney. Source: United Nations Environment Programme: [http://na.unep.net/digital\\_atlas2/webatlas.php?id=157](http://na.unep.net/digital_atlas2/webatlas.php?id=157). The population of Sydney was 3 129 000 in 1975 and 4 135 637 in 2002 (ABS, 2014).

Quantifying fragmentation effects using total species richness (i.e. number of species) can, however, oversimplify and disguise biodiversity responses caused by habitat reductions. For example, although the species richness of insects and spiders did not differ between small and large fragments in a study in Sydney, the particular combination of the species present differed markedly, demonstrating that species have differential responses to habitat fragmentation (Gibb & Hochuli, 2002). Predators and parasitoids<sup>4</sup> are particularly sensitive to fragmentation, while generalist species can often exploit highly disturbed smaller patches (Gibb & Hochuli, 2002). Thus, smaller urban fragments are not a substitute for large patches of remnant vegetation due to changes in species assemblages (Gibb & Hochuli, 1999). Habitat loss and fragmentation reduces the size of local populations of individual species while increasing their isolation from each other. Small populations are well known to be at risk of loss of genetic diversity, and this problem is exacerbated when isolation leads to a lack of gene flow (Frankham, 1996). Especially for species with limited capacity for dispersal in urban landscapes, the loss of genetic diversity associated with habitat fragmentation is a significant factor contributing to extinction risk (O'Grady *et al.*, 2004).

The loss of habitat not only decreases the area available to support populations, it also leads to a subsequent decline in habitat quality. These changes may be driven by the increased edge-to-area ratio, changes to species composition, or changes to disturbance regimes (e.g. fire frequency). In Sydney, for example, the native fire-sensitive plant *Pittosporum undulatum* is now a common understorey plant in many small stands of remnant vegetation due to higher nutrient levels and the lower frequency of fires, but it does not occur in large fragments (Rose & Fairweather, 1997; Gibb & Hochuli, 2002).

<sup>4</sup> Parasitoids are organisms that need to live inside or on the outside of a host organism to complete their lifecycles, similar to a parasite. Parasitoids differ from parasites in that they eventually kill their host. Parasitoids are important in ecosystems because they help regulate the population sizes of other species.

The edge-to-area ratio increases as remnant patches decrease in size (**Figure 3.3**). Changes to biodiversity in smaller remnant fragments may be attributable, therefore, to either the smaller habitat or edge effects (Christie *et al.*, 2010). Edges are directly implicated in some of the responses of fauna and flora to urban fragmentation (Drinnan, 2005; Horak, 2016). Changes in assemblage structure due to reduced remnant habitat area and associated edge effects can lead to changes in ecological interactions, including herbivory (Christie & Hochuli, 2005; Christie *et al.*, 2010), predation (Anderson & Burgin, 2008; Maron *et al.*, 2013) and competition (Piper & Catterall, 2003; Maron *et al.*, 2013). Smaller remnant patches in Sydney, for example, have a higher rate of herbivory than the interiors or edges of large remnants (Christie & Hochuli, 2005), which is driven by increased numbers of grazing insects and a decreased abundance of predators and parasitoids (Christie *et al.*, 2010). Increases in insect herbivory due to changes in species composition are associated with the extensive eucalypt dieback that occurs in these remnants (Hochuli *et al.*, 2004). Edge effects are often driven by a subset of species that flourish in edge habitat (i.e. edge specialists) and which are often well adapted to disturbance.

Not all species are similarly affected by urban habitat fragmentation, however (Sewell & Catterall, 1998; Hamer & McDonnell, 2008). Patches of remnant vegetation are isolated within the urban matrix. For some species, the urban matrix is inhospitable and represents a barrier to movement between patches; for other species, however, the urban matrix may represent lower-quality habitat that can still be used or tolerated in moving between patches. Some species may even spend a higher proportion of time in the urban matrix than in remnant habitat (Davis *et al.*, 2012). For example, some non-indigenous marine species benefit from the addition of artificial structures to previously sedimentary areas (Glasby *et al.*, 2007; Dafforn *et al.*, 2012). These matrix specialists (also called 'suburban species') may be pre-adapted or have adapted to exploiting the resources available in novel urban habitats (McDonnell & Hahs, 2015).

The urban matrix is not a homogeneous landscape, comprising various land uses that can differ in the degree of urbanisation. This heterogeneity changes how species respond to the urban matrix (Godefroid & Koedam, 2007). In Brisbane, for example, the species richness of birds was found to be higher in suburbs that retained much of their original vegetation compared with planted suburbs, and planted suburbs had higher bird species richness than suburbs without vegetation (Sewell & Catterall, 1998). None of these suburb types supported high numbers of several species primarily associated with core areas of remnants (core-dependant/interior species) (Sewell & Catterall, 1998). As the patch sizes of remnant vegetation in cities decrease, local extinctions of core-dependent species increase, thus reducing overall species diversity in a city (Marzluff, 2005).

Urban fragmentation causes the isolation of patches from each other. The effects of such isolation are taxon-specific and dependent on the ability of organisms to move or disperse through the intervening matrix. Isolation effects have been observed for most taxa with increasing distance from other remnants (Drinnan, 2005; Kang *et al.*, 2015). When landscape fragmentation leads to a loss of movement between patches, populations can become genetically isolated, leading to decreased genetic diversity. Urban populations of the eastern red-backed salamander (*Plethodon cinereus*) in Montreal, Canada, for example, were found to have reduced genetic diversity compared with populations in more contiguous habitat (Noel *et al.*, 2007). For some species, strips of contiguous vegetation between patches (i.e. corridors; see below) may facilitate movement between remnant patches (Tewksbury *et al.*, 2002; Angold *et al.*, 2006). Alternatively, smaller stands of remnant vegetation, and even single trees situated between remnant fragments, may allow species to traverse an urban matrix between patches by using these stands or trees as 'habitat stepping stones' (Glasby & Connell, 1999).

Urbanisation has led to the extensive modification and often loss of transitional habitats between terrestrial and aquatic systems, such as mangroves, saltmarshes and stream riparian zones. The removal of riparian trees and mangroves to improve views or accessibility to waterways effectively removes or

reduces the quality of such habitat. In riparian zones, vegetation removals reduce bank stability, increasing susceptibility to scouring and erosion during rain and high-flow events (e.g. Zaimes *et al.*, 2004). These transitional habitats are also major sources of organic matter for aquatic ecosystems (Boulton *et al.*, 2015), which is lost when habitat is removed. Intact mangroves and riparian vegetation are effective natural filters, acting to improve the quality of runoff, especially by reducing the sediments (and associated contaminants) entering aquatic systems (see review by Eamus *et al.*, 2005). The increased volume of freshwater entering estuaries as a consequence of urban runoff has reduced salinity in the upper regions of some estuaries, causing a transition from mangroves to less-salinity-tolerant vegetation communities.

Fragmentation is also common in urban coastal ecosystems. In Sydney Harbour, the armouring of coastlines with artificial structures such as seawalls to reduce shoreline erosion and protect coastal infrastructure has reduced the extent of saltmarshes, mud flats and natural rocky shores, and many of the remaining natural ecosystems are now isolated from each other. Artificial structures like seawalls effectively fragment coastlines and lead to differences in assemblage compositions and diversity in separated habitat fragments (Goodsell, 2009). Many taxa have higher abundances when their habitats are not fragmented by artificial structures (Goodsell *et al.*, 2007; Goodsell, 2009). Propeller scarring from boat run-abouts (Dunton & Schonberg, 2002; Orth *et al.*, 2006) and damage from boat moorings (Hastings *et al.*, 1995) are common causes of seagrass-bed fragmentation and subsequent increases in edge effects (Fonseca & Bell, 1998) in populated coastal areas. Such fragmentation has increased in severity with increases in coastal populations and recreational boating (Larkin *et al.*, 2010). A scar formed in a seagrass bed often continues to grow because sediment in the scar is destabilised, further reducing the size of the seagrass patch (Walker *et al.*, 1989).

As low-lying points in urban landscapes, urban streams are particularly susceptible to increases in urbanisation in catchments. The high-volume, high-velocity flows associated with urban runoff (see below) cause erosion, channel incision and a loss of channel complexity (Walsh *et al.*, 2005, Bernhardt & Palmer 2007). The mobilisation of fine sediments in a catchment and their subsequent in-stream deposition lead to the homogenisation of sediments, the filling of deeper pools, and the smothering of coarse riffle substrates, causing the loss of the natural riffle-pool sequence and a reduction of deep pools, which are important thermal refuges in hot weather and low flows. The removal of habitat-forming woody debris from streams as a flood management measure leads to further habitat loss because such natural debris provides important physical habitat structure.

## **Changes to the abiotic environment**

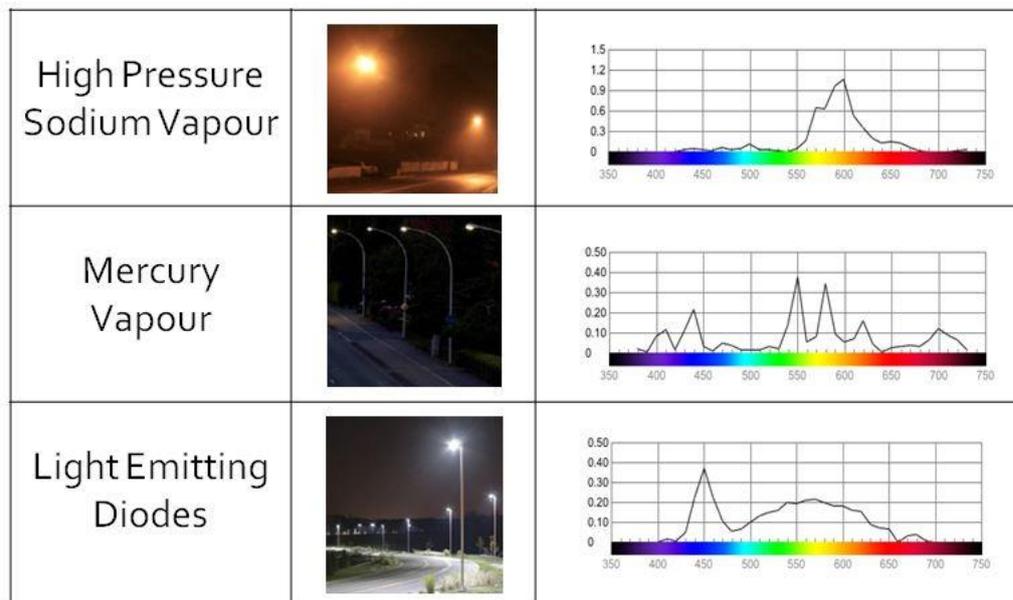
### **Lighting and noise**

Changes in lighting due to urbanisation can affect the behaviour, physiology, endocrinology and neurobiology of organisms, including humans (Navara & Nelson, 2007; Stevens & Zhu, 2015). The most noticeable change in lighting in urban environments is the addition of artificial night lighting to increase human safety and the duration of human activity in periods of darkness. Artificial night lighting can change the availability of light temporally and spatially (Gaston *et al.*, 2013; Gaston *et al.*, 2014). It can also transform the wavelengths of the available light, from very broad spectrum (such as sunlight and moonlight), to the specific peaks in wavelengths of orange sodium vapour and greenish fluorescent lights (van Grunsven *et al.*, 2014). Street and path lights, domestic and building lights, vehicle lights and lit advertising all contribute to ecological light pollution (Longcore & Rich, 2004; Gaston *et al.*, 2012). Light pollution in the environment can lead to changes in nocturnal assemblages by changing the circadian rhythms of organisms (Dominoni *et al.*, 2014), behaviour (Bolton *et al.*, accepted), vegetation structure (Bennie *et al.*, 2016) and light-induced mortality (e.g. moths in Germany; Eisenbeis & Hänel, 2009). For example, the activity patterns of lesser horseshoe bats (*Rhinolophus hipposideros*) decreased,

and bat commuting was delayed, when artificial night lights were installed along commuting corridors (Stone *et al.*, 2009). For these bats, therefore, artificial night lighting fragmented the landscape (Stone *et al.*, 2009; Hale *et al.*, 2015). Some nocturnal species, however, may benefit from artificial night lighting, with some fauna known to forage around street lamps because of the higher abundance of prey items attracted to the lamps.

Artificial night lighting may affect diurnal species by changing the timing of light-initiated behaviours. Some diurnal birds, for example, may be able to forage for longer into the night in the presence of artificial light; in areas of high light exposure, songbirds have been observed to initiate their songs before dawn (Miller, 2006). Such changes in behaviour and ecological interactions due to ecological light pollution can ultimately affect population structure (Longcore & Rich, 2004).

The type of light used in artificial night lighting can affect its impact on biodiversity. Streetlights, for example, differ in the wavelength and the broadness of the spectrum of light they emit (van Grunsven *et al.*, 2014) (**Figure 3.7**). Species vary in their responses to different types of light because of variations in organismal photoreceptor sensitivities to different wavelengths (van Grunsven *et al.*, 2014), which can lead to changes in ecological interactions (Davies *et al.*, 2013). In one study, mercury vapour lights, which are high in ultraviolet radiation, attracted more nocturnal insects than other light types, such as low-pressure sodium lights, ceramic metal halides and remote phosphor light-emitting diodes (LEDs) (van Grunsven *et al.*, 2014). Changing streetlighting from traditional mercury vapour lights to LEDs may have ecological impacts, therefore, because some species of microbat forage near mercury vapour streetlights due to the high numbers of nocturnal insects (especially moths) they attract (Jung & Kalko, 2010). Artificial lighting associated with jetties and other boating infrastructure has been documented to cause changes in predator–prey interactions in marine environments by attracting prey items and enabling foraging by visual predators (Becker *et al.*, 2013b; Davies *et al.*, 2014).



**Figure 3.7.** The spectrum of light emitted by three types of light commonly used in Sydney. Many councils are converting from traditional mercury lights to LEDs for energy efficiency, which will mean changes in the wavelengths emitted. Different organisms have different sensitivities to light and respond differently to the presence of artificial night lighting; the change in light type, therefore, will change ecological interactions. Light spectrums were measured using a photospectrometer by Joanna K. Haddock (USyd). Figure courtesy of J K. Haddock.

Changes in exposure in lighting regimes can also occur through habitat modification. For example, exposure to natural light is often high at the edges of habitat patches, and light will permeate into such patches for varying distances depending on the intensity of the light source and the amount of vegetation present to intercept it. Streams may also receive more natural light when riparian vegetation is removed or thinned, with the potential to increase the temperature of stream water (Castelle *et al.*, 1994) and affect the photosynthetic rate, both of which can change organismal physiology and ecological interactions (Paul & Meyer, 2001). Such effects may lead to increased algal and macrophyte growth (Bunn *et al.*, 1998), which might otherwise be light-limited in nutrient-enriched urban waterways. Changing natural light exposure through shading or increased water turbidity can affect photosynthesis and thermoregulation in ectotherms and change light-sensitive behaviours. For example, the shading of water by artificial structures in marine environments can create barriers to the movement of salmon (Toft *et al.*, 2007; Munsch *et al.*, 2014; Ono & Simenstad, 2014).

Anthropogenic noise increases in cities with high urbanisation (Joo *et al.*, 2011), potentially affecting the physiology, behaviour and biotic interactions of organisms. The impacts of anthropogenic noise on terrestrial and aquatic organisms include: distributional changes resulting from behavioural avoidance of noisy areas; the masking of acoustic communication between individuals; the disruption of predator–prey interactions influenced by hearing; and stress, which in turn influences growth and reproduction (reviewed by Slabbekoorn *et al.*, 2010; Shannon *et al.*, 2016). Noise in urban areas is often a source of stress for organisms (Tennesen *et al.*, 2014), and it also reduces the distance over which animals can detect auditory signals (Barber *et al.*, 2010). For some species, auditory detection is an important component of communication between individuals, for example in courtship, territoriality, parent–offspring recognition (Montague *et al.*, 2013; Lucass *et al.*, 2016) and for detecting predators or prey (Gomes *et al.*, 2016). Most research related to the terrestrial effects of noise pollution focuses on traffic noise along roads, but impacts may also include noise associated with construction and other transport vehicles (Barber *et al.*, 2010; Tennesen *et al.*, 2014).

Many animals are able to compensate for anthropogenic noise pollution by changing the pitch or volume of auditory signals or reducing their complexity (Parris *et al.*, 2009; Cunnington & Fahrig, 2010; Lampe *et al.*, 2012; Lowry *et al.*, 2012), or by relying more heavily on other sensory modes (Gomes *et al.*, 2016). The ability to modify auditory calls in response to urban noise pollution may be an important strategy in allowing some species to thrive in urban areas. For example, noisy miners have louder alarm calls when close to busy roads than on quiet roads (Lowry *et al.*, 2012).

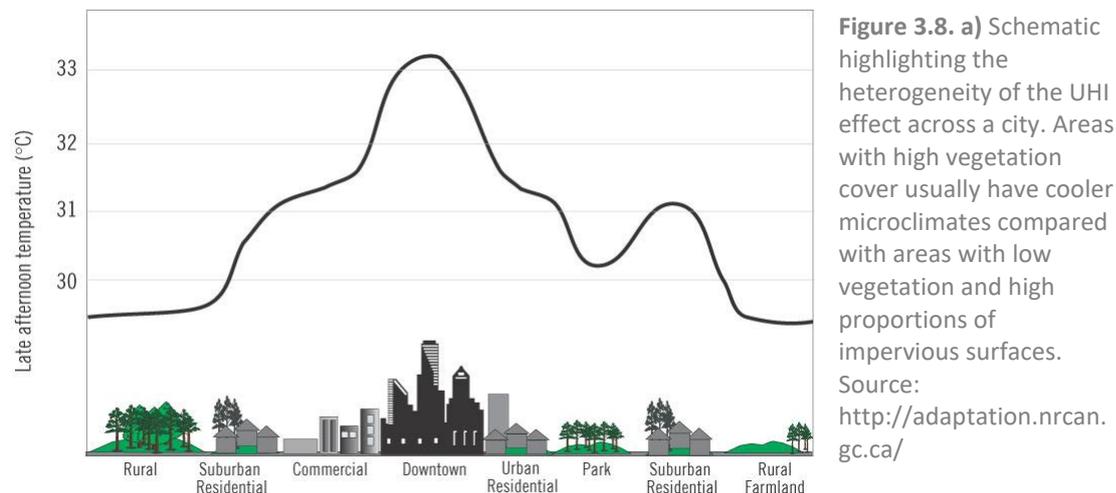
Human-generated underwater noise may have large impacts on aquatic organisms (Slabbekoorn *et al.*, 2010). Sources of noise in aquatic urban environments include the construction of artificial structures such as piers and seawalls, the operation of desalination and other industrial plants, and vessels for container shipping, public transport, fishing and recreational activities (Einav *et al.*, 2003; Haviland-Howell *et al.*, 2007; Slabbekoorn *et al.*, 2010). Water is an excellent medium for sound transmission, and pile driving can produce noise that is twice as loud as background levels at 100m from the site of construction and is detectable up to 70km away (Bailey *et al.*, 2010). To date, studies investigating the effects of human-generated noise on aquatic organisms have focused on marine mammals (see Slabbekoorn *et al.*, 2010), but there is also evidence that noise may affect fish and aquatic invertebrates (Vasconcelos *et al.*, 2007; Codarin *et al.*, 2009; de Soto *et al.*, 2013; Wale *et al.*, 2013).

### Microclimate

Urbanisation leads to changes in microclimates in cities, manifested, for example, in changes in temperature, wind patterns, humidity and rainfall events. Such microclimatic changes (e.g. in rainfall patterns; Grimm *et al.*, 2008) may affect surrounding landscapes.

The most pervasive change to city microclimates is an increase in temperature (including minimum and maximum temperatures), especially at night (Pickett *et al.*, 2001). The increased temperature syndrome is often called the UHI effect. It is caused by changes in land cover, including an increased area of impervious surfaces and a decreasing area of vegetation, anthropogenic waste heat production, and changed water flows. Impervious surfaces often trap solar radiation as heat and then release the heat back into the atmosphere at night. Changes to vegetation can increase the area of impervious surfaces exposed to solar radiation through a reduction in shading. Changes in vegetation and water runoff associated with more impervious surfaces also decrease the cooling ecosystem service provided by natural areas via evapotranspiration (Grimm *et al.*, 2008; Gaston *et al.*, 2010).

Although the UHI effect occurs across a whole city, there is high heterogeneity in heat profiles, often depending on the amount of vegetation and impervious surfaces in an area as well as the effect of air movement (e.g. coastal sea breezes) (**Figure 3.8**). Temperature is a crucial abiotic driver of biological processes, especially for ectotherms<sup>5</sup>, for which the temperature of the surroundings affects body temperature and thus can alter biochemistry, physiology and behaviour. Increasing temperatures in cities, therefore, can change ecosystem processes and ecological interactions. For example, one study found pest herbivores (scale insects) to be more than ten times more abundant on hot street trees than on cold street trees (Meineke *et al.*, 2013).



Higher temperatures in cities also increase the probability that an organism will experience heat stress. All organisms have a maximum temperature above which they will not survive, with maximum temperature thresholds varying among species (Lutterschmidt & Hutchison, 1997). Due to the UHI effect, urban organisms are likely at greater risk of encountering temperatures exceeding their maximum lethal thresholds, especially during heatwaves and on extreme temperature days. The frequency and magnitude of heatwaves and extreme temperature events are likely to increase due to climate change (e.g. Alexander & Arblaster, 2009). Higher temperatures in cities compared with natural areas may act, therefore, as a selective pressure that determines whether individuals can persist in urban environments (Chown & Duffy, 2015). Intertidal organisms, which already experience

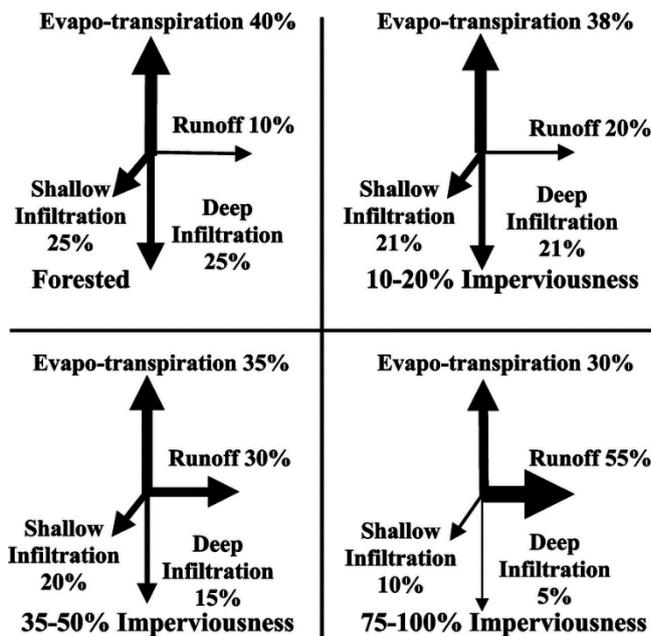
<sup>5</sup> Ectotherms, often referred to colloquially as ‘cold-blooded animals’, are animals that rely on external sources of heat (e.g. sunlight and warm ground and rocks) to regulate their internal body temperature. Body temperature affects animal performances such as running speed, digestion rates and prey capture ability. In heatwaves and days of extreme heat, ectotherm body temperatures may increase to levels high enough to cause death, unless the animals can find cool refuges (e.g. in burrows or under large rocks) (e.g. van den Berg *et al.*, 2015).

temperatures close to their thermal thresholds (Somero, 2012), and other animals with low thermal safety margins (Deutsch *et al.*, 2008), may also be at higher risk of experiencing lethal temperatures due to urbanisation. Microhabitats that provide shading and retain moisture at low tide can be important in enabling organisms to persist on intertidal rocky shores (McAfee *et al.*, 2016). Species may be lost when such microhabitats are lost due to the loss of habitat-forming species that provide these functions or to substrate homogenisation by the introduction of artificial structures.

## Hydrology

Urban drainage systems are often highly modified, with small streams removed or diverted by development and modifications made to rivers, canals, wetlands and other water bodies (Grimm *et al.*, 2008). The introduction of culverts and weirs to urban streams can alter water flows and act as physical barriers to the migration of those fish species that complete their life cycles partly in freshwater and partly in marine environments (Sheer & Steel, 2006; Aprahamian *et al.*, 2010; Bishop *et al.*, in press). Dams that control natural flow patterns can interfere with patterns of spawning and migration downstream because many species use changes in flow rate as biological cues (Drinkwater & Frank, 1994; McCarthy *et al.*, 2008). Changes in flow patterns due to artificial structures may cause asynchrony between the timing of biological cues and the conditions appropriate for migration or spawning (e.g. peak runoff) (Bishop *et al.*, in press).

The increase in the area of impervious surfaces in urban environments dramatically changes the hydrology of urban landscapes by increasing flow volumes and rates and changing the timing of when flows reach waterways (Paul & Meyer, 2001). Urbanisation changes flow volume by modifying the proportion of water leaving an area as surface runoff. Arnold and Gibbons (1996) calculated the changes in the allocation of urban water to runoff, shallow and deep infiltration and evapotranspiration for different percentages of impervious surface cover (ISC). Even at relatively low ISC (10–20%), surface runoff volume was double that of runoff volume in forested areas. As ISC increased, so did the percentage of water removed via surface runoff, with a resultant reduction in the volume of water available for evapotranspiration and infiltration. Compared with forested catchments, 35–50% ISC resulted in three times as much water allocated to runoff, and 75–100% ISC produced runoff volumes five times the natural volume (Arnold & Gibbons, 1996) (**Figure 3.9**). Reductions in the volume of water available for evapotranspiration can lead to microclimatic changes in urban areas, such as differences in humidity and a reduction in the natural ecosystem service of cooling surfaces and air. A reduction in the volume of water that infiltrates the ground changes the time required for water to move from its source to streams, rivers and estuaries. Water that has infiltrated the ground will gradually enter streams as subsurface water (or basal flows) (Paul & Meyer, 2001); in vegetated areas, therefore, water moves more slowly from the source to the stream, meaning a more gradual increase in the water volume entering streams and peak flows that are smaller and delayed relative to a given rainfall event. The volume of water in a stream decreases gradually after a peak flow. In urban areas, when the majority of water enters streams as surface runoff, water will rapidly enter a stream after a rainfall event, and the volume of water in the stream will increase rapidly. The peak flow occurs soon after the rainfall event, and the water leaves the stream more rapidly compared with non-urban streams.



**Figure 3.9.** Changes in the percentage of water that leaves an area through evapotranspiration, runoff, shallow infiltration and deep infiltration as a result of the area of impervious surface cover. Source: Paul and Meyer (2001).

Runoff picks up suspended solids, contaminants and nutrients as it passes over impervious surfaces and other forms of urban land cover (Paul & Meyer, 2001). This can affect stream health by increasing turbidity (Roy *et al.*, 2003) and the deposition of fine sediments, and through eutrophication.<sup>6</sup> Turbidity can affect photosynthetic organisms by decreasing the amount of light available for photosynthesis (Robinson *et al.*, 2014) and impeding feeding structures in filter-feeding organisms (Birch & O’Hea, 2007). Sediment size is a particularly important determinant of species composition in aquatic ecosystems. The addition of fine sediments to stream systems, such as occurs in urban runoff, has wide-ranging impacts. Sediments suspended in the water column can be abrasive to biota, damaging gills and other soft body structures (Wood & Armitage, 1997). Fine sediments deposited on streambeds smother coarser sediments and clog the pores and interstitial spaces that provide habitat for biota (Hogg & Norris, 1991). The filling of deep pools with sediments over time can remove important refuge habitat.

Water leaving an urban area as runoff requires a system of drains, pipes and channels to divert it to streams or coastal outflows. The purpose of this infrastructure is to quickly drain water away from its source to minimise the risk of flooding, which is more likely to occur in developed areas because of the increase in surface runoff. The negative effect of this functionality is that an increased volume of runoff enters streams at a higher velocity, with the potential to disturb streams and lead to the loss of vegetation and aquatic fauna, bank erosion, and a subsequent increase in stream width (Paul & Meyer, 2001). The erosion of stream channels can also scour sediments and lower streambeds to bedrock, thereby disrupting the natural riffle-pool habitat sequence. Changes due to increased flow, therefore, have implications for aquatic ecosystems and can lead to depauperate aquatic assemblages (Roy *et al.*, 2003).

Even low percentages of ISC can lead to stream degradation, with percentage ISC in a catchment or watershed negatively correlated with streambed sediment size, bank erosion, base flow, and species richness and diversity for fish and other aquatic organisms (Paul & Meyer, 2001; Wang *et al.*, 2001; Roy *et al.*, 2003). A review of urban stream ecosystems found that ISC percentages as low as 10-20% were associated with stream degradation thresholds for most variables (Paul & Meyer, 2001). In Sydney’s Ku-

<sup>6</sup> Eutrophication is the enrichment of water bodies with nutrients, usually nitrogen and phosphorous.

ring-gai Local Government Area, urban streams – which in general have much higher impervious surface cover (95% of streams with ISC >20%) than nearby non-urban streams (<2% ISC) – were found to have significantly lower aquatic macroinvertebrate richness and were more uniform in their assemblages, with a reduction in sensitive taxa, than non-urban streams; the amount of surrounding bushland and ISC were important predictors of decreases in assemblage composition and water quality in urban streams (Davies *et al.*, 2010). Importantly, however, reductions in catchment imperviousness and connectivity alone are typically insufficient to bring about meaningful improvements in the condition of urban waterways, and a combination of catchment-scale and reach-scale improvements to in-stream habitats are needed to increase stream biodiversity (Bernhardt & Palmer, 2011; Violin *et al.*, 2011).

### Nutrients and contaminants

Urbanisation can change the chemical composition of soils, air and water. Changing the availability of nutrients through the use of fertilisers, wastewater discharges, and the introduction of contaminants into natural systems can cause biotic changes at the cellular, organismal and community levels (Rochman *et al.*, 2016). Changes to biogeochemical cycles can span many spatial scales across terrestrial, freshwater and marine ecosystems (Grimm *et al.*, 2008).

The addition of nutrients from fertilisers, stormwater runoff and sewage discharge into natural ecosystems modifies soil chemistry, resulting in changes to vegetation composition and structure. This is particularly apparent in many Australian ecosystems, which typically have nutrient-poor soils. In Sydney bushland fragments, for example, the addition of nutrients to sandstone-derived soils was found to increase the number of exotic (both invasive and non-invasive) plants and decrease native species richness (Lake & Leishman, 2004).

The addition of nutrients to streams and downstream aquatic ecosystems through stormwater runoff and wastewater can lead to eutrophication (Nixon, 1995). Increases in nitrogen and phosphorous allow increases in primary productivity in aquatic systems, leading to algal blooms that can cause large diurnal fluctuations in dissolved oxygen; low levels of dissolved oxygen can lead to the death of aquatic organisms. In coastal environments that are nutrient-limited, the addition of nutrients, including sewage discharge, appears to be positive in many instances (contrasting with the findings of studies in Europe and the US) (Bishop *et al.*, 2006; York *et al.*, 2012; Kelaher *et al.*, 2013), leading to increases in the diversity and abundance of species in estuarine systems (Dafforn *et al.*, 2013; Clark *et al.*, 2015). For example, seagrass beds in the Brisbane Waters National Park increased in biomass and supported high abundances of predators when artificially enriched with fertiliser compared with beds with no artificial fertiliser enrichment (Kelaher *et al.*, 2013). The early life-history stages of some kelps are, however, highly sensitive to nutrient pollution. The local extirpation of crayweed (*Phyllospora comosa*) in the Sydney metropolitan area may have been caused by shoreline sewage discharge (Coleman *et al.*, 2008). Water quality has increased on the Sydney coastline since the construction of deep-water outfalls, allowing the successful restoration of crayweed (Campbell *et al.*, 2014).

The geochemistry of water in urban waterways can be modified by movement through concrete pipes, with an increase of ions like bicarbonate and calcium and changes in pH (Davies *et al.*, 2010; Wright *et al.*, 2011), which can affect freshwater communities, including diatoms (Potapova & Charles, 2003). In the Georges River catchment (a sandstone-dominated catchment in Sydney), for example, bicarbonate and calcium loads were found to be more than an order of magnitude higher in streams in urban areas than in non-urban areas, which was attributed to the type of concrete used in urban drainage (Tippler *et al.*, 2014).

Contaminants such as metals, oils, pesticides and large debris (e.g. rubbish, including plastics) are a pervasive problem in urban areas. They can be added to the environment directly (e.g. from industrial,

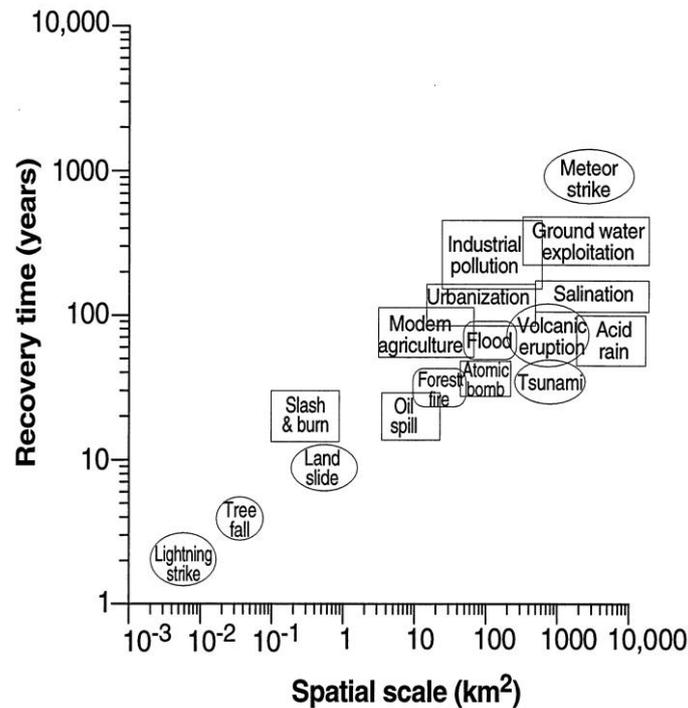
dumping and residential sites), leach through substrates, or enter natural systems from stormwater and air (Grimm *et al.*, 2008). Stormwater, for example, can pick up vehicular contaminants such as hydrocarbons and heavy metals as it passes over impervious surfaces like car parks and roads. Because contaminants are often associated with sediment, toxic sediment layers can build up in aquatic systems and cause declines in aquatic species abundance (Olguin *et al.*, 2000). Different functional groups of organisms have different responses to contaminants, which can lead to changes in species composition (Johnston & Roberts, 2009; Johnston *et al.*, 2015).

The pervasiveness of contamination in stormwater has led to a significant research effort on the impacts of contaminants, including metals, plastics (including microplastics; Rochman *et al.*, 2016) and parabens (Evans *et al.*, 2016) on aquatic organisms. Davis and Birch (2010, 2011) described Sydney Harbour as one of the world's most contaminated environments. The innermost parts of the harbour, which receive little flushing, have particularly high levels of contaminants (Sutherland *et al.*, in press). Such contaminants are now found in sediments as well as fish, algae, plants and animals, including commercially important fish and oysters (reviewed in Mayer-Pinto *et al.*, 2015). Contaminants that end up in marine environments can have consequences for ecosystem services. In a meta-analysis, Johnston and Roberts (2009) found that polluted sites have 40% lower species richness than non-polluted sites in marine systems, and this can change ecosystem processes (e.g. reducing primary productivity and increasing respiration) and corresponding ecosystem services (Johnston *et al.*, 2015). Commercial fishing was banned and recreational fishing restricted in Sydney Harbour in 2006 due to the high levels of dioxins recorded in fishes there (Birch *et al.*, 2007).

Predicting the impacts of contaminants can be complicated by chemical and ecological interactions. For example, although plant growth is reduced by high ozone concentrations, the growth of cottonwood clones in New York City was higher in urban areas than in surrounding rural areas due to the presence of nitric oxide and nitrogen dioxide molecules in urban areas, which reduced ozone levels there compared with rural areas; this finding demonstrates, however, that urban air pollution can have ecological consequences beyond city boundaries (Gregg *et al.*, 2003).

### Disturbance

Disturbance (e.g. by storms, tree falls and fires) is an integral part of ecosystems; it is a cause of natural patchiness in ecosystems and allows for species turnover. The various spatial and temporal scales of disturbance, and its frequency and intensity, affect the resiliency of ecosystems in recovering to pre-disturbance states (**Figure 3.10**). Urbanisation causes changes to traditional disturbance regimes (in frequency and intensity) and introduces novel disturbances to ecosystems.



**Figure 3.10.** The relationship between the spatial scale (km<sup>2</sup>) of a disturbance and the time (years) needed for the system to return to a pre-disturbance state. In general, the larger the spatial scale of a disturbance, the longer it will take the system to recover. Source: Dobson *et al.* (1997).

Fire is an important disturbance in many Australian ecosystems; it can have profound influences on assemblages and habitat heterogeneity and is crucial for the life cycles of many Australian plants (Woinarski *et al.*, 2015). Natural fire regimes have been disrupted, however, in part to reduce the risk of damage to property, infrastructure and lives (Whelan, 2002), resulting in changes in fire frequency and intensity. A reduction in fire frequency can affect flora that is dependent on fire for seed dispersal or germination, and a build-up of understorey can lead to more intense (if less frequent) fires (Lindenmayer, 2007). Increasing the duration of time since fire in dry sclerophyll vegetation can change species composition and habitat structure by increasing the abundance of fire-sensitive species (Morrison *et al.*, 1995). On the other hand, fire occurs at a higher frequency in remnant bushland in many urban areas, a phenomenon that the NSW Office of Environment and Heritage has listed as a 'key threatening process' for many ecological communities in the vicinity of Sydney, including the Cumberland Plain woodland, the eastern suburbs banksia scrub and the Kurnell dune forest (NSW Office of Environment and Heritage, 2013). An increase in fire frequency may mean that ecosystems have insufficient time to recover from a fire before the next one occurs, disrupting natural strategies for coping with fire (e.g. resprouting and seed release and/or germination). Plants that rely on the post-fire germination of seeds as a strategy, for example, may have insufficient time to mature and produce new seeds before the next fire, leading to local extinction (Lindenmayer, 2007). Fire frequency in urban remnants should be managed with respect to both risk to sensitive infrastructure and the requirements of ecological communities and sensitive fauna and flora species. In North Head in the Sydney Harbour National Park, for example, fire regimes are managed to protect important infrastructure (e.g. Manly Hospital and the Quarantine Station) while maintaining fire frequencies appropriate to various

ecological communities, such as the eastern suburbs banksia scrub and threatened or vulnerable species.<sup>7</sup>

The installation of roads, tracks, boating routes and other transport infrastructure in urban areas, and the associated traffic, create a multitude of disturbances in ecosystems, including physical disturbance (Bishop, 2008; Rhodes *et al.*, 2014). The impacts of boating in marine environments include vessel strike, noise pollution, chemical and oil leaks (Whitfield & Becker, 2014), boat wakes that erode sediments and fauna (Bishop & Chapman, 2004), and the displacement of organisms from seagrass (Bishop, 2008). Such disturbance can lead to changes in behaviour (e.g. fish in response to boats; Becker *et al.*, 2013a; Whitfield & Becker, 2014) and the dispersal of propagules, and it can increase the probability of human–wildlife interactions. Increased traffic in transport thoroughfares can reduce species richness (Bishop, 2008) and increase the probability of transport-related mortality (e.g. car collisions and vessel strikes). Vehicle strikes on bushland roads, for example, were identified as a key threat to an endangered population of bandicoots in Sydney’s North Head (Banks, 2004). Increased traffic and the addition of new transport thoroughfares with growing urban populations is likely to lead to more disturbance and an increased probability of traffic-related wildlife mortality (Rhodes *et al.*, 2014).

Human movements can also be a direct source of disturbance in urban ecosystems. Urban habitat damage has been linked to human trampling on rock platforms in southeastern Australia (Povey & Keough, 1991; Keough & Quinn, 1998) and, elsewhere in the world, to high intensities of unregulated diving and snorkelling by inexperienced operators (Tratalos & Austin, 2001). Recreational activities such as boating, snorkelling and diving that bring humans into close proximity with wildlife also have the potential to modify animal behaviour when conducted at high frequency and intensity (Davenport & Davenport, 2006). In particular, the modification of breeding and anti-predator behaviours may lead to adverse ecological outcomes when not managed appropriately (Davenport & Davenport, 2006). Recreational facilities such as walking tracks and bike paths may have significant impacts on surrounding biodiversity. Recreational dog-walking has been shown to have negative effects on biodiversity (Banks & Bryant, 2007), and mountain biking and trail walking may also have negative environmental impacts in relatively natural areas (Taylor & Knight, 2003). Urban recreational amenities such as park cycle ways, therefore, should not be located in or near potentially ecologically sensitive areas such as riparian corridors, mangroves and saltmarshes.

In freshwater and marine systems, urbanisation can change the resilience of systems to storms. In non-urban systems, large storm events can disturb stream ecosystems due to large increases in the volume and flow rate of water from surface runoff (Paul & Meyer, 2001). Stream ecosystems are generally resilient to such disturbances through drift from upstream intact aquatic communities (relatively fast recovery) and the re-establishment of aquatic fauna from the surrounding riparian zone (slower recovery). In urban areas, the increase of ISC decreases the magnitude of rain events causing substantial disturbance to aquatic ecosystems due to changes in hydrology (see section 3.4). Consequently, substantial disturbance occurs more frequently and thus reduces the amount of time that the system has to recover before the next disturbance event. This reduction in recovery time, coupled with decreases in habitat quality in upstream ecosystems and riparian zones due to other urbanisation processes, can decrease the resilience of ecosystems and lead to lower species richness (Roy *et al.*, 2003). Marine ecosystems may also be affected, with increased volumes of stormwater and

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<sup>7</sup> The North Head Precinct Fire Management Strategy is available at [www.environment.nsw.gov.au/resources/firemanagement/final/090538NorthHeadFms.pdf](http://www.environment.nsw.gov.au/resources/firemanagement/final/090538NorthHeadFms.pdf)

quantities of total suspended solids, contaminants and nutrients entering urban estuaries after such high water-flow events, disturbing assemblages.

The presence of hard structures can be particularly disruptive on exposed beaches. In natural beach-dune systems, sand is 'borrowed' from dunes after a storm and transported down the beach face to balance the sediment budget. Beaches are unable to recover from storm disturbance when physical barriers like seawalls interrupt the natural flow of sand, and they will continue to erode to the point where coastal residents – both human and nonhuman – are threatened. In addition to acting as barriers to sediment flows, hard structures may also block the landward migrations of sandy beach fauna in anticipation of storms (Lucrezi *et al.*, 2010; Noriega *et al.*, 2012). Such fauna will likely perish in storms if unable to obtain refuge in backshore areas, with consequent effects on the assemblage composition of beaches. Ecosystem resilience is contingent on the accessibility of 'support areas' (e.g. dunes) to link species that recolonise beaches after storms (Bernhardt & Leslie, 2013). Resilience is compromised when such links are broken and beach fauna decline.

### Artificial structures

One of the most pervasive changes in urban areas is the replacement of natural areas with artificial surfaces such as roads, footpaths, buildings and, in aquatic environments, seawalls, pontoons and pilings, as well as other types of built infrastructure. Many such structures are impervious to resources (i.e. water, gases and sediments, etc., are unable to pass through them), leading to dramatic changes in connectivity in urban areas. They also absorb solar radiation and therefore are a major cause of the UHI effect, while additionally shading adjacent substrate.

Artificial structures replace natural surfaces with novel habitat. Some species may benefit from such habitats and the new resources they offer (Chapman & Bulleri, 2003). Gutters, roofs and building cavities, for example, provide nesting sites for common (or Indian) mynas (Lowe *et al.*, 2011). Swimming nets in Sydney Harbour can enhance seahorse habitat (Clynick, 2008), and subtidal pilings and floating pontoons can increase the surface area available for attachment by marine fouling organisms, which typically are substrate-limited (Glasby, 1999). Although artificial structures can provide habitat, however, such habitats often differ from their natural equivalents in the conditions they provide (Connell & Glasby, 1999; Holloway & Connell, 2002). Compared with natural rocky shores, for example, seawalls are typically dominated by vertical rather than horizontal surfaces and provide a relative homogenous habitat devoid of microhabitats such as rockpools, crevices and complexity; in many instances they are constructed of man-made materials, such as concrete, rather than natural materials (Airoldi *et al.*, 2005; Bulleri, 2005a; Chapman, 2006; Bulleri & Chapman, 2010). Because artificial structures provide a blank canvas for the colonisation of species, the communities they support are often dominated by non-native species that make their reproductive propagules available year-round and which are able to rapidly capitalise on newly available space (Glasby *et al.*, 2007; Tyrrell & Byers, 2007; Dafforn *et al.*, 2012). Consequently, assemblages of organisms that use artificial structures usually differ from their natural equivalents (Connell & Glasby, 1999; Glasby, 1999; Chapman, 2006; Clynick *et al.*, 2008) and cannot be seen as surrogates of lost natural habitat (Connell & Glasby, 1999; Connell, 2001; Chapman & Bulleri, 2003).

The addition of artificial structures not only introduces novel habitat into urban areas, it may also modify the environmental conditions of surrounding habitats. By reflecting wave energy and interfering with natural cycles of accretion and erosion of shorelines, seawalls can cause erosion in adjacent sedimentary shorelines, steepen their profiles and coarsen sediments, altering the availability and quality of habitat for sediment-dwelling organisms (Pilkey & Wright, 1988; Brown & McLachlan, 2002; Dugan *et al.*, 2008). Shading caused by pontoons and pilings can reduce the growth rates and even

cause the death of aquatic macrophytes such as seagrasses (Deslous-Paoli *et al.*, 1998; Burdick & Short, 1999). The new environmental conditions can sometimes change the behaviour, survivorship and fitness of organisms (Clynick, 2008). Golden orb-weaver spiders in Sydney, for example, were found to have greater longevity and higher fitness in areas with increased impervious surface cover, possibly due to increased temperatures (Lowe *et al.*, 2014; Lowe *et al.*, 2016). Fishes may avoid shaded areas under wharves, where it renders them more susceptible to ambush predators and interferes with their ability to detect prey (Toft *et al.*, 2007; Munsch *et al.*, 2014; Ono & Simenstad, 2014).

The addition of artificial structures modifies habitat configurations and connectivity in landscapes and seascapes. Roads, shipping channels and seawalls can fragment habitats (Goodsell *et al.*, 2007; Rhodes *et al.*, 2014), and impermeable structures can reduce ecological connectivity (Bishop *et al.*, in press). For example, groynes constructed perpendicularly to shorelines are designed to impede long-shore sediment transport, but they also impede the long-shore transport of organisms and other resources, such as organic matter (Goodsell *et al.*, 2007; Oldham *et al.*, 2010; Pattiaratchi *et al.*, 2011; Lechner *et al.*, 2014; Bishop *et al.*, in press). In other circumstances, artificial structures can increase the connectivity of organisms, materials, chemicals and energy (Bishop *et al.*, in press). This may be advantageous for some native species, but it can also increase the spread of non-indigenous species (Brown *et al.*, 2006). In marine environments, artificial structures constructed in otherwise sedimentary environments can act as stepping stones for the spread of fouling organisms across previous dispersal barriers (Airoldi *et al.*, 2015; Mayer-Pinto *et al.*, 2015; Bishop *et al.*, in press). In terrestrial systems, roads may aid the dispersal of cane toads (Brown *et al.*, 2006).

### **Changes to the biotic environment**

The extensive changes to the biotic environment caused by urbanisation have been well documented for certain taxa, with international reviews or meta-analyses covering birds (Chace & Walsh, 2006; Aronson *et al.*, 2014), mammals (McKinney, 2008), plants (McKinney, 2008; Aronson *et al.*, 2014), invertebrates (Kaupp *et al.*, 2004; McKinney, 2008; Niemelä & Kotze, 2009), frogs and reptiles (Hamer & McDonnell, 2008; McKinney, 2008). Species have varying responses to urbanisation, but some general patterns emerge from reviews. Overall, for most taxa, species diversity is lower in highly urbanised areas compared with natural habitats outside cities (Hamer & McDonnell, 2008; McKinney, 2008). Reductions in species diversity can have impacts on ecosystem function and services: for example, a reduction in bee diversity in urban areas can lead to a decrease in pollination services, especially for specialist species (Pauw & Hawkins, 2011).

Urbanisation facilitates the accidental and intentional introduction of non-indigenous species into urban ecosystems. Although most introduced species have little impact on surrounding ecosystems, some thrive, either within the urban matrix or in adjacent natural ecosystems (Williamson & Fitter, 1996). This may be particularly apparent in marine environments, where species are frequently introduced inadvertently through ballast water or hull fouling on transport vessels (Carlton & Geller, 1993; Ruiz & Carlton, 2003). Shipping transport routes often link cities, and many species introduced in this way, therefore, are already well adapted to the environmental conditions associated with urban estuaries (Dafforn *et al.*, 2009; McKenzie *et al.*, 2012) and quickly become invasive. The introduction of exotic species can change assemblage composition and affect ecological interactions in urban ecosystems (e.g. marine algae, *Caulerpa taxifolia*, in Sydney Harbour; Mayer-Pinto *et al.*, 2015). On the other hand, sometimes the replacement of native fauna by non-indigenous species can maintain ecosystem function in novel urban ecosystems (e.g. pollination services by the introduced honey bee, *Apis mellifera*; Lomov *et al.*, 2010).

Many studies capture changes to biodiversity along a gradient of urbanisation (McDonnell & Hahs, 2008). Species richness generally increases for plants and birds at an intermediate level of urbanisation but decreases for insects and non-avian vertebrates (McKinney, 2008). The increase in bird and plant richness at an intermediate level of urbanisation can be explained by the heterogeneity of the environments and the intentional introduction of species, particularly plants, in suburban areas (McKinney, 2008; Catterall *et al.*, 2010). Although species richness might increase or remain steady, however, the richness of native species often declines dramatically (Aronson *et al.*, 2014).

Australian cities have recorded changes in their biota. In Adelaide, for example, 132 native species are no longer present in the city, although 648 new species have been added. These changes have been driven mainly by increases in the species richness of introduced plants; for birds, the number of species now locally extinct ( $n = 21$ ) has been offset by the colonisation of new bird species ( $n = 20$ ) (Tait *et al.*, 2005). Mammal declines have been substantial in Adelaide, however, with a decrease of more than 50% of native mammal species in the urban area (Tait *et al.*, 2005). A decline in small-mammal species has also been observed in Melbourne, where only 29 of the 54 historical (pre-European settlement) populations of mammal species are likely to still occur; most of the extinctions have been of small ground-dwelling marsupials (van der Ree & McCarthy, 2005). In Melbourne's Port Phillip Bay, 160 bottom-dwelling marine species that were either introduced or of unknown origin were observed in 1995/1996, mainly around shipping ports (Hewitt *et al.*, 2004). In Sydney, differences in bottom-dwelling invertebrates were observed between urban and non-urban sandy estuarine habitats (Lindgarth & Hoskin, 2001). A comparison between the current and historical (as determined from museum specimens) bird composition in Sydney showed that dramatic changes have occurred in assemblage composition and structure, with larger species (e.g. parrots and carnivorous species) becoming more abundant and smaller species, especially insectivorous birds, decreasing in number (Major & Parsons, 2010). These observations are similar to changes in bird community structures observed in other Australian cities, where large nectarivorous birds have become more dominant and the number of small insectivorous birds has declined (Sewell & Catterall, 1998; Catterall *et al.*, 2010), although these patterns differ from those observed in urban areas globally (Chace & Walsh, 2006).

Organisms in urban areas can be classified into species that persist in (urban adapters), thrive in (urban exploiters) or avoid (urban avoiders or urban-sensitive species) urban environments. Urban exploiter species may be pre-adapted to the novel environments in urban environments (e.g. disturbance specialists), or they may have adapted to the new conditions presented to them in cities (McKinney, 2006; McDonnell & Hahs, 2015).

Many factors can potentially change the ability of species to tolerate urban areas, including changes to abiotic conditions (see above), resource availability (Cleary *et al.*, 2016), and biotic interactions (Parsons *et al.*, 2006; Howes *et al.*, 2014; Turrini *et al.*, 2016). For example, the reduction of dense native mid-storey vegetation in suburban areas has led to a reduction in small insectivorous birds, such as the superb fairy-wren, *Malurus cyaneus* (Parsons *et al.*, 2008). Alternatively, the availability of some resources may be greater in the urban matrix than in remnant vegetation, leading to increased abundances of species that use those resources. The planting of exotic flowering plants, and native vegetation with prolific flowering displays or durations, increases the availability of nectar in Australian cities compared with adjacent remnant vegetation (Davis & Major *et al.*, 2015). This increase in the abundance and consistency of nectar resources in urban areas had led to an increase in populations of larger nectarivorous birds (Davis & Major *et al.*, 2015). Such changes in the availability of resources in urban environments can affect intra- and interspecific interactions, which, in turn, can affect trophic systems (Faeth *et al.*, 2005; Fenoglio *et al.*, 2013; Maron *et al.*, 2013). Mechanistic effects can be disentangled from the overall process of urbanisation as a whole by quantifying the effect of various

aspects of urbanisation on the physiology, morphology, behaviour and fitness of species in urban areas (e.g. Lowe *et al.*, 2014; Meillere *et al.*, 2015).

The differing pre-adaptability of taxa, or their ability to adapt to the novel environments found within the urban matrix, leads to changes in the composition of assemblages in urban areas compared with native habitats (**Table 1**). The sensitivity of particular functional groups to urbanisation affects the composition, structure and function of urban assemblages and leads to changes in ecological interactions (Lotze *et al.*, 2006; Howes *et al.*, 2014; Turrini *et al.*, 2016).

**Table 3.1.** Examples of studies that demonstrate changes in the functional composition of assemblages in urban areas compared with non-urban areas.

Classification	Specification	Observed trends in urban areas compared with non-urban areas	Reference
Plants	Grassland plants	Fewer plants with underground storage organs or buds that persist during winter at the soil surface in urban areas compared with non-urban areas. Fewer plants with wind or ant seed dispersal	Williams <i>et al.</i> (2005)
Nematodes		Fewer omnivorous and carnivorous species observed in urban riparian soils compared with non-urban riparian soils	Pavao-Zuckerman & Coleman (2007)
Arthropods	Carabid beetles	More small, open-canopy specialist beetles and fewer omnivorous, predatory and forest-dwelling species in urban areas compared with non-urban areas	(2004); Niemelä & Kotze (2009); Vergnes <i>et al.</i> (2014)
Vertebrates	Amphibians	More generalist species and species with lower dispersal requirements in urban environments	Hamer & McDonnell (2008)
	Birds	In Australia, more larger nectarivorous birds in urban areas and fewer small insectivorous birds	(2005); Catterall <i>et al.</i> (2010); Major & Parsons (2010)
	Microbats	Greater activity among fast-flying species with flexible roosting and foraging requirements in urban areas compared with species that are sensitive to night light, are slower-flying, or have more specialised roosting requirements	Threlfall <i>et al.</i> (2012)

Cities worldwide are similar in form, and species that are particularly adapted to living in one highly modified city are likely to be similarly able to survive and flourish in another (Evans *et al.*, 2010). If dispersal can occur between cities, such species (e.g. rock doves and house sparrows) can become ubiquitous components of urban biodiversity. If the distributions of species that are pre-adapted to living in urban areas (Chown & Duffy, 2015; McDonnell & Hahs, 2015) span several cities (e.g. rainbow lorikeets and noisy miners in Australia), they may also become key components of urban landscapes. The dominance of some species in urban environments can lead to the homogenisation of biodiversity across cities globally (McKinney, 2006). Even though species richness is often high in cities, at least in suburban areas, the ‘sameness’ of urban biodiversity and the increasing area of land converted to urban landscapes reduces global biodiversity. Thus, protecting and managing native species in urban areas can

have benefits for global biodiversity conservation. Section 3.6 focuses on practices for managing and protecting native biodiversity, particularly locally indigenous species.

### 3.6 Conservation actions and design interventions

The causes of biodiversity declines in cities are varied and taxon-specific. Mitigating a decline in biodiversity thus requires an integrated approach that identifies and addresses major causes. This section highlights conservation actions that can be taken to protect and enhance urban biodiversity. Evidence from the scientific literature, including meta-analyses, scientific experiments, correlative surveys and modelling, and computational analyses, are used to support the recommendations made. Examples of projects that integrate best practice into their management plans or designs are provided. Recommendations are provided in two parts: conservation actions that require landscape-scale management and planning, and those that can be implemented at a local scale.

#### Spatial planning

The large spatial extent of urbanisation and the connectedness of ecosystems in landscapes mean that, for many conservation actions, landscape-scale approaches are necessary. Often, planning decisions and assessments of development impacts on biodiversity are made at small spatial scales or are based on only a few species. This can lead to the accumulation of impacts that degrade ecosystems through the incremental loss of habitat, the reduction of habitat quality and the introduction of multiple stressors. To mitigate the accumulation of impacts, sometimes termed ‘death by a thousand cuts’ (Laurance, 2010) or ‘death by a thousand pipes’ (Davies *et al.*, 2011), landscape and regional planning must replace case-by-case decisions (Whitehead *et al.*, 2016). This section highlights how spatially explicit planning and effective policy can conserve urban biodiversity by retaining native remnant patches in their entirety; providing spaces for corridors; catchment management and design; the spatial arrangement of artificial marine structures; and the design of compact urban development interspersed with large green spaces overlapping with areas of high ecological value. Such landscape decisions need to be made in the planning stages of development at the regional (metropolitan) to subdivision planning scales. Poor management decisions are often hard to reverse, and it is more expensive to retrofit solutions later.

#### Large native remnant patches

##### Conservation action summary

- Retain all remnant terrestrial, freshwater and marine habitats.
- Maintain the quality of remnant habitats and their suitability for core-dependent species by maintaining or increasing the size of reserves rather than decreasing reserve size.
- Monitor the quality of existing remnant habitats and mitigate reductions in habitat quality by restoration and addressing the causes of quality reductions.

A central tenet of the academic literature describing the responses of biodiversity to urbanisation is the importance of large areas of remnant habitat (see section 3.5). Many studies reported in the literature recommend the retention of large patches of remnant habitat in urban areas for the benefit of multiple taxa, including birds (e.g. Catterall *et al.*, 1989; Sewell & Catterall, 1998; White *et al.*, 2005; Palmer *et al.*, 2008; Aronson *et al.*, 2014), plants (e.g. Hahs *et al.*, 2009; Aronson *et al.*, 2014), amphibians (e.g. Hamer & McDonnell, 2010) and mammals (e.g. Basham *et al.*, 2011). These large urban remnants are particularly important for the provision of resources that are absent or limited in the urban matrix and for providing crucial habitat for interior-specialist species that may be unable to survive in other areas in cities. In Melbourne, for example, native vegetation planted along streets supported a large number of

native bird species, but some species, predominantly small insectivorous birds, were not found in the urban matrix (White *et al.*, 2005). Protecting and maintaining large remnant patches of terrestrial, riparian, coastal and marine habitats should therefore be one of the main – if not the highest – priority in planning for the maintenance of biodiversity in cities (White *et al.*, 2005; Palmer *et al.*, 2008).

Land clearing for development and the introduction of artificial structures and infrastructure decreases the patch size of remnant habitat. Taken separately, decisions to clear small areas on sites may involve only small losses of remnant habitat; taken together, however, multiple case-by-case decisions can mean considerable habitat losses. Incremental losses ultimately result in small patch sizes and the consequent loss of biodiversity and reduction in habitat quality (Laurance, 2010). Offsetting schemes like the NSW BioBanking scheme, where an equivalent area of habitat is ‘reserved’ in exchange for clearing a piece of bushland, does not adequately curb the incremental loss of remnant habitat. Clearing one site in exchange for protecting another necessarily leads to an overall reduction in habitat (because the now-protected habitat already exists); thus, the claim of ‘no net loss’ is more correctly termed ‘averted loss’, with some existing habitat protected from future development. Such offsetting schemes are further compromised in their assessment of equivalence. The assumption that vegetation complexity, when measured and transformed into a single score, provides a surrogate for the compositional and functional biodiversity of a site has been demonstrated to be invalid for a critically endangered ecological community in western Sydney (Hanford *et al.*, 2016). Moreover, under the NSW BioBanking policy, when no equivalent ecosystem is available it is permitted to offset land clearing in ecosystems of different ecological communities (Maron *et al.*, 2016). The logical outcome of clearing land with no equivalent offset is a reduction in biodiversity.

Monitoring the occurrence of species in habitat remnants of different sizes allows for threshold analyses to determine the minimum size that remnants need to be able to support viable populations (Fahrig, 2001). Drinnan (2005) conducted field surveys of birds, frogs, plants and fungi in urban fragments of Sydney sandstone woodland and Sydney sandstone gully forest in southern Sydney of differing sizes and shapes and found that bird and frog species richness declined rapidly in remnants less than 4 ha in size, while plants and fungi had a threshold of 2 ha. Certain species are more affected by reductions in area than others, however (Palmer *et al.*, 2008). More sensitive species are rarely associated with the edges of large remnants and are not found in smaller remnants; they are referred to, therefore, as ‘interior specialists’. Minimum size thresholds of remnant habitat differ dramatically for such species. Drinnan (2005) found that the minimum size of remnant habitat indicated above were inadequate to support interior-specialist birds; 50 ha was a more adequate threshold for such species. The values estimated by Drinnan (2005) are similar to the average values calculated from a global synthesis of data on the impact of urbanisation on biodiversity across multiple taxa, which specified thresholds of  $53 \pm 12.1$  (SE) ha for interior-specialist species and  $4.4 \text{ ha} \pm 0.85$  (SE) for urban-adapted species (Beninde *et al.*, 2015). A study of urban-sensitive microbat species in Sydney also estimated that a minimum size of 40 ha was required to support populations of the light-sensitive long-eared bat (Threlfall *et al.*, 2013).

The minimum threshold habitat area will differ for individual species and between ecological communities, depending on the reproduction potential of a species, the rate of emigration from a remnant, the quality of the surrounding matrix and, to a lesser extent, the habitat pattern (Fahrig, 2001). Determining the threshold for a species, therefore, requires basic biological knowledge of the organism. Because the minimum size threshold varies between species, actions aimed at conserving urban biodiversity should not set limits on remnant habitat size at average values; rather, the minimum size threshold required for the most area-sensitive species should be determined and then used to inform management practices (e.g. Watson *et al.*, 2001).

Cities often carry an 'extinction debt', in which non-viable populations of organisms persist in areas where they will eventually become locally extinct (Hahs *et al.*, 2009). Average minimum thresholds, therefore, may underrepresent the area needed for viable populations and, where possible, management decisions on minimum sizes of remnant habitat should account for this possibility by conserving areas larger than the estimated average minimum threshold. Relatively young cities like Sydney are more likely than older cities to carry an extinction debt because, although they retain significant areas of natural habitat, substantial areas have been lost in recent decades, and long-lived species may take decades to centuries to become extinct in remaining habitat fragments (Kuussaari *et al.*, 2009).

Species-specific approaches can also be used to calculate minimum size thresholds, especially when a particular target species is of conservation concern or poses ecological problems. Understanding the use of the space by a target species, in both remnant vegetation and the urban matrix, can enable managers to counteract reductions in urban biodiversity caused by problem species through spatial planning. For example, by observing the distances from edges that aggressive edge-specialist noisy miners nested in (20m) and used regularly (100m) and infrequently (up to 200m), Piper and Catterall (2003) determined that this species would entirely dominate patches less than 10 ha in size. Patches 10 ha in size or smaller, therefore, are unlikely to support those small insectivorous birds excluded from areas by noisy miners.

Human disturbance needs to be minimised in large remnant habitats, especially in their interiors and around riparian zones (Marzluff & Ewing, 2001; Kang *et al.*, 2015). Pathways and other infrastructure have the potential to make core areas of remnant habitats unsuitable for interior-specialist species and their installation, therefore, should be limited to the outer edges.

## Restoration

### Conservation action summary

- In restoration projects, select realistic benchmarks and timelines, address the original causes of decline, and provide ongoing monitoring with adaptive management, including after project completion.
- In natural areas where the causes of decline cannot be addressed, accept the emergence of novel ecosystems that still provide ecosystem functioning and services.

One way of increasing the area of remnant habitat to support urban biodiversity and ecosystem services is the restoration of existing patches of lower quality, or the rehabilitation of areas modified for other purposes. The practice of habitat restoration spans marine, terrestrial and riparian ecosystems. The extent of restoration depends on the extent of degradation and the historical context of a given site. The restoration of degraded sites within an existing remnant habitat may only require the addition or removal of focal species; on the other hand, restoration efforts in heavily degraded sites may need to change soil chemistry or structure, remove chemicals and artificial structures, or change vegetation to allow the establishment of target species (Hobbs & Norton, 1996). Habitat restoration projects can be divided into three broad types, based on the extent of intervention: 1) natural regeneration (i.e. natural recovery following cessation of degrading practices); 2) assisted regeneration (i.e. the removal of causes of degradation plus active interventions); and 3) reconstruction (in which almost all biota need to be reintroduced) (McDonald *et al.*, 2016).

Many restoration projects in urban areas have improved habitat quality and restored ecosystem functioning. For example, saltmarsh habitat was restored at Sydney Olympic Park and the Tomago Wetland, resulting in a return of several bird species to the area (Saintilan, 2013). Crayweed has become

re-established in coastal waters around Sydney, allowed the formation of macroalgae forests that provide important habitat in marine areas (Campbell *et al.*, 2014). In western Sydney, revegetation of the endangered Cumberland Plain woodland led to an increase in species richness of butterflies and moths compared with the pastures from which it was converted (although species richness was still lower than in bushland sites; Lomov *et al.*, 2006). Despite a lower species richness of ants at regenerated sites in the Cumberland Plain woodland, and the dominance of pollinator communities by the European honey bee *Apis mellifera*, seed removal and pollination ecosystem functions were equivalent to bushland reference sites (Lomov *et al.*, 2009, 2010). These projects demonstrate that although species composition may be dissimilar in regeneration sites compared with natural sites, ecosystem functions may be restored, and rehabilitation and restoration can still be beneficial in urban areas.

In *Framework for Restoration Ecology*, Hobbs and Norton (1996) pointed out that, for restoration to succeed, the causes of degradation need to be identified and processes put in place to remove or minimise them. Without removing the causes of the problem, resources will be put into restoring sites that will likely continue to degrade. Restoration projects require benchmarks that set realistic goals of restoration, the history and context of the site should be considered, and observable measures should be determined for evaluating success in achieving restoration goals (Hobbs & Norton, 1996). Restoration projects should also take into account the future climate to which a restored area may be exposed. If local-provenance plants are unlikely to survive predicted future climatic conditions, genetic stock from areas with climates similar to those predicted in the future should be used (Hancock *et al.*, 2016; McDonald *et al.*, 2016). Restoration sites should be subject to ongoing monitoring, and processes should be modified if goals are not being achieved (Hobbs & Norton, 1996). The components of *Framework for Restoration Ecology* were recently integrated into the National Standards for the Practice of Ecological Restoration in Australia (McDonald *et al.*, 2016), which provide guidance for restoration and rehabilitation projects in Australia, including in urban areas.

*Framework for Restoration Ecology* highlights some significant issues in efforts to restore sites in urban areas to pre-urban conditions. Land-use history, current nearby land management practices, and the new species assemblages in the urban matrix may mean that ecosystems are unable to ever return to a pre-urbanised condition, despite restoration efforts (Bernhardt & Palmer, 2007). In such circumstances, the National Standards for the Practice of Ecological Restoration in Australia recommend that the rehabilitation<sup>8</sup> of a site would be more appropriate than restoration (McDonald *et al.*, 2016). The scale and multifunctionality of urban areas often mean that the problems that have led to degradation are unable to be moderated (e.g. decreased fire regimes in remnant vegetation surrounded by residential housing, changes to soil chemistry due to fertiliser use, and irreversible changes to hydrology due to artificial modification). Given this, expectations may need to be lowered on what is achievable in restoration (Bernhardt & Palmer, 2007), and acceptance may be needed of novel ecosystems (Hobbs *et al.*, 2006) that maintain ecosystem function and provide ecosystem services. Another problem for restoration in urban areas may be an absence of reference sites that reflect pre-urban conditions. For example, oyster reefs were once dominant in Sydney but, by 1989, virtually no oysters occurred in

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<sup>8</sup> The National Standards for the Practice of Ecological Restoration in Australia distinguish between restoration and rehabilitation. **Restoration** projects are 'projects that aim to ultimately achieve full recovery relative to an appropriate local indigenous reference ecosystem. ... Full recovery is defined as the state whereby all ecosystem attributes closely resemble those of the reference ecosystem' (p. S7); **rehabilitation** projects are 'based on a local indigenous reference ecosystem but [are] unable to adopt the target of full recovery' (p. S7) (McDonald *et al.*, 2016).

Sydney Harbour (Birch *et al.*, 2013). Efforts to restore oyster reefs in the harbour for biodiversity, coastal protection and water filtration purposes (Gillies, 2016) therefore lack local reference sites.

The magnitude of problems facing habitat restoration in urban areas is illustrated by stream restoration. Maintaining high-quality streams is beneficial for numerous ecosystem services, including water provision, water filtration, bank stabilisation, habitat provision and aesthetic value, and restoring degraded streams in urban environments, therefore, would provide multiple benefits. Much effort has been put into doing so, especially in the US (Bernhardt & Palmer, 2007). Urban streams, however, suffer from changes in hydrology due to the installation of impervious surfaces and resultant changes in geomorphology, increases in levels of contaminants, sediments and nutrients from runoff, changes in the quality and quantity of natural organic matter, the reduction of aquatic species, and the clearing or degradation of riparian vegetation. Restoration efforts, therefore, may require, for example, the in-stream re-establishment of habitat complexity, the modification of bank morphology (e.g. channel reconfiguration and bank regrading), and the re-establishment of native riparian vegetation, including the removal of weeds. Restoring in-stream complexity may involve installing debris dams, rocks and logs, removing accumulated fine sediments, and maintaining added structures free of fine sediments. Although such measures may be beneficial for biodiversity, they may be unsuitable in many urban streams due to the risk of flooding during storm events (Groffman *et al.*, 2005), especially when large areas of impervious surfaces are connected to a stream. Moreover, habitat structures and other features associated with bank stabilisation may be washed downstream during peak flows because of the high stream power associated with urban runoff. Attempts to recreate habitats based on reference sites in natural areas may therefore be inappropriate for the rehabilitation of urban streams (Bernhardt & Palmer, 2007).

Native riparian vegetation is important for bank stabilisation, with plant roots helping to hold soils together. Riparian vegetation also deposits large and small woody debris into streams, thereby providing habitat and food for fish and invertebrates. Importantly, native riparian vegetation generates leaf litter to which in-stream biota are adapted; the leaf litter generated by exotic vegetation species, on the other hand, typically has different nutritive values to native vegetation, and such species may shed leaves at different times of year (thus providing organic matter influxes at times when normally they would not occur). Riparian vegetation provides habitat for the terrestrial adults of aquatic invertebrates and therefore has an important function in supporting in-stream communities, also providing shade for streams that is crucial for maintaining water temperature. Restoring good-quality riparian vegetation should be an aim of riparian stream regeneration, and it should be done regardless of the minimum width of land available for restoration (e.g. due to pathways or development; Bernhardt & Palmer, 2007). In addition to restoration measures, it is essential to minimise the factors that originally caused the stream degradation. This might require changing the hydrology by reducing the area of ISC and the connectedness of those surfaces with streams (e.g. through the use of WSUD features; see section 5.6) and the removal of contaminants, sediments and nutrients entering streams through runoff. The inability to convert a sufficiently large area of developed land in a catchment to WSUD (see section 3.6) to minimise the effective area of impervious surfaces means that the goal of restoring streams to a pre-development state is often unreasonable (Bernhardt & Palmer, 2007). The goal of rehabilitating ecosystem function in modified stream is more realistic.

## Green corridors

### Conservation action summary

- Provide habitat corridors to facilitate movement through the urban matrix between habitat patches. Riparian zones are especially effective as habitat corridors.

- Minimise the use of corridors for human recreation, especially in the centres of corridors.
- Determine the potential for using existing linear infrastructure as corridors, and identify where improvements can be made to increase their function as corridors.
- Create buffer zones alongside corridors by implementing biodiversity-friendly management actions in surrounding green spaces (e.g. the retention of remnant trees, providing complex habitats, and decreasing the use of pesticides).

In a global review across multiple taxa on the impact of urbanisation on biodiversity, patch area and the presence of corridors were found to be the most positive drivers of biodiversity, although these findings were based on only a small number of studies (Beninde *et al.*, 2015). Corridors were more significant for enhancing biodiversity than ‘stepping stone’ habitats, and the authors concluded that, although increasing habitat area was the most important component determining biodiversity, maintaining functional corridors was the second-most important (Beninde *et al.*, 2015). A functional corridor is one in which structural features (e.g. trees) facilitate animal movements and other dispersal events that lead to gene flow (Taylor *et al.*, 1993). The creation of corridors may therefore play a key role in the conservation of taxa that require dispersal within the urban matrix for persistence (e.g. Mortberg & Wallentinus, 2000; Hamer & McDonnell, 2008, 2010; Kang *et al.*, 2015). However, the addition of corridors to a landscape is unlikely to be a substitute for reducing habitat area (Harrison & Bruna, 1999).

The benefits of corridors for dispersal can be evaluated by comparing assemblages in patches of habitat near or connected to corridors with those unconnected to corridors. Such comparisons have shown benefits of corridors for a number of taxa: mammals (FitzGibbon *et al.*, 2007; Munshi-South, 2012); birds (Mortberg & Wallentinus, 2000; Drinnan, 2005; Kang *et al.*, 2015); frogs (Drinnan, 2005); plants (Drinnan, 2005; Penone *et al.*, 2012); and invertebrates (Vergnes *et al.*, 2012). A number of studies, however, found no benefits to dispersal via corridors, at least for some taxa, beyond the benefits afforded by the associated increase in habitat area (Whitmore *et al.*, 2002; Angold *et al.*, 2006). Variation in observed responses to corridors appears linked to the movement and dispersal abilities of the studied organisms (Penone *et al.*, 2012; Vergnes *et al.*, 2012). In one study, for example, no effect of corridors was observed for spiders (for which dispersal is based mainly on wind as juveniles), but rove beetles had higher species richness in gardens connected to woodlands by corridors compared with disconnected gardens (Vergnes *et al.*, 2012). In evaluating the benefits of corridors for dispersal across multiple taxa, Angold *et al.* (2006) found that corridors may aid the dispersal of some small mammal species but had no effect on the dispersal of invertebrates (beetles and butterflies) and plants. Although the role of corridors in dispersal is inconsistent across taxa, the benefits provided by corridors for the dispersal of some species, and the benefit for others of the extra habitat (Angold *et al.*, 2006), justifies the incorporation of corridors into urban spatial planning, although more research is required (Beninde *et al.*, 2015). A greater understanding of which species in an urban environment require, or benefit from, corridors will allow managers to make local modifications to corridors to increase their functionality for those species (Fernandez-Juricic, 2000).

The incorporation of functional corridors in linear infrastructure in the urban matrix has been demonstrated for several species. In New York City, for example, functional corridors existed in the urban matrix between populations of the white-footed mouse (*Peromyscus leucopus*) in isolated city parks, incorporating cemeteries, thin linear parks and street medians, because of the canopy cover those areas provided (Munshi-South, 2012). Linear infrastructure such as railway lines can enhance connectivity in landscapes, at least for plants (Penone *et al.*, 2012). There is potential to increase the functionality of space in existing linear infrastructure such as highways, road medians (**Figure 3.11**), railway lines and areas provisioned for power lines to include habitat provision. For example, native

regrowth along highways in Perth was found to have a higher species richness of ants than residential backyards, and although the assemblages were distinct from bushland sites, the vegetated corridors along highways could function as source populations for the surrounding urban matrix (Heterick *et al.*, 2013). More research is required into this potential management strategy in Australia; Sydney's suburban rail system<sup>9</sup>, for example, includes 369km of easements of varying widths and degrees of vegetation (Cielo Roldan, NSW Transport: Asset Standards Authority, *pers. comm.*).

a)



b)



**Figure 3.11.** Vegetated road medians in Sydney. **a)** Glebe. **b)** Macquarie Centre, North Ryde. Source: F van den Berg (taken 2016).

Because corridors are often long and thin, they have high edge-to-area ratios (**Figure 3.3**) and are therefore likely to provide more functional habitat, and thus be more appropriate for dispersal, for edge-specialist species, which are often already overrepresented in urban areas compared with interior specialists (Mason *et al.*, 2007). High edge-to-area ratios in corridors increase the likelihood that factors from the surrounding urban matrix, such as pesticides, high-nutrient stormwater runoff, and exotic pest species, will permeate in, decrease habitat quality in corridors. Despite assertions that corridors increase the dispersal of pest species, however, a literature review and meta-analysis found no evidence for non-native invasions into habitat due to corridors (Haddad *et al.*, 2014). Edge effects in corridors can be minimised by buffering efforts to make the surrounding built environment more biodiversity-friendly (Hostetler *et al.*, 2011) and by increasing corridor width to decrease the edge-to-area ratio, which will both increase the habitat quality of the corridor and encourage its use by interior-specialist species (Mason *et al.*, 2007). Note that the installation of recreational infrastructure such as cycle and pedestrian tracks through the middle of corridors acts to reduce their functional width (Mason *et al.*, 2007).

Making use of riparian zones as corridors has the advantage of using and protecting an existing natural linear structure that already has high ecological value and increases the area of habitat available for

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<sup>9</sup> The Sydney rail network spans an area encompassing Berowra, Richmond, Carlingford, Emu Plains, Macarthur and Waterfall.

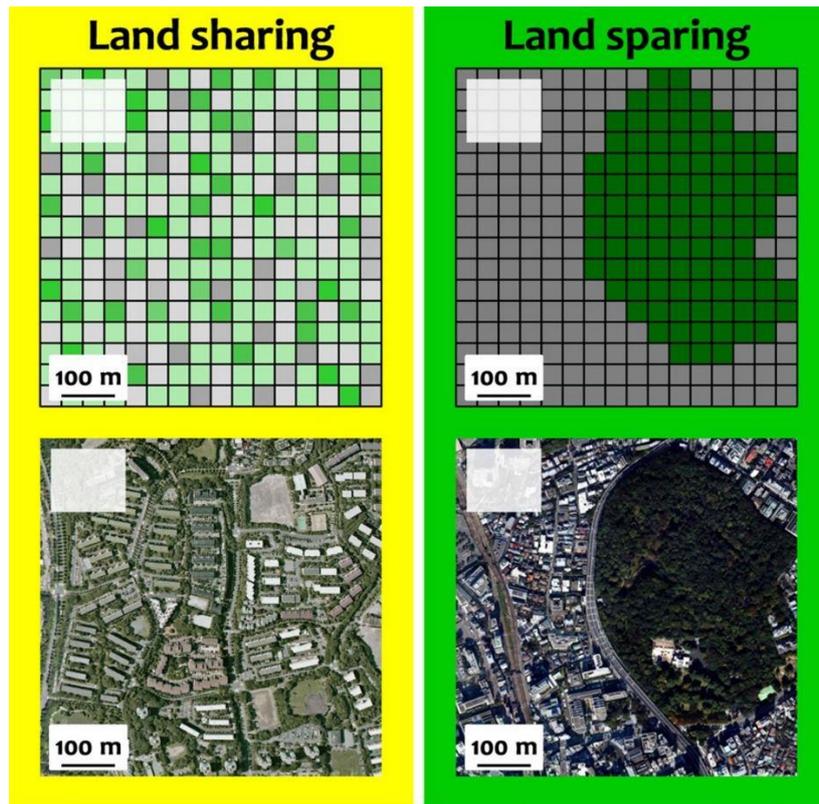
riparian-dependent species (e.g. aquatic organisms) (Angold *et al.*, 2006; Palmer *et al.*, 2008), which can be important for conservation (Hamer & McDonnell, 2008). Although the benefits of using riparian-zone vegetation as corridors are not always apparent (Dallimer *et al.*, 2012), riparian vegetation is an important component of riparian ecosystems and provides habitat. For example, it is a key determinant of avian species richness, especially when integrated with remnants (Palmer *et al.*, 2008). Riparian zones can also provide crucial habitat for the adult life stages of aquatic insects, which are essential to the health of streams important in the provision of ecosystem services (e.g. leaf-litter decomposition). Restoring riparian-zone vegetation and the active management of that vegetation, therefore, will have multiple benefits – providing linear corridors between patches of remnant vegetation, maintaining stream integrity by regulating organic matter input into streams, and providing essential habitat.

## Urban sprawl or compact urban development

### Conservation action summary

- Prioritise compact development over sprawling development as the relatively few existing studies suggest that this will have the least ecological impact.
- Identify and conserve areas of high ecological significance when planning for compact development. Areas of lower ecological significance within the remaining land area can then be identified for development.
- Maintain relative density of high-density residential zones at a level that allows the retention of some biodiversity.

There are two main scenarios for urban development: urban sprawl, and compact urban development. These are analogous to ‘land sharing’ and ‘land sparing’ in debates on agricultural ecosystems (Lin & Fuller, 2013). Urban sprawl is associated with low-density dwellings, usually with a high proportion of private green spaces (e.g. backyards). Compact urban development scenarios, on the other hand, are characterised by high-density living, with large green spaces interspersed among high-density housing areas. Ecologically, sprawling developments are thought to have a lower ecological impact than the same unit area of compact development, but the total area of land required for sprawling development is much larger than required for compact development (Lin & Fuller, 2013; Sushinsky *et al.*, 2013) **(Figure 3.12).**



**Figure 3.12.** Examples of two types of development. The yellow column demonstrates sprawling development, which has low-density housing with a high proportion of private green space but a low proportion of large public green spaces. The green column demonstrates compact development, characterised by high-density development, with a low proportion of private green space but, crucially, large areas of ‘spared’ green space. The top row represents the concept of sprawling versus compact development using pixels. The intensity of green in each pixel depicts the amount of vegetation in each pixel; grey cells have little vegetation and dark-green pixels have dense vegetation. The lower row comprises aerial photographs demonstrating the two types of development. Image from Soga *et al.* (2014).

The ecological impact of the two urban development scenarios has not been widely studied, but those studies conducted to date concluded that, although both scenarios decrease biodiversity (Sushinsky *et al.*, 2013), compact development, despite high human population densities and intense land use in built areas, is preferable for urban biodiversity at the landscape scale (Sushinsky *et al.*, 2013; Concepcion *et al.*, 2016), especially at high levels of urbanisation (Soga *et al.*, 2014). This is mainly because of the retention of large green spaces and remnant vegetation in compact development, which is necessary to provide habitat for interior-specialist species (Threlfall & Williams *et al.*, 2016), sustain the provision of ecosystem services (Stott *et al.*, 2015), and maintain access to public green space (Sushinsky *et al.*, 2013; Stott *et al.*, 2015). In reality, however, not all areas of compact development have large green spaces, and many types of green spaces (public, private, large and small) may be needed to maintain people’s access to nature.

Careful planning at the city spatial scale can enhance the biodiversity benefits of compact urban design by identifying areas to be maintained as large green spaces and those to be developed. ‘Spared’ green spaces should overlap with areas identified to have high ecological significance, and built areas should be concentrated primarily on land with low biodiversity value (in terms of net biodiversity loss; Lopucki & Kiersztyn, 2015). Areas of high ecological value should be identified based on habitat preferences, the minimum size threshold for maintaining viable populations, and the capacity for dispersal between patches (Polasky *et al.*, 2008). Local council planners often lack sufficient ecological knowledge, however, to plan for biodiversity, and they tend to prioritise recreational or health benefits over

biodiversity when planning green spaces rather than strive to achieve the three benefits concurrently (Sandström *et al.*, 2006).

Compact development through, for example, the construction of multi-resident dwellings, subdividing existing properties, and in-fill increases the density of both housing and population in an area. In a study in the United Kingdom, increases in housing density generally led to reduced ecosystem metrics such as tree cover, gardens and green space, water runoff and carbon sequestration, although, even at high densities, there was variation in the extent of such reductions (Tratalos *et al.*, 2007). Bird species richness increased as housing densities increased from low to medium but declined at higher densities, even for urban-adaptor species. For most species, abundance had a hump-shaped distribution with increasing housing density. For urban-avoider species, however, richness did not increase as housing densities increased beyond 'low' (Tratalos *et al.*, 2007). Therefore, although compact development may be better for biodiversity overall, there can be decreases, even in urban-adaptor species, at high to very high densities (Tratalos *et al.*, 2007).

Similar responses were observed in microbat responses to changes in housing density in Melbourne. For most bat species, even low housing densities caused a decrease in occurrence probability and activity. Responses were dependent, however, on whether bats were matrix, patch or edge specialists. The occurrence and activity of patch and edge specialists were halved at densities of 11–45 dwellings per ha and 26–103 dwellings per ha, respectively. Vegetation only positively affected activity at low housing densities. For microbats, land sharing is impractical as they occur only at very low housing densities. Land sparing was a better option for microbats in Melbourne if at least 20% forest cover was maintained (Caryl *et al.*, 2016). Conversely, a study of microbats in Sydney found that many urban-sensitive species could persist if 30% tree cover was maintained in moderately urbanised areas (Threlfall *et al.*, 2012), suggesting that the ecological impact of land sparing or sharing is likely to be species- and city-specific.

Increasing population density decreases the access of residents to private green spaces by reducing backyard area, which is important in fostering connections with nature (Sushinsky *et al.*, 2013). Moreover, although access to public green spaces is maintained in compact development, the amount of green space provided in cities, at least in Europe, is often a function of the size of the city rather than the population density, with the outcome that compact cities actually provide very little green space per capita (Fuller & Gaston, 2009). This can lead to the over-use of public green spaces, reducing their ecological integrity by increased human disturbance of them (Kang *et al.*, 2015).

## Catchment design

### Conservation action summary

- Decrease the amount of ISC within a catchment, particularly close to streams.
- Reduce the connectedness of ISC to streams across a catchment by retaining water at the source through the use of rain tanks, water-holding landscape features such as wetlands, bioretention basins, raingardens (WSUD), and unsealed soil.
- Restore riparian-zone vegetation to promote evapotranspiration and stormwater interception.

Designing cities that are 'friendly' to the biodiversity of aquatic ecosystems requires management at a large spatial scale. Healthy riparian ecosystems are important for the maintenance of urban biodiversity, with riparian-zone condition correlated with the species richness of birds, aquatic invertebrates and aquatic vertebrates. Catchment design is also important for estuaries, which are the ultimate receiving waters. Diffuse runoff from urban areas and increased sedimentation from destabilised soils is a major issue in estuarine areas. Minimising the extent of impervious surfaces in a

catchment can help avoid the degradation of streams that are in good condition (Arnold & Gibbons, 1996). A high ISC in urban areas was a major factor in the loss of species richness and assemblage structure in urban streams in northern Sydney (Davies *et al.*, 2010). An ISC higher than 10–20% is a threshold level above which stream degradation, as indicated by numerous measures of stream quality, starts to occur (Paul & Meyer, 2001). The effect of ISC increases as its proximity to streams increases (Wang *et al.*, 2001). Thus, undeveloped buffer zones along streams are recommended (Wang *et al.*, 2001). In new development areas, spatial planning should aim to minimise total ISC and increase the distance between areas of high ISC and streams. This planning should be done at a catchment scale rather than development by development. Catchment boundaries often span multiple council areas, so collaboration is needed between councils, or governing bodies that operate across councils need to be established.

In urban areas that are already extensively developed, reducing the total ISC can be challenging, although impervious materials can be replaced in some instances by porous substitutes that allow water to infiltrate into the ground. It may be possible to retain the total area of ISC at a lower level of impact if the connectedness of ISC with the stream area can be reduced (Walsh *et al.*, 2005).

There are two possible scenarios for reducing connectedness. First, stormwater can be transported away from its sources towards watercourses using traditional water management (e.g. drains, pipes and culverts) and stalled in water-holding structures before it enters natural watercourses. This will reduce the speed at which water enters streams. During even moderate rainfall events, however, the volume of runoff generally exceeds the capacity of such holding structures, reducing the mitigation effect. In the second scenario, the connectedness of ISC is broken at the source through a series of WSUD features such as wetlands, rain tanks, raingardens and bioretention basins, with the aim of maximising the time that water is held at the source (Walsh *et al.*, 2005). Such practices can also benefit residents because the retained water can be used for other purposes, such as irrigation or, if treated, household uses; they also reduce the volume of runoff entering streams and more closely mimics pre-urbanisation flow rates back to streams. Walsh *et al.* (2005) recommended that water-holding features should be associated with all impervious surfaces in a catchment, and, if these measures are undertaken, the area of ISC that can be maintained in the catchment could be as high as 50% without affecting stream quality.

Once catchment-scale WSUD is implemented, the riparian zone can be restored with native vegetation and in-stream habitat to promote biodiversity in urban streams.

### Spatial planning in marine areas

#### Conservation action summary

- Conduct spatial planning of marine areas, including where to introduce artificial structures, to reduce the cumulative impacts of multiple human uses.
- Due to changes in connectivity caused by artificial structures, assess potential development sites to determine whether areas are 'sources' or 'sinks' of aquatic organisms, and avoid development in areas that are sources.
- Avoid developing areas that support endangered or threatened species or ecological communities.

In terrestrial systems, comprehensive, integrated land-use planning is a central component of development, but such coordinated approaches are lacking in marine systems (Douve, 2008). The marine environment is governed sector by sector, which leads to uncoordinated, fragmented and, often, disjointed rules and regulations (Foley *et al.*, 2010). Environmental impact assessments and reviews of environmental factors generally consider the impacts of developments in isolation and at the local scale. Such approaches fail to acknowledge the potential for cumulative impacts of multiple

developments in highly urbanised estuaries (Dafforn & Glasby *et al.*, 2015). Elsewhere in the world, artificial structures built across entire sedimentary coastlines with very little spacing have facilitated the dispersal and proliferation of non-native species at the expense of native species, for which they do not provide suitable habitat (Airoidi & Bulleri, 2011; Airoidi *et al.*, 2015). In Sydney Harbour and its tributaries, seawalls armour more than 50% of the shoreline (Bulleri & Chapman, 2010) and there are more than 40 marinas, making the cumulative impacts of multiple structures a real possibility.

Spatially explicit consideration of the multiple human uses of marine and estuarine systems is crucial for avoiding the unintended consequences of marine urbanisation that extend over large spatial scales (Bishop *et al.*, in press) and for ensuring the continued delivery of valuable ecosystem services (Foley *et al.*, 2010). In marine environments, the introduction of artificial structures has particularly large-scale and severe impacts where such structures modify connectivity by acting as barriers or conduits for the dispersal of species or their resources (Bishop *et al.*, in press). For example, water-retaining structures such as dams and weirs can interfere with the migration of fish and other organisms between freshwater, estuarine and marine environments, thereby affecting ecosystems far beyond the footprints of those structures (Gillanders *et al.*, 2003; Rolls, 2011). Additionally, artificial structures that provide new habitat for fouling organisms can facilitate the spread of non-native marine pests along coastlines (Airoidi & Bulleri, 2011; Airoidi *et al.*, 2015). Assessing whether potential sites for development are 'sinks' or 'sources' for aquatic species might help in evaluating – before installation – the likely impacts of proposed developments. In theory, structures built in source areas will have greater impacts than those in sink areas (e.g. Crowder *et al.*, 2000), but empirical evidence for this is lacking.

Development regulations are needed that incorporate development footprints as well as context-specific spatial planning (Dafforn & Glasby *et al.*, 2015). In planning new structures, for example, areas that support endangered or threatened species or ecological communities should be avoided (Snyder & Kaiser, 2009). The seagrass *Posidonia australis*, an endangered ecological community in NSW, is particularly sensitive to damage from swing mooring buoys, shading from jetties, pontoons and marina developments, and dredging (Larkum & West, 1990; Fitzpatrick & Kirkman, 1995; Demers *et al.*, 2013). Planning should also consider whether artificial structures will serve as vectors for the spread of invasive species from their point of introduction. For example, pontoons constructed in port environments might facilitate the spread of non-native species introduced via ballast water or on vessel hulls.

### **Improving the suitability of the urban matrix for biodiversity**

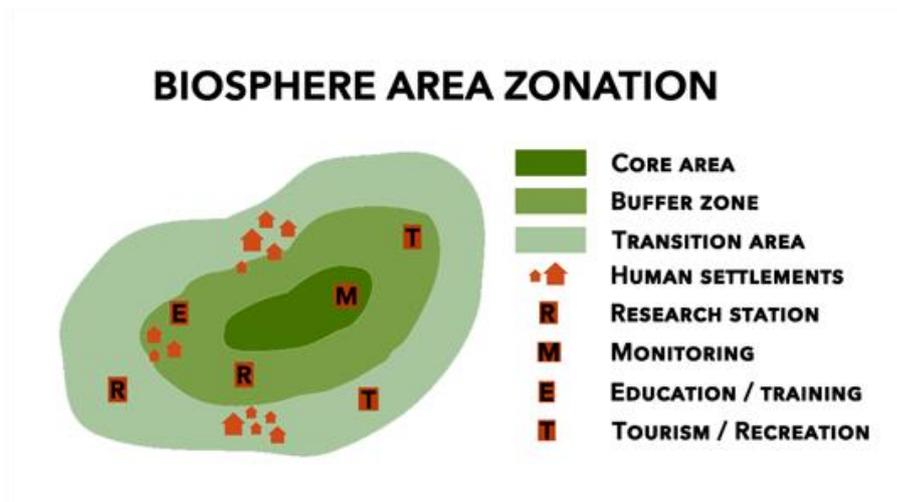
Conservation action summary

- Improve the suitability of the matrix for linking remnant patches or expanding isolated ones, thereby creating buffer zones that will minimise edge effects and increase the effective habitat for species restricted to habitat remnants.

Maximising the retention of remnant habitat is the most crucial action for retaining urban biodiversity (Palmer *et al.*, 2008; Barth *et al.*, 2015). When determining minimum size thresholds for remnant habitats, Fahrig (2001) found that the higher the habitat quality of the surrounding matrix, the smaller the minimum size required to maintain populations of species. In many urban areas, remnants are already small or are being reduced in size by development pressures. The next most important conservation action for maintaining urban biodiversity after retaining remnant habitat and increasing native vegetation through restoration is to increase the quality of the surrounding matrix (Fahrig, 2001), thereby making the transition between remnant vegetation and highly developed areas more gradual. Increasing the extent to which the matrix resembles the native vegetation will improve habitat quality in

remnants (Marzluff & Ewing, 2001) and increase the suitability of the matrix for multiple species (Barth *et al.*, 2015).

Changing the habitat quality of the matrix has the added benefit of creating buffer zones between highly urbanised areas and remnant vegetation (**Figure 3.13**). The concept of buffers uses principles applied by UNESCO's Man and the Biosphere Programme in maintaining zones around important conservation areas in order to minimise edge effects. In urban areas, buffer zones will minimise the infiltration of exotic organisms, contaminants and excess nutrients from surrounding suburban and industrial areas into remnants, minimise some of the abiotic changes associated with edges in fragmented landscapes (Marzluff & Ewing, 2001; Hostetler *et al.*, 2011), and increase the effective habitat area for species that are restricted to habitat remnants.



**Figure 3.13.** Schematic demonstrating the concept of buffer zones (medium green) around ecologically sensitive areas (core-areas; dark green) from the Netherlands National Commission for UNESCO (<https://www.unesco.nl/artikel/man-and-biosphere-will-netherlands-become-more-active>, accessed 10 Aug 2016). Activity in the core area is restricted to monitoring. In buffer zones, the amount of residential development is reduced, while activities like ecotourism, recreation, education and training can be implemented in these zones. There is greater scope for residential development in the transition areas (light green). This concept can be applied to urban areas by decreasing the amount of activity that occurs in the centre of remnant habitat and restricting recreation activities to buffer zones around the edges of patches. The surrounding urban matrix can be modified to increase its similarity to remnant habitats. In terrestrial areas, this might include increasing the percentage of plantings of native species of local provenance and the provision of limited habitat resources. The concept of increasing the suitability of the surrounding urban matrix to act as buffer zones for key ecologically sensitive areas is embedded in Sutherland Shire's Greenweb strategy (<http://www.sutherlandshire.nsw.gov.au/files/assets/website/documents/outdoors/plants-and-bushcare/greenweb/greenwebstrategyfeb2001.pdf>).

This section reviews the literature pertaining to increasing the suitability of the urban matrix for biodiversity conservation, focusing on local management decisions. Local, management and biotic habitat variables appear more important than landscape, design or abiotic variables in determining biodiversity in cities (Clergeau *et al.*, 2001; Philpott *et al.*, 2014; Beninde *et al.*, 2015). Small-scale decisions, such as how many and which species of shrubs and trees to plant, and what management practices to adopt in individual green spaces in the urban matrix, can have impacts on biodiversity. The following sections present examples, using evidence from the literature, of how the quality of habitats in the urban matrix can be enhanced by each of the following six actions:

- 1) Increasing the density of trees, especially mature native trees.
- 2) Increasing understorey cover.

- 3) Increasing the provision of limited habitat resources.
- 4) Providing quality water sources.
- 5) Modifying artificial structures to improve complexity.
- 6) Changing artificial lighting practices.

These actions are applied to common green spaces in the urban matrix, spanning both public and private areas.

## Urban forests

### Conservation action summary

- Limit removals of any trees in the landscape to those that are absolutely necessary. Of crucial importance is the retention of large (>30cm diameter at breast height) remnant trees within the urban matrix, including in new housing developments, rather than clearing trees and replacing them by planting new trees.
- Preference native trees over exotic trees in plantings.
- Retain trees along streets. Preferably these will be native, with low numbers of cultivated native hybrids that produce large, nectar-rich floral displays (inflorescences).
- Avoid management practices (e.g. mowing) that reduce the recruitment of new trees into the ecosystem, and actively plant new trees.

Trees provide multiple benefits in urban environments, including microclimate mitigation, bank stabilisation and improved aesthetics, as well as health and wellbeing benefits. For example, trees can reduce the UHI effect by shading hard surfaces that would otherwise store infrared radiation, changing wind-flow patterns, and evaporative cooling.

Trees can also benefit biodiversity in urban areas by making the matrix between core habitat patches more permeable to a range of species (Catterall *et al.*, 1991). Trees are often defined as keystone structures in modified landscapes like urban or agricultural landscapes because their ecological impact, as defined by value and the provision of ecosystem services, is much greater than the land area they occupy (Manning *et al.*, 2009; Stagoll *et al.*, 2012). Trees increase the ecological integrity of modified landscapes by providing habitat for species and a structure for greater connectivity (Manning *et al.*, 2009), and effectively acting as corridors (Fernandez-Juricic, 2000) or stepping stones (Fischer & Lindenmayer, 2002) for some species. Large trees (diameter at breast height > 80cm) have been demonstrated to have positive impacts on urban bats and birds, regardless of whether they are native or exotic (Threlfall & Williams *et al.*, 2016). Large urban native and exotic trees need to be protected, therefore, and removals minimised, with the exception of known weedy species (e.g. camphor laurels) and trees causing other negative environmental impacts (e.g. exotic deciduous trees that deoxygenate waterways when their leaves drop).

Much of the literature on the benefits of trees in urban areas for wildlife focuses on birds and, to a lesser extent, bats. This is unsurprising, given that a global meta-analysis of the drivers of changes in urban biodiversity found that birds are strongly affected by tree cover (Beninde *et al.*, 2015). In Australia, bird and bat richness is correlated with increased canopy cover and tree density, particularly if trees are native (Threlfall & Williams *et al.*, 2016). Birds use urban trees, including along streets, for a variety of functions, including foraging, nesting, perching, shelter and resting, and they use their hollows (Young *et al.*, 2007). When trees are available, birds use built infrastructure only 11% of the time; when trees are absent (for example in new housing developments), however, birds use built infrastructure 60% of the time (Barth *et al.*, 2015).

Maintaining a high level of tree cover in an urban landscape is crucial for the future ability to cater for biodiversity (Stagoll *et al.*, 2012). New trees are not readily recruited into the system, however, because of intense management strategies such as mowing. Setting aside areas in urban areas where there is low or no mowing, complemented with active tree planting, will allow the replacement of trees into the future (Manning *et al.*, 2009). Areas set aside for tree plantings, and the selection of species for planting, however, needs careful consideration to minimise future conflicts over safety and property damage and to ensure tree health and the capacity of species to survive under future climatic conditions (Hancock *et al.*, 2016). Initiatives such as National Tree Day<sup>10</sup> can help engage school students and the public in tree-planting activities, through which they can learn about the roles played by trees in urban ecosystems and develop Earth stewardship. Such tree-planting initiatives need to be managed over time, including by weeding, staking and watering, to ensure that planted trees survive and continue to grow.

The type of trees planted in the urban matrix will affect the bird communities that use them. Native trees are more beneficial than exotic trees, at least for native bird species (White *et al.*, 2005; Young *et al.*, 2007). In Perth, for example, Davis and Gole *et al.* (2013) calculated that 83% of terrestrial bird species are reliant on native vegetation. In Melbourne, a study found that bush remnants had the highest number of bird species, particularly of urban-avoider insectivorous birds; streets with native trees had higher native species richness and abundance than streets with exotic vegetation; and streets with exotic vegetation supported a higher proportion of introduced birds than native streetscapes (White *et al.*, 2005). Such findings demonstrate that, without careful planning, the urban matrix may inadvertently be designed to support introduced bird species in place of native bird species.

Tree planting along streets is a common management practice for increasing the density of trees and canopy cover within the urban matrix. The ability of streets with native vegetation to enhance the suitability of the urban matrix near reserves was observed in Canberra, where patches of native remnant vegetation surrounded by suburbs with more than 30% native eucalypt tree cover had higher species richness, higher native urban-adaptor species richness, and a higher probability of the presence of exotic adapter species than suburbs planted with exotic tree species (Ikin *et al.*, 2013). Moreover, the diversity of native birds was higher in reserves next to suburbs that had native vegetation along roads (Ikin *et al.*, 2013). Along roads, not only the tree species planted but potentially also the traffic flow may affect overall bird occurrence, with heavier traffic tending to reduce bird occurrence (Young *et al.*, 2007), including of urban-adaptor species (Ikin *et al.*, 2013).

Even the type of native tree species planted can affect the composition of birds in an urban area, although associations between fauna and particular tree species may differ seasonally (Young *et al.*, 2007). The hyperabundance of certain types of native birds in urban areas is attributed to the increase in food resources available in multiple seasons. In Melbourne, for example, the increase in abundance of rainbow lorikeets (*Trichoglossus haematodus*) and musk lorikeets (*Glossopsitta concinna*) has been attributed to the widespread planting of six eucalypt species not native to the Melbourne area: the constant flowering of these trees in spring and summer, which provides the birds with abundant food resources, enables areas with these tree species to support high numbers of the birds (Smith & Lill, 2008). The increased abundance of red-faced wattlebirds has also been attributed to the increased flowering of native plants, particularly planted *Callistemon* and *Grevillea* species along streets (Davis & Major *et al.*, 2015). The hyperabundance of particular urban-exploiter species due to increased resources may not always be a good outcome. An increase in the number of cultivated native hybrid

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<sup>10</sup> [treeday.planetark.org/news](http://treeday.planetark.org/news).

plants with large nectar-rich flowers is thought to be associated with the increased abundance of noisy miners and a subsequent decrease in smaller insectivorous birds due to the aggression of the noisy miners (Sewell & Catterall, 1998). It is important, therefore, that trees are not planted in isolation but are part of a more complex habitat, which can be achieved, for example, by planting a native mid-storey, in which smaller birds can seek shelter from the noisy miners (White *et al.*, 2005; Barth *et al.*, 2015). Native bird biodiversity can be enhanced, therefore, by maintaining or planting native trees and mid-storey species – similar in composition to remnant habitat – throughout the urban matrix, including in streetscapes (White *et al.*, 2005; Ikin *et al.*, 2013; Barth *et al.*, 2015).

Larger, mature native trees have a higher value for biodiversity conservation than smaller, younger trees. In Brisbane, for example, the number of remnant trees on vegetated streets was positively correlated with bird species richness and abundance in new high-density suburban housing developments (Barth *et al.*, 2015). This pattern is supported in other studies that showed positive correlations between bird species biodiversity and larger trees (Stagoll *et al.*, 2012; Le Roux *et al.*, 2015; Threlfall & Williams *et al.*, 2016). The planting of several new trees to offset the removal of a single large remnant tree (e.g. for new housing developments) is an unsatisfactory tradeoff because decades or centuries would be required for the new trees to provide the same habitat as the old tree they replaced. A study by Le Roux *et al.* (2015) found that, although several small-to-medium-sized trees supported the same species diversity as large trees in highly urbanised areas, the same pattern was not apparent in parklands, with several small-to-medium-sized trees supporting fewer species than single large remnant trees; 29% of birds were only found in large trees. One of the reasons why large remnant trees offer more habitat is that they feature resources like hollows and coarse woody debris, which younger trees are unable to provide (Le Roux *et al.*, 2014). It can take centuries for newly planted trees to develop important habitat resources, like hollows (Le Roux *et al.*, 2014). Priority should be given, therefore, to protecting large remnant trees in urban landscapes and to recruiting new trees through active planting and a reduction in management practices that inhibit seedling establishment (e.g. mowing) to enable the replacement of old trees when they reach the end of their lives. The retention of mature trees in urban landscapes can create tensions, however, because of the perceived and actual increased risk associated with mature trees (e.g. the risk of limb drop, which can damage property and threaten human safety, and of bushfire), the potential of poorly selected tree species to exacerbate human allergies, and the structural damage that trees can cause to infrastructure. The public, too, often associates trees with ‘mess’ or the obstruction of views. An ongoing challenge for urban ecology is to find ways of retaining large, mature trees in landscapes while addressing risk and conflicts associated with trees. More detail on such conflicts and possible solutions are discussed in the UERI ‘What We Heard’ document.

## Ground-story and mid-storey cover and complexity

### Conservation action summary

- Improve vertical vegetation complexity in urban areas by planting or retaining vegetation and structures (e.g. shrubs logs, rocks and long grasses) that provide complex ground-storey and mid-storey cover.
- Increase the provision of dense mid-storey cover to provide shelter for small insectivorous birds and other biota.
- Select native plant species to improve ground-storey and mid-storey cover, with consideration given to local provenance, planting objectives and survival under future environmental conditions.
- Reduce the availability of cultivated native hybrids that produce large, nectar-rich floral displays (inflorescences) with extended flowering durations.

- Decrease management practices that reduce the complexity of ground cover, such as mowing and clearing fallen logs and branches, and, where possible, allow the accumulation of leaf litter.
- Reduce the area of manicured lawn, which generates little biodiversity value.

Vegetation structure is a key variable affecting the biodiversity of cities. In a global meta-analysis spanning many taxa, multiple components of vegetation structure were found to correlate positively with urban species richness, including herb cover, density and structure, shrub structure and cover, tree structure and cover, and overall vegetation structure (Beninde *et al.*, 2015). This is unsurprising, because increasing the complexity of vegetation structure creates more habitat niches and provides more natural resources (White *et al.*, 2005), thereby supporting a more diverse biotic community. The importance of increasing tree cover is discussed above; the present section discusses how increasing vegetation complexity also requires the restoration of ground-storey and mid-storey cover.

Ground-storey and mid-storey density is often low in urban landscapes, with preference given to recreational green spaces dominated by lawn and scattered trees (Figure 3.14; Threlfall & Ossola *et al.*, 2016). The lack of complex vegetation has been implicated in the reduction of particular taxa in the urban matrix (Threlfall *et al.*, 2017). For example, a reduction of dense native shrubby vegetation correlates with a loss of small insectivorous birds, which use such vegetation for shelter and food, and ground cover (grass and leaf litter) is the variable that most strongly affects non-flying insects (Beninde *et al.*, 2015). Given the positive effects of ground-storey and mid-storey cover on urban biodiversity, simple management actions to increase volume and complexity in these vegetation layers can aid the conservation of urban biodiversity (Fahrig, 2001; Beninde *et al.*, 2015; Kang *et al.*, 2015; Threlfall & Ossola *et al.*, 2016; Threlfall *et al.*, 2017). For example, shrub cover was planted in patches in Sydney Olympic Park in 2008 in response to an observation that the lack of mid-storey cover increased the abundance of noisy miners and reduced the richness of small woodland species. After five years, there was higher species richness of woodland birds, and lower noisy miner abundance, at sites with increased vegetation complexity (O'Meara *et al.*, in review).



**Figure 3.14.** Differences in vertical structural complexity in areas with different amounts of understory cover at Sydney Olympic Park, Sydney. **a)** Low vertical structural complexity, with managed lawn surrounding trees; **b)** high vertical structural complexity in an area managed to restore understory complexity (i.e. weedy understory was removed and replaced with shrubs); and **c)** high vertical structural complexity in a natural remnant (Newington Nature Reserve). Source: J. O'Meara.

The selection of plant species to increase vegetation structure in ground-storey and mid-storey cover is important. In one study, for example, fairy wrens were found in areas where grassy areas were surrounded by dense native shrubs but were absent in areas with exotic plants, regardless of plant density (Parsons *et al.*, 2008). The notable exception was areas with lantana, which were able to adequately replicate the structural resources provided by dense native shrubs. Therefore, native plants

should be selected to improve ground-storey and mid-storey cover. Plants of local provenance should be considered in restored or revegetated areas, but non-locally occurring native species may be suitable for newly created novel habitats and in areas likely to be subject to future climate change. All plant selection decisions should consider plant survival under predicted future climates, and plant selections should be aligned with the goals of planting (e.g. to restore locally native vegetation communities, versus to create novel habitats in highly altered urban green spaces).

Planting bias for 'showy' cultivated native hybrid species (e.g. grevilleas) that produce large nectar-rich floral displays (i.e. inflorescences) in gardens and streetscapes can lead to the increased abundance and duration of nectar resources in suburban areas compared with nearby native remnant bushland. Although these prolifically flowering hybrids can increase the abundance of several nectarivorous species, they have been implicated in the hyperabundance of rainbow lorikeets and noisy miners in cities (Sewell & Catterall, 1998), the latter of which can lead to declines in smaller native insectivorous birds (Maron *et al.*, 2013). Therefore, when native plants are used to increase vegetation structure, a desirable outcome is to use a planting palate that reflects the ratios of species abundance in nearby native remnant vegetation, thus providing similar habitat and resources (White *et al.*, 2005). Similar principles were applied to the selection of plants used to revegetate Barangaroo Reserve, where 75,000 native plants covering all vegetation strata were planted. All but 5 of the 84 species planted were native to the Sydney Basin, and they were arranged in configurations that reflected various vegetation types.<sup>11</sup>

Maintenance practices (e.g. removing weedy species, fallen branches and leaf litter, and mowing) often decrease habitat complexity by removing structure and resources from the various storeys (Shwartz *et al.*, 2008; Rupprecht *et al.*, 2015). Areas of intensely mown lawn, for example, provide very little structure in the ground storey. Studies that compared areas of lawn with less-managed areas have found very few benefits for biodiversity in mown areas (Kazemi *et al.*, 2009; Kazemi *et al.*, 2011); moreover, the practice of mowing can be the dominant factor decreasing biodiversity in some urban green spaces (Helden & Leather, 2004). Large areas of manicured lawn, which are often found in urban parks (including sports fields), golf courses and private residential land, therefore, may make very low contributions to urban biodiversity. A report on the biodiversity potential of Sydney golf courses, for example, found that species richness was lower for birds and ants on fairways than in less-manicured areas of golf courses (remnant vegetation, boundary areas and areas between fairways; HIE UWS, 2015). More biodiversity-friendly mowing practices include increasing mow height and the time between mowing events, which can increase the structural complexity of lawn areas, and replacing lawns with local native grass species, which require infrequent or no mowing. Overall, however, decreasing the area of lawn and replacing it with more diverse vegetation, with structure across all heights, will have greater benefits for biodiversity (Marzluff & Ewing, 2001). Such less-intense management strategies can be viewed negatively by the public due to perceptions of increased risk/fear of nature and general untidiness/decreased aesthetics. To enable the implementation of ecological management strategies, the public needs to be made aware of the benefits such strategies can provide for urban biodiversity (see UERI 'What We Heard' document for further discussion).

Management strategies often involve the removal of weedy species such as blackberry and lantana to minimise their spread, reduce their impact on native vegetation, and improve an area's aesthetics. Although these are important objectives, both blackberry and lantana can provide dense structure in the mid-stratum cover. Small insectivorous birds, which are often missing in urban areas because of the lack of structural complexity in the mid-storey, have been observed to use both lantana (e.g. fairy wren

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<sup>11</sup> [www.barangaroo.sydney/about/how-does-our-garden-grow](http://www.barangaroo.sydney/about/how-does-our-garden-grow)

in the Illawarra; Parsons *et al.*, 2008) and blackberry (Stagoll *et al.*, 2010). These noxious weeds should not be encouraged, but it should also be recognised that their removal may reduce habitat quality for mid-storey-dependent species. One way of addressing this issue is to pre-establish a native mid-storey in the immediate area to compensate for losses accrued when weeds are removed. Alternatively, lantana plants can be cut off at the base, which kills the plant, and the woody structure left in place while new shrubby species grow around it.

### Increasing limited habitat resources, including access to hollows

#### Conservation action summary

- Determine which habitat resources are limiting the use of the urban matrix by target species and increase the provision of those resources through habitat restoration or by providing artificial resources that replicate their function (e.g. bee hotels, nest boxes and artificial ponds).
- Increase the provision of hollows in urban areas by:
  - Retaining mature remnant trees.
  - Planting new trees to allow the replacement of mature trees in the future, and amending management practices that reduce the recruitment of local tree species into the system (e.g. mowing). Tree plantings should consider the appropriateness of the species planted and the ability of the area to support large trees without conflict (e.g. safety, property damage).
  - Provide nest boxes to compensate for a lack of hollows in urban areas. Modify the size, entrance size and location across the matrix to suit target species.
  - Provide education on the importance of hollows as a resource in urban areas.

All organisms have key resource requirements, which, if limiting, can decrease their abundance in an environment. Understanding which resources limit the distribution or regulate population numbers in urban areas enables planners and managers to take action to mitigate these limitations, such as by enhancing natural habitats or providing artificial, substitute resources. For example, bee houses (usually made of plastic, clay or bamboo pipes, or wood with holes drilled in them) and artificial ponds can be incorporated into wildlife-friendly backyard management to increase the availability of resources that are otherwise limited in urban areas (Gaston *et al.*, 2005), and also placed in public spaces. Although additional research is needed to ascertain the efficacy of some artificial structures, such as bee hotels (Maclvor & Packer, 2015), in enhancing target species, others have been demonstrated to improve outcomes. For example, many animals are adapted to sheltering in gaps under loose surface rocks (Goldsbrough *et al.*, 2003). This is especially the case in the sandstone landscapes that predominate in much of the Sydney Basin (including Newcastle and Wollongong), which have characteristically thin rocks that exfoliate from sandstone blocks. Urbanisation and rock removal for landscaping has reduced this habitat considerably, and natural erosion is far too slow a process to compensate. Experiments with artificial rocks (created with concrete and painted to blend in with the landscape) have shown that these can provide suitable replacement habitat for invertebrates and reptiles (Croak *et al.*, 2010).

Hollows are used by more than 300 species of Australian animal, many of which are threatened (Gibbons & Lindenmayer, 2002). Tree hollows are a limited resource in urban matrices of Australian cities, including Sydney (Davis & Major *et al.*, 2013; Davis *et al.*, 2014). The number of hollow-bearing trees is positively correlated with hollow-nesting fauna in urban areas, including microbats (Basham *et al.*, 2011). The limited availability of hollows can change the intensity of interactions between species,

with the number of aggressive hollow-associated encounters much higher in urban areas than in contiguous forest, especially for parrots in Sydney (Davis & Major *et al.*, 2013). Management practices that allow the removal of mature or hollow-bearing trees will further exacerbate the problem of hollow limitation.

Le Roux *et al.* (2014) modelled the decline of hollow-bearing trees in urban areas in Canberra and predicted that, under current management practices, there would be an 87% loss in hollow-bearing trees in 300 years, although they are likely to persist in bushland reserves. The loss of hollow-bearing trees cannot be offset by replacement with several smaller trees, at least in the short term, because of the long time required for hollows to form in trees. Nest boxes attached to trees, therefore, have become an important mitigation strategy for increasing the number of hollow-like resources in urban areas (**Figure 3.15**). Adding nest boxes can increase the abundance and richness of hollow-using species (Le Roux *et al.*, 2016), but not all hollows are equivalent in their characteristics for particular species (Davis *et al.*, 2014) and the type, size and placement of nest boxes will affect their potential for improving urban biodiversity. For example, the addition of nest boxes has been demonstrated to be beneficial for bird biodiversity if attached to large trees, but not when attached to medium-sized and small trees (Le Roux *et al.*, 2016). Moreover, entrance size affected which species colonised new nest boxes: for example, boxes with small entrances were occupied predominantly by the European honeybee *Apis mellifera*, boxes with medium-sized entrances were colonised by the common myna *Acridotheres tristis* and the eastern rosella *Platycercus eximius*, and boxes with large entrances were used by brushtail possums *Trichosurus vulpecula* (Le Roux *et al.*, 2016). In Canberra, the introduced cavity-dwelling common myna most often uses nest boxes in areas of low tree density, eastern rosellas use nest boxes at intermediate tree densities, and crimson rosellas use them at high densities (Grarock *et al.*, 2013). Although the provision of nest boxes has benefits, many boxes are occupied by common species in urban areas, and therefore they may not offer habitat substitutes for hollow-bearing trees for all species (Le Roux *et al.*, 2016).



**Figure 3.15.** Two nest boxes attached to a tree at the University of Sydney. Nest boxes can provide additional habitat for hollow-dwelling species in the urban matrix when the occurrence of hollows is generally limiting. Nest boxes like these have been shown to increase the numbers of hollow-nesting fauna in an area. Involving the community in the provision of nest boxes can be a useful strategy in increasing nest box numbers in the urban matrix and encouraging greater connections between people and nature. Not all hollow-dwelling species have been observed using nest boxes, however, and protecting hollow-bearing trees is still an important component of urban biodiversity strategies. Source: F. van den Berg (taken 2016).

Based on modelling, Le Roux *et al.* (2014) found that the only way to decrease the loss of hollow-bearing trees into the future would be by immediately implementing management strategies that:

1. Leave trees standing for 40% longer than their currently accepted lifespans by management practices (i.e. at least 450 years).
2. Increase seedling establishment by a minimum of 60%, to reach at least 60 tree plantings or natural germinations per ha.
3. Increase the use of artificial structures (e.g. nesting boxes) and accelerated hollow formation techniques to compensate for the long time lag in establishing new hollow-bearing trees (Le Roux *et al.*, 2014).

The implementation of management actions to retain mature trees is likely to create public resistance due to the increased risk of limb drop by eucalypts as they age. Planners can take steps to incorporate old remnant trees in the design of new developments and landscape features. Such steps could include designs that minimise risk to infrastructure and public safety by buffering the distance between old trees and buildings and other infrastructure (e.g. foot paths and park benches). The judicious pruning of dead limbs while leaving hollows can also decrease risks associated with maintaining mature trees in urban landscapes.



**Figure 3.16.** Retention of very old (estimated 600 years) remnant *Eucalyptus sclerophylla* in Glenbrook Park, Glenbrook, NSW ([http://www.nationalregisterofbigtrees.com.au/listing\\_view.php?listing\\_id=734](http://www.nationalregisterofbigtrees.com.au/listing_view.php?listing_id=734)). The park is very high-use, but the risk of limb strike has been minimised by the addition of fencing past the drip line. The tree is next to children’s play equipment, but the council has managed the tree in such a way that the recreational values of the park are not compromised by the retention of the tree. Source: C. Threlfall (taken 2016).

Planting gardens with complex or spikey ground-storey and mid-storey cover, and fencing around remnant trees in public areas, can decrease the probability of limb strike (**Figure 3.16**). Alternatively, the creation of ‘habitat trees’ (**Figure 3.17**) can provide additional hollows in urban areas without the risk of limb strike; no research has yet been conducted, however, demonstrating the benefits of these for biodiversity. Educating the public about the importance of hollows in urban landscapes, such as through programs like the Royal Botanic Garden’s ‘Hollows as Homes’<sup>12</sup> and by providing interpretative signage, can help change public perceptions of mature remnant trees in landscapes. Hollows as Homes uses citizen science and public media to document the locations of hollows in landscapes and encourages residents to identify animal species in their areas that are using such hollows as habitat.

Given the long lifespans of trees, careful thought needs to be given to the species planted and the location of plantings. As part of these decisions, managers need to consider the survival of trees planted now in the face of future climatic conditions (Hancock *et al.*, 2016), as well as the environmental impacts of the planted tree species, avoiding known weedy species (e.g.

<sup>12</sup> [www.rbgsyd.nsw.gov.au/HollowsHome](http://www.rbgsyd.nsw.gov.au/HollowsHome)

camphor laurels) and other species that might have negative environmental impacts. Consideration should also be given to the planting area and space required – both in the deep soil and above ground – to maintain tree health and minimise future conflicts and environmental impacts.

a)



b)



c)



**Figure 3.17. a)** Urban habitat tree at Addison Road Community Centre, Marrickville. Instead of removing dead trees, their limbs can be trimmed to reduce the risk of limb drop and artificial hollows cut into the tree to provide multiple hollows. To date, no research has been published that demonstrates the benefits of these habitat trees for biodiversity. **b)** Signage at the base of the habitat tree to provide the public with information about the tree and to engage the community in citizen science. **c)** A rainbow lorikeet (silhouette) using one of the artificial hollows in the habitat tree. Source: F. van den Berg (taken 2016).

## Artificial wetlands

### Conservation action summary

- Increase the provision of wetlands in urban areas to provide crucial habitat for aquatic (and semi-aquatic) organisms and waterbirds.
- Construct wetlands managed for WSUD purposes in ways that can also increase habitat suitability for urban biodiversity. Depending on the target species, this could include:
  - Provision of emergent and submerged vegetation
  - Provision of vegetation and open space around the perimeter of wetlands
  - Decreased shading of wetlands.

Natural wetlands have decreased in urban landscapes, resulting in a loss or decline of freshwater and estuarine species. Australian wetlands were previously not highly valued and deliberately cleared and filled (Straka *et al.*, 2016), or their area was reduced through changes in hydrology and the rates of water extraction (Nebel *et al.*, 2008; Davies & Wright, 2014). Additionally, estuarine wetlands such as saltmarshes have suffered extensive habitat loss in southeastern Australia due to stressors such as reclamation for development and foreshore protection, vehicle and human disturbance, weed incursions, and pollution (Daly, 2013). Displacement by mangrove habitat due to the increased sedimentation of estuaries following land clearing, nutrient enrichment, and southward range expansion under climate change may further reduce this wetland habitat type (Saintilan & Williams, 1999; Saintilan *et al.*, 2014).

Recently, environmental management in urban landscapes has seen the restoration of degraded wetlands, the re-creation of lost wetlands, and the creation of new wetlands in areas not previously wetland habitat (**Figure 3.18**). Many freshwater wetlands are being created using WSUD principles to help retain stormwater and increase water filtration while also providing landscape features for new subdivisions and standing water bodies for use, for example, in firefighting in subdivisions adjacent to bushland (NSW Rural Fire Service, 2006). In addition to other benefits (e.g. in filtering solids, nutrients, bacteria and other contaminants from stormwater), the retention of water can increase aquatic biodiversity in urban streams and in estuaries. Some WSUD constructions in Sydney, however, do not filtrate stormwater to a quality sufficient for maintaining stream health (Oulton, 2016). Despite changes in water chemistry due to runoff, ponds managed for stormwater also have potential to provide as much habitat for wetlands species as ponds managed for other purposes, while still maintaining other ecosystem services (Hassall & Anderson, 2015). In Alberta, Canada, it was found that although artificial wetlands do not support abundant or species-rich amphibian populations, they can provide valuable breeding sites (Scheffers & Paszkowski, 2016). In urban areas, where the aquatic environment is reduced, constructed wetlands may therefore provide important resources for aquatic (or semi-aquatic) organisms and waterbirds (Murray *et al.*, 2013).

Wetlands can differ in their size, shape, water availability and permanence, vegetation cover and structure, slope, substrate and connectedness to other water sources. This variation affects the quality of habitat for different taxa. For example, wetlands with more aquatic vegetation have been found to support more aquatic macroinvertebrates and amphibians (Hamer & Parris, 2011; Hassall *et al.*, 2011),

a)



b)



c)



d)



e)



f)



**Figure 3.18.** Constructed wetlands around Sydney and Wollongong. These differ in their purposes, amount of surroundings, emergent and submerged vegetation, type of banks (type of surface and slope), size, water availability and permanence, and shape. **a)** Moore Reserve wetland, Kogarah; **b)** Riverwood Community Centre, Riverwood; **c)** Newland Reserve, Milperra; **d)** Edgewood Estate wetland, Woonona; **e)** Cup and Saucer Creek wetland, Canterbury; **f)** Victoria Park, Camperdown. Photos courtesy of J. Hanford (a-d) and F. van den Berg (e-f) (taken 2016).

especially if the wetland contains both emergent and submerged vegetation (Scheffers & Paszkowski, 2016). Vegetation and open space around the perimeters of wetlands is also important: wetlands with a greater proportion of vegetation around their perimeters have been shown to have higher waterbird abundance and density (Murray *et al.*, 2013), while amphibian species richness increases with higher proportions of surrounding open space (Hamer & Parris, 2011). A decrease in shading increases plant, invertebrate and amphibian species richness (Hassall *et al.*, 2011). Freshwater biodiversity can benefit, therefore, from the incorporation of ecological principles into wetlands designed for other purposes. The key environmental variables correlated with abundance and richness differ between taxa, and designing constructed wetlands that benefit particular taxa may therefore decrease the presence of others (Hassall *et al.*, 2011; Murray *et al.*, 2013). Additionally, the presence of particular organisms can change the abundance of other taxa through ecological interactions such as predation and competition. For example, the presence of amphibian species is negatively correlated with the presence of predatory fish in wetlands (Hamer & Parris, 2011). Maximum biodiversity in an urban catchment is most likely to be achieved, therefore, by providing heterogeneity in wetland habitat (Hassall *et al.*, 2011).

Some design features of constructed wetlands that improve ecosystem services are also beneficial for biodiversity. In Australia, for example, waterbird species richness and microbat activity is positively correlated with the surface area of artificial wetlands (Murray *et al.*, 2013; Straka *et al.*, 2016). The surface area of constructed wetlands and bioretention basins can determine their capacity to provide stormwater filtration services, with a recent study in Sydney demonstrating that only the largest wetlands are able to remove most contaminants (Oulton, 2016).

An exemplar of a constructed wetland in Sydney is the Cup and Saucer Creek wetland in Canterbury<sup>13</sup>, which was constructed by Sydney Water's Bank Naturalisation Project. The wetland is in an infrequently used large grassed area in Heynes Reserve. In consultation with residents, the wetland was developed as a way of removing pollutants and collecting sediments from local stormwater before it enters Cooks River. The wetland design included the planting of 40 species of native vegetation of local provenance. Local volunteers perform ongoing maintenance in regular working bees, and water quality is monitored in testing stations positioned at influent and effluent water streams. Although the creation of this wetland has great local benefits by providing valuable freshwater habitat and has been demonstrated to improve water quality, its impact on the water quality of Cooks River is unlikely to be significant because it services only a small amount of the degraded area in the catchment. In a large catchment such as Cooks River, a more integrated, catchment-wide series of wetlands of a similar quality is needed to mitigate stream flows, reduce contaminants and improve freshwater biodiversity.

## Eco-engineering in marine and coastal ecosystems

### Conservation action summary

- Use soft engineering practices, like the construction of living shorelines, for the protection of coastlines, where land and management can be maintained. Soft engineering approaches will be more beneficial than hard engineering practices for urban biodiversity.
- Use eco-engineering when artificial structures need to be incorporated into marine ecosystems.
- Build complexity into structures, including water-retaining features.
- Use ecologically friendly materials.
- Incorporate skylights or grates into large structures that shade ecosystems below them.
- Construct sloped rather than vertical infrastructure.

<sup>13</sup> [www.canterbury.nsw.gov.au/Environment/Cooks-River/Cup-Saucer-Creek-Wetland](http://www.canterbury.nsw.gov.au/Environment/Cooks-River/Cup-Saucer-Creek-Wetland)

- Seed new structures with native species as a way of reducing colonisation by non-indigenous species.

Marine infrastructure like seawalls, breakwaters and pilings is pervasive in urban estuarine, coastal and marine environments (Dafforn & Mayer-Pinto *et al.*, 2015). Such structures can destroy or modify natural habitats (section 3.5; Goodsell *et al.*, 2007; Goodsell, 2009), introduce novel habitats, and modify environmental conditions in surrounding areas (Clynick, 2008; Airoldi *et al.*, 2009; Dafforn & Glasby *et al.*, 2015; Henry *et al.*, in press). These new conditions can lead to changes in species assemblages (Chapman, 2006; Clynick *et al.*, 2008) and connectivity (Bishop *et al.*, in press). Despite providing habitat for some species, therefore, marine structures can rarely be considered ecological equivalents of natural ecosystems (Chapman & Bulleri, 2003; Chapman & Underwood, 2011). Changing the way engineering issues are addressed in marine and coastal ecosystems and modifying the types of artificial structures used can help in mitigating their impacts on biodiversity.

Traditional management approaches to coastal protection involve hard engineering and structures such as seawalls, breakwaters and groynes. There is increasing interest, however, in the use of soft engineering approaches such as living shorelines and beach nourishment because these are perceived to be more environmentally benign (e.g. Peterson & Bishop, 2005; Cooke *et al.*, 2012). ‘Living shorelines’, whereby shellfish, coral reefs, salt marshes and mangroves are rehabilitated to stabilise shorelines and protect them from storms and floods, is an under-used approach in Australia. It has been demonstrated to increase coastal resilience and provide other ecosystem benefits, such as nursery habitat for threatened commercially and recreationally important species, and carbon sequestration and storage (Davis & Currin *et al.*, 2015; Gittman *et al.*, 2016). Small pockets of restored habitat may have aesthetic value, but studies are needed to determine the minimum area of such sites for the provision of ecosystem services (Chapman & Underwood, 2011). Beach nourishment (the placement of externally derived sand on beaches to extend them seawards) and beach scraping (the redistribution of sediments within a beach compartment) are widely and increasingly used methods of shoreline protection in Australia (Cooke *et al.*, 2012). Beach nourishment and scraping protect coastal infrastructure and help maintain public beach amenity, but their impacts on Australian sandy beach ecosystems are not well understood. Elsewhere, it has been demonstrated that beach nourishment can have large impacts on sandy beach fauna when the colour, grain size and chemistry of ‘fill’ (imported) sediments is not well matched with native beach sediments, where new recruits are smothered by sediment addition, and where fine sediments are eroded from nourished beaches, causing turbidity plumes (Peterson *et al.*, 2014). Because fill sediments typically erode over time, beach nourishment needs to be repeated every 5–10 years, leading to the potential for cumulative impacts (Manning *et al.*, 2014). Soft engineering techniques require coastal land to be set aside for the retention of ecosystems and ongoing maintenance (Dafforn & Mayer-Pinto *et al.*, 2015). In many built urban landscapes, the required space for these engineering practices is unavailable due to existing coastal development. In such cases, traditional hard engineering options, or combinations of hard and soft engineering (e.g. the planting of vegetation seaward or landward of seawalls), may be needed (Chapman & Underwood, 2011).

Where hard engineering or the introduction of artificial structures for other purposes (i.e. boating infrastructure and aquaculture) is unavoidable, eco-engineering – the incorporation of ecological principles into the design of artificial structures (Chapman & Underwood, 2011) – may be used to mitigate their ecological impacts and enhance biodiversity. Ideally, this is done at the design phase for new developments (Chapman & Blockley, 2009) by building complexity into structures, the use of ecologically friendly materials, approaches that increase the area of substrate available to organisms, and, in the case of pontoons and piers, the use of grates or skylights to provide light penetration to substrates below (Chapman & Underwood, 2011; Dafforn & Glasby *et al.*, 2015). However, retrofitting

existing structures with modules that add microhabitats or complexity (Browne & Chapman, 2011; Loke & Todd, 2016) can also enhance biodiversity at small scales.

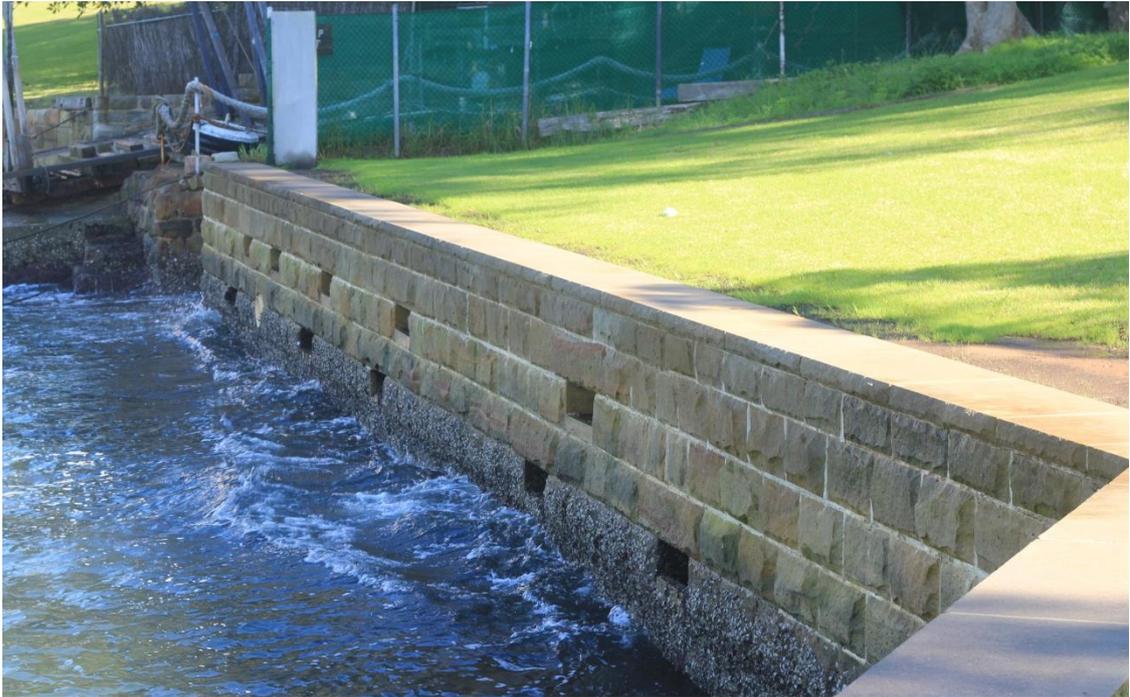
The construction of sloped as opposed to vertical artificial structures can enhance the biodiversity outcomes of built infrastructure. Vertical structures provide limited surface area, particularly at intertidal elevations, for the attachment of organisms (Bulleri, 2005b; Bulleri & Chapman, 2010; Chapman & Underwood, 2011), and they expose such organisms to the full brunt of wave action (Bulleri, 2005b). One method of constructing sloped seawalls is to use a series of blocks stepped up on an angle (Chapman & Underwood, 2011). The construction of revetments composed of small boulders in place of smooth seawalls can also increase the surface area of structures and increase habitat complexity (Chapman & Underwood, 2011). According to ecological principles, sloped structures should have higher biodiversity than vertical seawalls due to their greater surface area (Chapman & Underwood, 2011; Dafforn & Mayer-Pinto *et al.*, 2015); evidence for this is lacking, however, and more research is needed.

The roughness and chemical composition of materials used in artificial structures can have a large influence on biodiversity (e.g. Bers & Wahl, 2004; Bulleri, 2005a; Coombee *et al.*, 2015; Perkol-Finkel & Sella, 2015). Surfaces with small-scale pits, grooves or elevations can provide microhabitats that encourage the development of fouling communities by providing protected microhabitats for new recruits (Thomason *et al.*, 2002; Bers & Wahl, 2004; Guarnieri *et al.*, 2009). The chemical composition of materials can affect whether they release cues that attract or inhibit recruitment, and it can also influence the ability of organisms to attach. For example, concrete leaches calcium hydroxide, which can serve as a settlement cue for oysters (Anderson, 1996) but deter other organisms (Perkol-Finkel & Sella, 2015). Where possible, natural substrates should be used in the construction of artificial structures; for example, sandstone is an appropriate building material for seawalls in Sydney Harbour because it is also the rock type of local rocky shores. Where it is not possible to use natural substrates, ecologically friendly concrete mixes of low alkalinity (e.g. EConcrete; Perkol-Finkel & Sella, 2015) can be used to better mimic the chemistry of natural substrates. Fish and invertebrate diversity was found to be higher on breakwaters made with EConcrete blocks than those made with traditional Portland cement (Perkol-Finkel & Sella, 2015).

Compared with natural rocky reefs, artificial structures are typically low in complexity, and interventions that add microhabitats or complexity can have particularly large effects on biodiversity at small scales (Chapman & Underwood, 2011). The addition of water-retaining features to intertidal marine infrastructure has been particularly successful in enhancing intertidal biodiversity in artificial structures such as seawalls (Chapman & Blockley, 2009; Browne & Chapman, 2011; Chapman & Underwood, 2011; Browne & Chapman, 2014; Firth *et al.*, 2014; Evans *et al.*, 2015; Morris, 2016). This can be achieved in the design phase by building cavities into seawalls (Figure 3.19a; Chapman & Blockley, 2009) or casting holes into breakwater blocks (Firth *et al.*, 2014). Water-retaining structures can also be retrofitted to existing structures (Browne & Chapman, 2011; Browne & Chapman, 2014), and cavities can be drilled into existing structures (Chapman & Underwood, 2011). In Sydney Harbour, concrete 'flowerpots' that mimic some of the functions of natural rockpools by retaining water at low tide have been attached to existing seawalls (Figure 3.19; Browne & Chapman, 2011; Browne & Chapman, 2014). These novel habitats may not support all benthic species found in natural rock pools (Chapman & Blockley, 2009; Evans *et al.*, 2015; Morris, 2016). After seven months, however, the pots were found to contain 40% more algal species, 39% more species of sessile animal and 118% more mobile species than unmanipulated seawalls (Browne & Chapman, 2011). The addition of flowerpots also benefited higher trophic levels, such as fish, by increasing habitat complexity and food resources (Morris, 2016). The

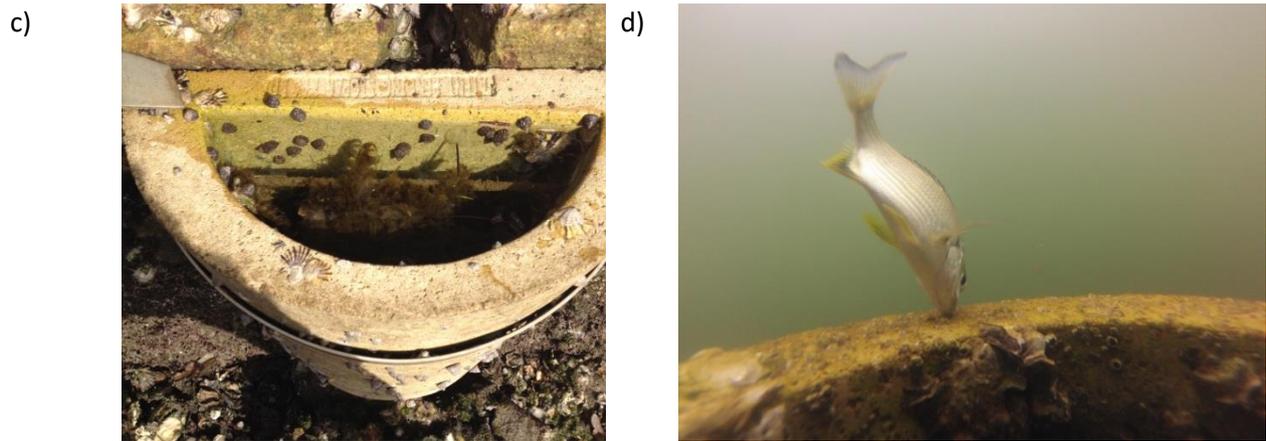
retrofitting of such structures may be particularly beneficial in areas such as Sydney Harbour, where seawalls have historical significance and cannot be removed.

a)



b)





**Figure 3.19.** Adding habitat complexity into seawalls through a) incorporating cavities in structures at the construction phase or b) retrofitting water-holding structures onto existing seawalls using, for example, flowerpots. Flowerpots attached to seawalls in Sydney Harbour had more c) algal and sessile organisms and d) higher trophic-level organisms, such as fish, than non-altered seawalls. Photos courtesy R. Morris (a-b: taken 2013; c-d: taken 2014).

The Vancouver Convention Centre<sup>14</sup> and Seattle’s Elliot Bay Seawall<sup>15</sup> are examples of seawall designs that incorporate ecological principles such as decreased vertical slopes, the incorporation of shallow habitats, and increased complexity for habitat provision. In Elliot Bay, novel ‘skylights’ have been incorporated into the design of coastal walkways to decrease the shading caused by the coastal infrastructure and as an aid to the movement of salmon. The redevelopment of the foreshore in Headland Park in Barangaroo Reserve<sup>16</sup> in Sydney has also been based on ecological principles. Sandstone blocks that differ in size to increase heterogeneity have been used to replicate nearby natural sandstone headlands and stepped to decrease slope and create rock pools.

Irrespective of their design, new structures add bare substratum to the marine environment that is readily colonised by opportunistic species, including non-native pests, the propagules of which are present year-round in the water column (Glasby *et al.*, 2007; Tyrrell & Byers, 2007; Dafforn *et al.*, 2012). Artificial structures in metal-polluted environments may be particularly prone to invasion by non-native species because the hull-fouling vector for the translocation of non-indigenous marine species can select for metal-tolerant individuals able to survive exposure to metal-based anti-fouling paints (McKenzie *et al.*, 2011; McKenzie *et al.*, 2012). New structures may be seeded with native species to decrease or slow colonisation by non-indigenous species that pre-empt space and create unfavourable environmental conditions for non-indigenous species (Stachowicz *et al.*, 2002). If such native species are habitat-forming, they could have added benefits for native biodiversity (Perkol-Finkel *et al.*, 2012; Ng *et al.*, 2015).

Although many studies demonstrate the benefits for native biodiversity of eco-engineering in marine environments, the scale of enhancements, and of associated monitoring, has typically been small (see Chapman & Underwood, 2011) and their capacity to produce biodiversity benefits at larger scales is unclear. Given the differing spatial scales at which ecological processes operate, inferring the impacts of large-scale interventions from small-scale trials is problematic, and more research is needed to determine the effects of eco-engineering interventions at larger scales (Chapman & Underwood, 2011).

<sup>14</sup> <https://lmnarchitects.com/case-study/vancouver-greened-waterfront>

<sup>15</sup> <http://waterfrontseattle.org/seawall/tour1>

<sup>16</sup> [www.barangaroo.com/media/203921/headland-park-october-2014.pdf](http://www.barangaroo.com/media/203921/headland-park-october-2014.pdf)

## Artificial night lighting

### Conservation action summary

- Maintain areas of 'dark space' in the urban matrix.
- Change the spatial and temporal extent of artificial night lighting, reduce the intensity of emitted light, and select lights that emit wavelengths likely to have lower ecological impact.

The presence of artificial night lighting can reduce the occurrence of light-sensitive species and change the behaviours of both diurnal and nocturnal species. Changing the current approach to artificial night lighting can improve the quality of habitat for light-sensitive biodiversity, with the added benefit of providing residents with clearer views of the night sky. Maintaining areas in the urban matrix as 'dark areas' by removing lights will increase the connectivity of the urban matrix for nocturnal species. Such dark areas should be concentrated around water bodies and in areas where there is high ecological potential for nocturnal fauna (Gaston *et al.*, 2012). Artificial night lighting has been shown to reduce the area of habitat available for microbat species in Sydney (Threlfall *et al.*, 2013). Some large green spaces, such as golf courses, may have high microbat activity, however; such spaces often have stands of native remnant vegetation that provide dark areas within the urban matrix (Threlfall & Williams *et al.*, 2016).

In areas where the removal of artificial night lights is impractical, changing the duration, intensity and direction of lighting and the wavelengths emitted can have positive impacts on nocturnal fauna (Gaston *et al.*, 2012; Hale *et al.*, 2015). In a review of management options for minimising ecological light pollution, Gaston *et al.* (2012) described the tradeoffs for humans, and the possible impacts for biodiversity, for each option and recommended that:

1. **Changing the duration and intensity of lights**, and the use of more directional lighting, will save on energy costs. Reducing the overall duration of lighting throughout the day may not produce a great ecological advantage, however, because much of the impact of artificial night lighting is at dusk. Reducing night lighting seasonally to reduce impacts on yearly events (such as turtle hatchings and bird migrations) may be beneficial. Structural changes to the design of lights, so that light does not reach areas for which it is unintended (e.g. the sky above street lamps and the edges of remnant vegetation), will also benefit nocturnal fauna by increasing the patchiness of light in an area and enabling nocturnal fauna to access dark spaces more readily. Because humans have a lower sensitivity to light than many nocturnal animals, reducing light intensity may not reduce the impact of lights on nocturnal fauna in the immediate vicinity. A reduction in light intensity will, however, mean that less light enters areas not intended to be lit and thus will increase the area of dark space in the environment.
2. **Changing the type of lights used** in artificial night lighting can change the species affected. Removing wavelengths known to be attractive to targeted nocturnal fauna will have benefits for biodiversity, although it may have negative impacts on fauna that exploit light sources for foraging (Jung & Kalko, 2010). For example, the removal of ultraviolet-rich lighting like mercury vapour lights may decrease the number of insects attracted to lights. Some councils in Sydney are already replacing mercury vapour lamps, usually for energy consumption reasons<sup>17</sup>, but more research is needed to determine the difference in attraction between lower ultraviolet lighting options (van Grunsven *et al.*, 2014) and the effects of changing light type at a

<sup>17</sup> e.g. [www.northsydney.nsw.gov.au/Business\\_Parking/Traffic\\_Transport/Street\\_Lighting](http://www.northsydney.nsw.gov.au/Business_Parking/Traffic_Transport/Street_Lighting)

community level. Moving away from white light will decrease the spectrum over which light is emitted. The impacts on nocturnal fauna in Australia of the introduction of more 'biodiversity-friendly' artificial night lighting, and large-scale changes of streetlighting to LEDs, require further research.

### Green spaces within the urban matrix

This section describes the benefits of different types of green space (e.g. public parks, golf courses, sports fields and the curtilage surrounding them, such as private gardens and residential backyards, informal green spaces and additions to the built environment) in urban areas and suggests ways in which green spaces can be managed to improve the habitat suitability of the urban matrix. Differences in the spatial scale and ownership of green spaces mean that each type of green space should be considered separately.

#### Parks and golf courses

##### Conservation action summary

- Retain pockets of remnant vegetation and hollow-bearing trees.
- Plant vegetation that will provide good ground-storey and mid-storey cover.
- Choose native vegetation for parklands and golf courses, taking into consideration local provenance, planting objectives and survival under future environmental conditions.
- Increase habitat diversity by incorporating water features and retaining logs, fallen branches and leaf litter, or by providing artificial habitats such as artificial rock shelters.
- Decrease the intensity of management practices such as mowing and reduce the proportion of area covered by lawn. Create 'no mow' areas on the edges of green spaces and in areas that receive little public use.
- Eliminate the unnecessary use of pesticides in green spaces.
- Make use of interpretive features (including signage) to inform the public of the ecological reasons behind management decisions.

Public parks, including sports fields, and the curtilage surrounding them can be beneficial in urban areas by providing residents with access to green space from which they can derive recreational, physical health and educational benefits. Urban parks can also promote biodiversity conservation by maintaining remnant vegetation, hollow-bearing trees and other wildlife habitat. For example, Australian parklands have been shown to have higher bird species richness than residential areas (White *et al.*, 2005; Taylor *et al.*, 2013) and bees (Threlfall *et al.*, 2015).

Areas of green space can be beneficial for urban biodiversity in their own right, especially when they are large in area, well designed, support a diversity of habitat types (e.g. patches of native vegetation with multiple layers of structural complexity, ponds and unmanaged areas) and use ecologically sensitive management practices (Philpott *et al.*, 2014) while still maintaining other public-interest objectives. The importance of large, mature native trees in urban areas is discussed elsewhere, and the same principles of maintaining trees in streetscapes can be applied to parks. Urban parks provide good public spaces in which managers can actively protect mature native trees (Stagoll *et al.*, 2012). New native trees can also be planted to increase tree density, which can be a predictor of urban biodiversity (Threlfall & Williams *et al.*, 2016).

As well as tree density and canopy cover, other non-tree native vegetation (ground-storey and mid-storey vegetation) can be important for increasing biodiversity in parks. Native birds, for example, have higher diversity in parks compared with residential areas (White *et al.*, 2005; Taylor *et al.*, 2013), with

more feeding guilds represented in parks than in vegetated streetscapes (White *et al.*, 2005). This higher native bird species diversity has been attributed to the higher habitat complexity in parks compared with streetscapes due to their more complete ground-storey, mid-storey (shrub) and tree-canopy cover (White *et al.*, 2005). In a Brisbane parkland, for example, insectivores and frugivores were found to be associated with understorey vegetation density, in addition to canopy cover (Slater, 1995). Such site-specific studies support the general finding that, across all taxa, vegetation complexity at all levels has a positive effect on urban biodiversity (Beninde *et al.*, 2015). Recognising this, park managers can increase biodiversity by restoring the complexity of ground and shrub covers, while incorporating crime prevention through environmental design (CPTED) requirements (see section 5.7).

A number of studies on urban parks have identified management practice as a key variable affecting biodiversity outcomes. A study in Tel Aviv, Israel, for example, determined that the most intensely managed parks had the lowest species richness and abundance of fauna and the highest proportion of urban-exploiter species. Intermediate levels of management usually had the highest biodiversity, and unmanaged areas had similar or slightly lower richness than intermediate management intensities (Shwartz *et al.*, 2008). This finding suggests that decreasing the intensity of management practices in parks, at least in sections of them, can be beneficial for biodiversity, with the co-benefit of reducing maintenance costs.

Many park systems are now employing biodiversity-friendly management practices such as reductions in pesticide use, the use of mulches, the retention of leaf litter and fallen logs, the minimisation of disturbance and soil compaction, a reduction in the area of mowed areas and the use of differential mowing (**Figure 3.20**). If mowed areas are present, raising the mowing height and increasing the time between mowing events can be beneficial. In North America and Europe, delaying management practices such as mowing to avoid important ecological events like nesting seasons and butterfly flight periods have been demonstrated to increase the survival of grassland species (Johst *et al.*, 2006; Gruebler *et al.*, 2012; Broyer *et al.*, 2016). In Paris, France, a 'differential management' program encourages park managers to use biodiversity-friendly management practices in their parks (Shwartz *et al.*, 2013), and the adoption of recommended principles can earn them biodiversity-friendly garden certification. Evaluations of the biodiversity outcomes of parks with 'biodiversity-friendly' ratings, compared with those without such ratings, indicate that differential management techniques can increase the biodiversity of all taxa studied. In such studies, local-scale management variables were found to be more important than landscape factors, demonstrating the role of small-scale management decisions in enhancing biodiversity, even in small public parks. Despite overall increases in biodiversity, individual management practices had different effects on different taxa (Shwartz *et al.*, 2013).



**Figure 3.20.** Contrast between areas of unmowed and mowed grass in Prince Albert Park, Surrey Hills, Sydney. Setting aside areas for low-maintenance management practices can increase urban biodiversity, especially when converted from traditionally manicured lawn. Source: F. van den Berg (taken 2016).

Increasing biodiversity-friendly gardening practices in public spaces could lead to ‘messier’ park because such practices promote less-structured vegetation cover, higher understories with more leaf litter, and the retention of fallen branches and logs, with potential impacts on aesthetic values. If, on the other hand, the messiness looks ‘in place’ in the surrounds (i.e. near remnant vegetation) or on purpose, or signs inform the public that the messiness is intentional and there are ecological benefits, these areas are viewed as attractive (Nassauer, 1988, 1992).

Golf courses provide similar benefits to large urban parks and often harbour more biodiversity than surrounding residential areas (Threlfall *et al.*, 2015; Threlfall & Williams *et al.*, 2016). Although access by residents may be restricted, the importance of these large green spaces to a city’s overall green space should not be overlooked. Golf courses may have added benefits by containing areas in which little or no maintenance is carried out and human disturbance is minimised (out-of-play areas) and by retaining remnant vegetation and providing ‘dark spaces’ at night (Threlfall & Williams *et al.*, 2016). Golf courses can contribute to the conservation potential of cities: in Melbourne, for example, species of microbats and birds were found in the remnant vegetation maintained on golf courses that were not found in residential areas or public parks (Threlfall & Williams *et al.*, 2016). The Australian Golf Course Superintendents Association acknowledges the capacity of golf courses to provide multiple environmental benefits when designed and managed well, although when managed poorly they can have negative environmental impacts (e.g. as sources of nutrients and contamination, and the degradation of native ecosystems) (Neylan, 2007). *Improving the Environmental Management of New South Wales Golf Courses* (Neylan, 2007) highlights how ecological principles can be incorporated into the planning, design, construction and ongoing maintenance of golf courses. Recommendations include avoiding environmentally sensitive areas and creating buffer zones around them; retaining, protecting and enhancing existing native vegetation; designing courses so that areas of native vegetation can serve

as wildlife corridors; reducing watering and fertiliser use and reusing stormwater; using native plants in landscaping in non-play areas; and protecting and enhancing habitats for beneficial wildlife species (terrestrial and aquatic) (Neylan, 2007). Maintaining golf courses as green spaces rather than converting them to development should be a priority as cities expand.

## Residential and private gardens

### Conservation action summary

- Provide education and access to biodiversity-friendly gardening resources.
- Encourage the planting of native plants that include complex ground-storey, mid-storey and canopy cover.
- Encourage the planting of dense native mid-storey vegetation and flowering plants and the provision of habitat resources (e.g. water features, nesting boxes, rock piles and logs).
- Discourage the planting of exotic plants and avoid planting species known to be weeds.
- Discourage the planting of cultivated native hybrids that produce large, nectar-rich floral displays over extended flowering periods.

Backyards and private gardens constitute a significant proportion of green spaces in cities, especially in areas of low-density housing. Consequently, gardens can contribute to residents' connection to nature and urban biodiversity: floral diversity is often much higher in backyards than surrounding natural areas due to the presence of exotic species (Thompson *et al.*, 2003). Even though the spatial scale of individual residential gardens is much smaller than that of public pockets of land set aside for conservation, the combination of multiple gardens, if appropriate gardening practices are applied collectively, can improve conservation and biodiversity outcomes in the urban matrix (Cooper *et al.*, 2007; Goddard *et al.*, 2010).

Residential gardens are not homogenous (Roche *et al.*, 2016) in structure, species composition, size, usage or resources provided. Philpott *et al.* (2014) found that most variation in garden biodiversity is driven by local factors, at least for invertebrates, and management practices, therefore, can affect biodiversity outcomes for urban gardens. A large study in the United Kingdom examined the importance of gardens to urban biodiversity (Thompson *et al.*, 2003; Gaston *et al.*, 2005; Smith *et al.*, 2005; Smith *et al.*, 2006; Loram *et al.*, 2007). This and other studies around the world and in Australia have identified key principles of biodiversity-friendly gardening practices. For example, compared to smaller gardens, larger gardens are more likely to have greater diversity of land-cover composition, more trees over 2m and canopy cover over 3m and more sustainable practices like vegetable patches and composting piles. As gardens decrease in size, the proportion of unvegetated areas increases (Smith *et al.*, 2005). Larger gardens may therefore increase biodiversity compared with small gardens, but their presence may also mean that more land is used for residential areas. Despite evidence suggesting that larger backyards may have higher biodiversity value than smaller backyards, conflicts arise between planning for larger backyards and decreasing suburban sprawl (see section 3.6). The trend towards smaller lot size and increasing house size also limits the amount of space available for backyards (see section 5.8), although minimum landscaping requirements are written into development control plans (DCPs, see section 4.4) in some local-government areas. Vegetating built structures (e.g. using green walls and roofs) may increase the provision of private green spaces in densifying cities, although the benefits for biodiversity of these structures may not be as great as those provided by ground-level green spaces.

Within a garden, small-scale spatial factors, especially vegetation cover (e.g. abundance of trees/canopy cover) affect invertebrate richness and abundance, although different taxa have different responses to certain variables (Smith *et al.*, 2006). Good habitat quality in backyards can increase biodiversity, and

the provision of certain resources can increase the presence of particular species. For example, the increased availability of flowering plants and the provision of habitat for nesting sites (e.g. bare ground, soft wood and small hollows) can increase pollinator assemblages (Matteson *et al.*, 2008; Bates *et al.*, 2011). In Chesapeake Bay, US, wildlife gardening practices can be stretched beyond the land boundaries of properties to docks that extend into the bay, with residents encouraged to create oyster 'gardens' in cages attached to their docks (Goldsborough & Meritt, 2001). Not all purported conservation actions associated with wildlife gardening are effective, however, at least in the United Kingdom (Gaston *et al.*, 2005). The addition of potential nesting structures for solitary bees (e.g. wooden blocks with holes drilled in them, plastic pipes, and tins filled with straw) was beneficial, but the provision of habitat for bumblebees (terracotta pots and wooden boxes) was not. Ponds and piles of dead wood have also been shown to have a habitat-provisioning function in backyards (Figure 3.21). Ponds are sources of mosquitoes and midge larvae (Gaston *et al.*, 2005), however, and are not appropriate in all urban gardens, especially in cities with the urban-adapted *Aedes aegypti* mosquito (Maneerat & Daude, 2016), which can transmit diseases such as dengue.



**Figure 3.21.** Residential garden in Ashburton, Victoria, which includes a pond to create wildlife habitat. Photo by J. Kurlyo (taken 2015).

Residential gardens in Sydney have been shown to support high levels of biodiversity, although not always as high as surrounding remnant vegetation (Heterick *et al.*, 2013). The potential of backyards to act as additional habitat near remnant bushland patches has been demonstrated in Sydney, where suburbs near bushland reserves with high tree cover in backyards support numerous microbat species (Basham *et al.*, 2011). Ecological principles can be applied to private gardens to increase the suitability of the urban matrix for biodiversity and the potential of green spaces to buffer ecologically sensitive areas; actions could include the retention of large trees, the conservation or establishment of native vegetation, and increased understorey volume (Threlfall & Williams *et al.*, 2016). Benefits can also be expected when plant assemblages in suburban gardens are similar to those of nearby reserves. By extending the distribution of key native plant resources, remnant habitats can be buffered and connected across the urban matrix, enhancing the movement of species able to use those resources (Goddard *et al.*, 2010).

The species of plants used in backyards influences the fauna species that will occur in those backyards. Gardens with high numbers of flowering plants, for example, were shown to support higher abundances of the introduced honeybee, *Apis mellifera* (Threlfall *et al.*, 2015). Gardens with more native vegetation generally support higher abundances and richness of native species, including rarer species, compared with predominantly exotic planted backyards (Daniels & Kirkpatrick, 2006; Parsons *et al.*, 2006; Burghardt *et al.*, 2009) (**Figure 3.22**). Exotic plants can become weeds and spread into neighbouring remnant vegetation. Local councils often issue environmental weed lists to highlight the potential environmental risk of planting particular exotics known to be weeds in an area. Even among native plants, however, the choice of species can influence the types of fauna that use backyards. In one study, native fauna preferred banksias and grevilleas to (non-native) hibiscus and camellias because the native species produced more nectar; banksias were preferred to grevilleas, however, because they produced more nectar and thus were a more productive food source (French *et al.*, 2005). It is hypothesised that increasing the number of cultivated native hybrids with nectar-rich large inflorescences (e.g. grevilleas) can increase the abundance of aggressive honeyeaters and decrease the number of smaller birds, leading to a decrease in biodiversity (Sewell & Catterall, 1998). Thus, biodiversity outcomes in urban areas will be improved by encouraging the planting of native species sourced in the local area, reducing the number of large, prolifically flowering native hybrids, and increasing dense shrub vegetation. Habitat Stepping Stones<sup>18</sup>, a Macquarie University program, encourages residents to plant native plants, including ground-storey, understorey and tree species sourced in the local area, and provide water and shelter features (e.g. nesting boxes, bird baths, ponds, shelter plants and rock piles) in their backyards. When residents 'pledge' to create a 'habitat stepping stone' by implementing at least three features, they can share their location on a map of Sydney. Such programs therefore encourage collective biodiversity-friendly backyard management.

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<sup>18</sup> [www.habitatsteppingstones.org.au](http://www.habitatsteppingstones.org.au)

**Figure 3.22.** Residential gardens that have incorporated native plants into their landscaping in **a)** Balywn North, Victoria, and **b)** Glen Iris, Victoria. Photos taken by J. Kurylo (2014-2015).

a)



b)



Because backyards are privately owned, homeowners will be the primary initiators of garden practices that enhance local biodiversity and minimise impacts on the surrounding environment, although some councils (e.g. Sutherland Shire's Greenweb; Figure 3.13) proscribe types of landscaping, including with prescriptive species lists. In the absence of mandatory landscaping requirements, however, educational services and resources should be made available to enable homeowners to make informed decisions. Bush Mates, a program run by the National Parks Association of NSW, is a good example of one such educational program in Sydney. This aim of this program is to educate residents in Sydney's new suburbs on practices in their backyards that will have minimal impacts on the surrounding remnant vegetation. The program encourages the planting of native local vegetation, including trees and spiky

shrubs, while avoiding weedy species; reducing water use; using environmentally friendly cleaning products; minimising the effects of pets by keeping them indoors or on leashes; reducing impervious surfaces; and providing resources like bird baths, nesting boxes, logs and rocks for use as habitat.

Residential backyards are important places for residents to connect with nature, and such connections can be used to increase understanding of the roles of gardening practices on biodiversity through citizen science (Cooper *et al.*, 2007). For example, volunteers helped survey the relationship between particular species of dominant urban bird species and other backyard practices (e.g. keeping pets and feeding birds) in backyards in Sydney (Parsons *et al.*, 2006). Among the survey's findings were: increasing native plants in Sydney gardens was an important way of increasing small-bird species richness; feeding birds can have both negative and positive effects on small-bird richness, depending on the functional group of birds targeted; and the presence of carnivorous pets had no impact. Citizen science was also used to monitor the use of birdbaths by birds in urban and rural backyards on Australia's southeastern coast. The large spatial scale (southern Queensland to Victoria) and sample size (992 citizen scientists) provided a clear demonstration of differences in the use of birdbaths between rural and urban areas and between biogeographical regions (Cleary *et al.*, 2016). The survey reflected past observations that large aggressive nectarivores were driving differences between urban and rural birdbaths in the Sydney Basin but found that such differences were not consistent across all bioregions in the study (Cleary *et al.*, 2016).

#### Informal green space

##### Conservation action summary

- Acknowledge the potential of informal green spaces (e.g. street verges, rail corridors, vacant lots, power line easements and spaces between building and fences) to support biodiversity.
- Decrease the intensity of maintenance in informal green spaces.
- Encourage the establishment of habitat complexity in informal green spaces (e.g. street verges and roundabouts) by decreasing mowing and planting native species with complex ground-storey and mid-storey layers and, where applicable, native tree species.

As well as public or privately managed green space, vegetated areas that are not formally managed have potential to improve the habitat quality of the urban matrix and increase the area of green space available for use as habitats, corridors and stepping stones (Bonthoux *et al.*, 2014; Rupprecht *et al.*, 2015). Such unmanaged areas can be valuable resources for residents, potentially providing them with nature experiences and additional recreational space (Rupprecht & Byrne, 2014). Unmanaged spaces, known collectively as 'informal green spaces' (IGSs), include vacant lots, brownfields, railway tracks and associated verges, street verges (such as road verges, roundabouts, footpaths and other traffic infrastructure), spaces under power lines, spaces between walls and buildings, and spontaneous vegetation growing on built structures or in cracks or holes in built infrastructure (Rupprecht & Byrne, 2014). Because much of the vegetation in IGSs arrives opportunistically, IGSs may not constitute native habitat but, rather, novel ecosystems (Rupprecht *et al.*, 2015). IGSs such as railway verges (Penone *et al.*, 2012) and road medians (Munshi-South, 2012) have the potential to provide stepping-stone or corridor functions. Rail reserves between Newcastle, Kiama, Lithgow and Macarthur, for example, collectively have a length of 721 km (Cielo Roldan, NSW Transport: Asset Standards Authority, *pers. comm.*), and their potential to function as biodiversity corridors and provide a range of co-benefits is underused.

In a global review of IGSs and their impacts on biodiversity, Rupprecht *et al.* (2015) concluded that high numbers of animals across a variety of taxa use IGSs. Often, IGSs have higher abundances than other forms of land use (e.g. lawns, forests and rural areas), although the review did not determine the extent to which the assemblages reflected native biodiversity. Informal green spaces have been shown, however, to provide habitat for rare species.

Local factors are considerably more important than landscape factors in determining species richness and diversity in IGSs, especially for arthropods (Philpott *et al.*, 2014). This is consistent with the global review of urbanisation and biodiversity by Beninde *et al.* (2015), which found that insects responded more to local factors than landscape factors. Managers may be able to increase the extent to which such spaces support biodiversity by adding habitat complexity.

Although not all types of IGS are well studied, general principles on the impact of maintenance practices on biodiversity can be identified. The intensity of management practices (e.g. mowing, pesticide use and vegetation removal) plays a large role in determining the biodiversity potential of sites, with biodiversity decreasing with increasing intensity and frequency (Helden & Leather, 2004; Angold *et al.*, 2006; Rupprecht *et al.*, 2015). Maintenance practices, especially mowing, remove habitat structure and complexity, decrease food and nesting resources for fauna, and result in spaces dominated by pioneer species. A reduction in the intensity of maintenance regimes in IGSs is likely, therefore, to promote biodiversity in urban areas, although such a reduction in intensity needs to be traded off against the aesthetic (and possibly safety) values of the space (Rupprecht & Byrne, 2014).

Street verges (**Figure 3.23**) were one of the most studied forms of IGS identified in the Rupprecht *et al.* (2015) review. The importance of tree coverage, tree type and tree age on streets in providing habitat and resources and aiding dispersal by acting as stepping-stone vegetation or corridors is discussed above. Not all species respond to the same local factors, and understanding which variables are related to desirable biodiversity can help in developing streets that promote biodiversity among key taxa (Philpott *et al.*, 2014). For example, it is recommended that new housing developments not only retain native trees but also increase the habitat complexity of understorey canopy layers on streets as a way of increasing the habitat potential of street verges for smaller birds (which noisy miners often exclude) (Barth *et al.*, 2015).

a)



b)



c)



d)



e)



f)



**Figure 3.23.** Street verges with varying degrees of vegetation and understorey complexity: **a)** complex understorey planted by the council in Glebe, Sydney (City of Sydney); **b)** complex understorey with a variety of plants, including natives, exotics, succulents and food plants, planted by a resident in Lewisham, Sydney (Inner West Council); **c)** stepping stones allowing residents to walk across a verge from where they park their cars to the footpath, Lewisham, Sydney; **d)** raised garden beds positioned on street verges for residents to grow food crops, Marrickville, Sydney (Inner West Council); **e)** comparison between lawn street verges (foreground) and complex vegetated street verges (behind), Dulwich Hill, Sydney (Inner West Council); and **f)** street verges with planted trees surrounded by impervious concrete, Dulwich Hill, Sydney (Inner West Council). Photos: F. van den Berg (taken 2016).

Road traffic islands can increase urban green space through the addition of vegetation, although maintenance may be a health-and-safety risk for staff. Vegetated road traffic islands can provide habitat for bacteria, fungi, invertebrates and plants (Whitmore *et al.*, 2002; Helden & Leather, 2004; Reese *et al.*, 2016). These areas are small and often spatially isolated by artificial surfaces from larger green spaces, at least for small organisms and organisms with limited dispersal. Consequently, the assemblages supported by street infrastructure are often not the same as those occurring in larger areas or contiguous habitat (Whitmore *et al.*, 2002; Reese *et al.*, 2016). Street infrastructure can provide habitat for some species, however, and thus provide more support for biodiversity than similar artificial structures without vegetation. Increasing the size of the vegetated area may increase biodiversity potential for some species (Helden & Leather, 2004), but the area–species richness relationship is not always observed in such areas (Whitmore *et al.*, 2002).

The importance of increased habitat complexity for biodiversity, and the potential for other purposes to be designed into IGSs, is demonstrated by two studies investigating the biodiversity potential of bioretention basins in street verges in Melbourne. Such bioretention basins work by capturing stormwater in vegetated depressions to filter out debris, nutrients and other contaminants and they also increase infiltration and evapotranspiration and slow the movement of stormwater by increasing the time taken to reach drains. Bioretention basins, therefore, are a crucial part of WSUD because they can decrease the connectedness of impervious surfaces to streams (**Figure 3.24**). Biodiversity can be increased by increasing the amount and diversity of vegetation used, especially in the mid-storey, in bioretention basins, and also by using diverse morphologies and substrates (Kazemi *et al.*, 2011). Bioretention basins and garden-style verges were found to have significantly higher biodiversity than lawn verges, although the species composition differed between bioretention basins and garden-style

verges. The presence of gravel, and increasing leaf litter depth and groundcover complexity, were beneficial for ground-dwelling invertebrates (Kazemi *et al.*, 2009). For above-ground invertebrates, increasing mid-storey coverage (e.g. shrubs, rushes, tall grasses, lilies and rushes) with higher numbers of flowering plants, incorporating depressions into the slopes of verges, and changing the pH, all had positive impacts on biodiversity (Kazemi *et al.*, 2011). Recommendations arising from the studies included maximising the biodiversity potential of street verges, incorporating a combination of bioretention basins and garden-style verges into gardening designs, and deploying low-maintenance regimes to allow the build-up of leaf litter (although see section 5.8 for a discussion of maintenance requirements). Lawn street verges should be minimised because they have few biodiversity benefits (Kazemi *et al.*, 2009; Kazemi *et al.*, 2011).

A consideration on the use of bioretention basins and other WSUD features for providing habitat is the routine maintenance needed to maintain the stormwater filtration function, which may involve the removal of sediment, debris and vegetation and may temporarily reduce habitat availability in an area. The impact of maintenance can be minimised by carrying it out on only a small proportion (approximately one-third) of WSUD devices in an area at any one time, and providing complementary or refuge habitats during maintenance.

a)



b)



**Figure 3.24.** WSUD features built into streetscapes in Glebe, Sydney (City of Sydney). These features increase habitat complexity compared with adjacent lawn verges by adding mid-storey vegetation, although plant selections in WSUD features are rarely species-rich because planting decisions are based on engineering considerations rather than biodiversity. Source: F. van den Berg (taken 2016).

## Green walls/green roofs

### Conservation action summary

- Create vegetated roofs with high habitat complexity, variation in vegetation type and resources such as flowering plants and nesting sites to encourage biodiversity.
- Acknowledge that green roofs will not provide habitat for all species due to their isolation (elevation), size and microclimate. Green roofs, therefore, will benefit biodiversity more than will bare roofs but are not a replacement for ground-level green space.
- More research is needed on the benefits of green roofs for urban biodiversity.

Designing or retrofitting vegetated components into buildings, artificial structures or traditionally unvegetated thoroughfares (e.g. laneways) is a novel way of increasing the amount of green space in urban environments. Such vegetated components can be designed to provide a variety of benefits, but

mostly they are designed for amenity or aesthetic purposes, water retention to minimise water runoff from impervious surfaces, and cooling.

Installing green walls and green roofs in an area with a high proportion of impervious surfaces may have indirect biodiversity benefits by reducing the rate of flow of water into streams through retention and decreasing local UHI effects, although the latter is likely to be minimal unless there is a high proportion of green roofs in an area. Although they not commonly done in Australia, green roofs can be designed to increase biodiversity (e.g. in the City of Toronto<sup>19</sup>; **Figure 3.25**). Biodiversity-friendly green roofs are composed of diverse mostly native plants, producing higher habitat complexity and quality compared with traditional green roofs; they can be modified to meet the habitat requirements of particular taxa (e.g. providing nesting sites for bees; Tonietto *et al.*, 2011). The low implementation of biodiverse green roofs in Australia can be attributed to a lack of awareness or knowledge among built-environment professionals, the design of green roofs for other purposes, and the exclusion of biodiverse green roofs from most local planning policies. More evidence and examples are needed of the benefits of biodiverse green roofs in Australia.

a)



b)

c)

<sup>19</sup> [www1.toronto.ca/City Of Toronto/City Planning/Zoning & Environment/Files/pdf/B/biodiversegreenroofs\\_2013.pdf](http://www1.toronto.ca/City Of Toronto/City Planning/Zoning & Environment/Files/pdf/B/biodiversegreenroofs_2013.pdf)



**Figure 3.25. a–b)** Green roof mimicking a native meadow at Prince Alfred Pool, Prince Alfred Park, Surry Hills, Sydney. **c)** Sign on the roof informing residents of the purpose of the roof and the behaviour expected of them. Despite lacking plant species diversity, the site is relatively structurally diverse and was found to provide habitat for a diverse insect assemblage (Berthon *et al.*, 2015). Source: F. van den Berg (taken 2016).

Results are mixed from studies on the benefits for species diversity and abundance of roofs designed for biodiversity compared with conventional green roofs (reviewed in Williams *et al.*, 2014). The small size of roofs, their isolation from other green spaces (which limits colonisation to flying or wind-dispersed organisms), and their harsh conditions (e.g. high winds, low shade and increased temperatures) make roofs undesirable habitats for many species (Latty, 2016), but green roofs are often purported to have benefits for biodiversity conservation. In a recent review of green roofs for urban biodiversity, Latty (2016) concluded that, although evidence for the benefits of green roofs for vertebrates is limited and mixed, there is increasing evidence that green roofs can support high abundances of terrestrial invertebrates, possibly due to their smaller body size, high mobility and capacity to survive in xeric environments, at least for some taxa. Berthon *et al.* (2016) compared green roofs and bare roofs in Sydney and found that green roofs increased the number of invertebrates, mainly true bugs and springtails: roofs with more than 30% vegetation cover supported three times as many species as bare roofs. The benefits were most apparent on green roofs with an area greater than 750m<sup>2</sup>. Non-mobile species were lacking on these green roofs, however, demonstrating that not all taxa can use such spaces unless they are intentionally introduced. Interestingly, bare roofs were found to support an assemblage of mainly predator and scavenger invertebrates, although these may not represent breeding populations.

Many studies of green roofs, although showing high abundances of invertebrates, do not compare assemblages with ground-level assemblages and therefore the roofs cannot be evaluated for their ability to be a replacement for, rather than a supplement to, ground-level green space (Williams *et al.*, 2014). When such comparisons are made, species richness is usually lower on green roofs than in ground-level habitat (reviewed by Williams *et al.*, 2014). Despite this difference between roof and ground-level assemblages, green roofs might still provide ecosystem services. In Chicago, US, for example, native grasses on roofs exhibited higher pollination rates than equivalent ground-level plants, despite reduced pollinator abundance and diversity on green roofs (Ksiazek *et al.*, 2012). In the United Kingdom, bats foraged more over biodiverse green roofs, possibly due to elevated levels of insects compared with bare roofs and roofs with a covering of sedum (Pearce & Walters, 2012). Two other studies (Kaupp *et al.*, 2004; Braaker *et al.*, 2014) demonstrated that vegetated roofs can act as habitat stepping stones in the urban matrix. If green roofs are installed to provide habitat for select taxa of invertebrates, therefore, they can be beneficial for urban biodiversity and may provide associated functions. If the purpose of green roofs is to offset a reduction in ground-level green space, however,

caution should be applied, even when such green roofs are of equivalent size to the spaces they are replacing. More research, with good experimental design, is needed to evaluate the overall benefits of green roofs for biodiversity (Williams *et al.*, 2014)

### 3.7 Discussion

In this chapter we recommend conservation actions and design interventions that will have positive benefits for biodiversity. Ecological theory and empirical research demonstrate that increasing the extent, quality and connectedness of habitats will likely support more species, more ecological communities, and more ecosystem services. The conservation actions recommended in this chapter draw on this research and seek to **retain and enhance habitat** (e.g. by increasing vegetation complexity), **connect biodiversity** by reducing the hostility of the urban matrix (e.g. by establishing green corridors), and **create new habitat** to support biodiversity and ecosystem services (e.g. by constructing artificial wetlands).

Positive outcomes are not guaranteed for any conservation action or design intervention, however. The potential benefits of an action for biodiversity must be weighed against its feasibility and cost. Explicit spatial planning is often needed to identify the most cost-effective opportunities – such as the best placement for a green corridor connecting urban remnants, requiring detailed spatial information on biodiversity. Sydney is fortunate that detailed vegetation mapping<sup>20</sup> (conducted by the Office of Environment and Heritage) is available for the metropolitan region, although this does not cover much of western Sydney. Detailed, complete and readily available biodiversity information (e.g. vegetation mapping) for the Sydney, Newcastle and Wollongong regions is an important prerequisite for achieving urban ecological renewal.

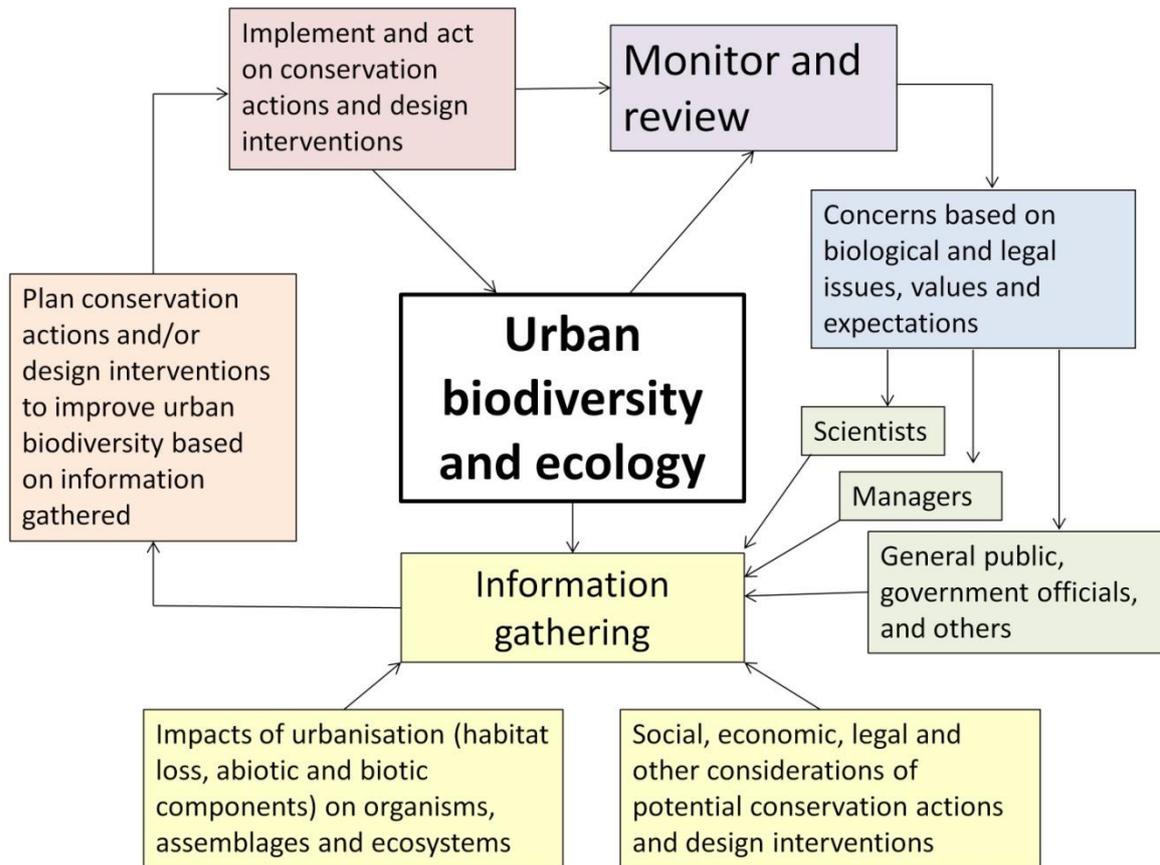
Evaluation is crucial for demonstrating the success or failure of urban ecosystem projects. Biodiversity (measured using pre-defined metrics based on the original aim of the intervention) must be monitored over the long term because changes in response to urbanisation can have a significant lag time (McDonald *et al.*, 2016). Standardised metrics for measuring outcomes are of great importance because they allow comparison across projects and simplify training in, and the implementation of, monitoring efforts. For biodiversity outcomes in terrestrial systems, the Biodiversity Assessment Methodology (BAM – now being implemented by the NSW Office of Environment and Heritage) assesses multiple aspects of biodiversity. Adopting the conceptual framework of Noss (1990), the BAM protocol captures information on the composition (e.g. percent of native species), structure (e.g. coverage of vegetation layers) and function (e.g. habitat provision) of vegetation remnants.

The renewal of urban ecosystems requires close engagement between researchers, practitioners and other stakeholders. Research in urban ecology is needed to identify crucial conservation actions. Explicit spatial planning and the requisite spatial information are needed to identify the most efficient and effective intervention opportunities. Whenever the aim is to benefit urban biodiversity, outcomes must be demonstrated through ongoing monitoring. An adaptive management process (**Figure: 3.26**) that iteratively monitors and reviews project outcomes and adjusts actions accordingly provides a framework for continuous evaluation, flexible implementation and engagement across sectors. Because values and concerns in urban areas are not purely ecological, projects should also be evaluated according to (for example) social and legal parameters. Such multidisciplinary efforts provide key roles for scientists, managers, the public and other stakeholders in evaluating the process. Ultimately, it must

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<sup>20</sup> See <http://www.environment.nsw.gov.au/surveys/VegetationSydMetro.htm>

be recognised that cities are ecosystems that primarily support human communities but also host a myriad of non-human species. If biodiversity is to be retained and increased in cities, the engagement and cooperation of all stakeholders is essential.



**Figure 3.26.** Schematic of an adaptive management process when applied to the aim of increasing urban biodiversity and ecology (central box). Initially, information is gathered (yellow) based on scientific research about the impacts of urbanisation on biodiversity as well as social, economic, legal and other considerations, and this information is used to plan conservation actions and design interventions expected to improve urban biodiversity (orange). The plan is implemented (red) and the outcomes monitored and reviewed based on the original aim. The conservation action/design intervention is evaluated for its performance in meeting biodiversity goals and on other issues, values or expectations. This process requires the integration of several perspectives, including those of scientists, managers and other stakeholders. Based on evaluation, if the conservation action/design intervention is not meeting expectations, new information is gathered to improve the intervention or change the approach, and the process continues. Source: Modified by F. van den Berg for urban biodiversity and ecology from an adaptive management process for protected areas in Primack (2010).

### 3.8 Chapter references

- ABS (Australian Bureau of Statistics). (2014). *Australian Historical Population Statistics*. Available at <http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3105.0.65.0012014?OpenDocument>
- Airoldi, L., Abbiati, M., Beck, M. W., Hawkins, S. J., Jonsson, P. R., Martin, D., Moschella, P. S., Sundelof, A., Thompson, R. C., & Aberg, P. (2005). An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. *Coastal Engineering*, *52*(10-11), 1073-1087. doi:10.1016/j.coastaleng.2005.09.007
- Airoldi, L., & Bulleri, F. (2011). Anthropogenic disturbance can determine the magnitude of opportunistic species responses on marine urban infrastructures. *PLoS ONE*, *6*(8), e22985. doi:10.1371/journal.pone.0022985
- Airoldi, L., Connell, S. D., & Beck, M. W. (2009). The loss of natural habitats and the addition of artificial substrata. *Marine hard bottom communities*. Berlin Heidelberg: Springer.
- Airoldi, L., Turon, X., Perkol-Finkel, S., & Rius, M. (2015). Corridors for aliens but not for natives: effects of marine urban sprawl at a regional scale. *Diversity and Distributions*, *21*, 755-768.
- Alexander, L. V., & Arblaster, J. M. (2009). Assessing trends in observed and modelled climate extremes over Australia in relation to future projections. *International Journal of Climatology*, *29*(3), 417-435. doi:10.1002/joc.1730
- Anderson, L., & Burgin, S. (2008). Patterns of bird predation on reptiles in small woodland remnant edges in peri-urban north-western Sydney, Australia. *Landscape Ecology*, *23*(9), 1039-1047. doi:10.1007/s10980-008-9252-5
- Anderson, M. J. (1996). A chemical cue induces settlement of Sydney rock oysters, *Saccostrea commercialis* in the laboratory and in the field. *Biological Bulletin*, *190*(3), 350-358. doi:10.2307/1543027
- Angold, P. G., Sadler, J. P., Hill, M. O., Pullin, A., Rushton, S., Austin, K., Small, E., Wood, B., Wadsworth, R., Sanderson, R., & Thompson, K. (2006). Biodiversity in urban habitat patches. *Science of The Total Environment*, *360*(1-3), 196-204. doi:10.1016/j.scitotenv.2005.08.035
- Aprahamian, M. W., Aprahamian, C. D., & Knights, A. M. (2010). Climate change and the green energy paradox: the consequences for twaite shad *Alosa fallax* from the River Severn, U.K. *Journal of Fish Biology*, *77*(8), 1912-1930. doi:10.1111/j.1095-8649.2010.02775.x
- Arnold, C. L., & Gibbons, C. J. (1996). Impervious surface coverage - the emergence of a key environmental indicator. *Journal of the American Planning Association*, *62*(2), 243-258. doi:10.1080/01944369608975688
- Aronson, M. F. J., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A., Warren, P. S., Williams, N. S. G., Cilliers, S., Clarkson, B., Dobbs, C., Dolan, R., Hedblom, M., Klotz, S., Kooijmans, J. L., Kuehn, I., MacGregor-Fors, I., McDonnell, M., Mortberg, U., Pysek, P., Siebert, S., Sushinsky, J., Werner, P., & Winter, M. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B-Biological Sciences*, *281*(1780), 20133330. doi:10.1098/rspb.2013.3330
- Arrhenius, O. (1921). Species and area. *Journal of Ecology*, *9*, 95-99. doi:10.2307/2255763

- Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G., & Thompson, P. M. (2010). Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. *Marine Pollution Bulletin*, *60*, 888-897.
- Banks, P. B. (2004). *Population viability analysis in urban wildlife management: modelling management options for Sydney's quarantined bandicoots*. Sydney, Australia: Royal Zoological Society of New South Wales.
- Banks, P. B., & Bryant, J. V. (2007). Four-legged friend or foe? Dog walking displaces native birds from natural areas. *Biology Letters*, *3*(6), 611-613. doi:10.1098/rsbl.2007.0374
- Barber, J. R., Crooks, K. R., & Fristrup, K. M. (2010). The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology & Evolution*, *25*(3), 180-189. doi:10.1016/j.tree.2009.08.002
- Barth, B. J., FitzGibbon, S. I., & Wilson, R. S. (2015). New urban developments that retain more remnant trees have greater bird diversity. *Landscape and Urban Planning*, *136*, 122-129. doi:10.1016/j.landurbplan.2014.11.003
- Basham, R., Law, B., & Banks, P. (2011). Microbats in a 'leafy' urban landscape: are they persisting, and what factors influence their presence? *Austral Ecology*, *36*(6), 663-678. doi:10.1111/j.1442-9993.2010.02202.x
- Bates, A. J., Sadler, J. P., Fairbrass, A. J., Falk, S. J., Hale, J. D., & Matthews, T. J. (2011). Changing bee and hoverfly pollinator assemblages along an urban-rural gradient. *PLoS ONE*, *6*(8), e23459. doi:e2345910.1371/journal.pone.0023459
- Becker, A., Whitfield, A. K., Cowley, P. D., Jarnegren, J., & Naesje, T. F. (2013a). Does boat traffic cause displacement of fish in estuaries? *Marine Pollution Bulletin*, *75*(1-2), 168-173. doi:10.1016/j.marpolbul.2013.07.043
- Becker, A., Whitfield, A. K., Cowley, P. D., Jarnegren, J., & Naesje, T. F. (2013b). Potential effects of artificial light associated with anthropogenic infrastructure on the abundance and foraging behaviour of estuary-associated fishes. *Journal of Applied Ecology*, *50*(1), 43-50. doi:10.1111/1365-2664.12024
- Beninde, J., Veith, M., & Hochkirch, A. (2015). Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters*, *18*(6), 581-592. doi:10.1111/ele.12427
- Bennie, J., Davies, T. W., Cruse, D., & Gaston, K. J. (2016). Ecological effects of artificial light at night on wild plants. *Journal of Ecology*, *104*, 611-620.
- Bernhardt, E. S., & Palmer, M. A. (2007). Restoring streams in an urbanizing world. *Freshwater Biology*, *52*(4), 738-751. doi:10.1111/j.1365-2427.2006.01718.x
- Bernhardt, E. S., & Palmer, M. A. (2011). River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation. *Ecological Applications*, *21*(6), 1926-1931.
- Bernhardt, J. R., & Leslie, H. M. (2013). Resilience to climate change in coastal marine ecosystems. *Annual Review of Marine Science*, *5*, 371-392. doi:10.1146/annurev-marine-121211-172411
- Bers, A. V., & Wahl, M. (2004). The influence of natural surface microtopographies on fouling. *Biofouling*, *20*(1), 43-51. doi:10.1080/08927010410001655533
- Berthon, K., Nipperess, D. A., Davies, P., & Bulbert, M. (2016). *Confirmed at last: green roofs add invertebrate diversity*. Paper presented at the State of Australian Cities Conference, Brisbane, QLD, Australia.
- Birch, G., & O'Hea, L. (2007). The chemistry of suspended particulate material in a highly contaminated embayment of Port Jackson (Australia) under quiescent, high-wind and

- heavy-rainfall conditions. *Environmental Geology*, 53(3), 501-516. doi:10.1007/s00254-007-0662-5
- Birch, G. F., Apostolatos, C., & Taylor, S. E. (2013). A remarkable recovery in the Sydney rock oyster (*Saccostrea glomerata*) population in a highly urbanised estuary (Sydney estuary, Australia). *Journal of Coastal Research*, 29(5), 1009-1015. doi:10.2112/jcoastres-d-12-00197.1
- Bishop, M. J. (2008). Displacement of epifauna from seagrass blades by boat wake. *Journal of Experimental Marine Biology and Ecology*, 354(1), 111-118. doi:10.1016/j.jembe.2007.10.013
- Bishop, M. J., & Chapman, M. G. (2004). Managerial decisions as experiments: an opportunity to determine the ecological impact of boat-generated waves on macrobenthic infauna. *Estuarine Coastal and Shelf Science*, 61(4), 613-622. doi:10.1016/j.ecss.2004.06.023
- Bishop, M. J., Kelaher, B. P., Smith, M. P. L., York, P. H., & Booth, D. J. (2006). Ratio-dependent response of a temperate Australian estuarine system to sustained nitrogen loading. *Oecologia*, 149(4), 701-708. doi:10.1007/s00442-006-0481-5
- Bishop, M. J., Mayer-Pinto, M., Airoidi, L., Frith, L. B., Morris, R. L., Loke, L. H. L., Hawkins, S. J., Naylor, L. A., Coleman, R. A., Chee, S. Y., & Daffon, K. A. (in press). Effects of ocean sprawl on ecological connectivity: impacts and solutions. *Experimental Marine Biology and Ecology*.
- Bolton, D., Mayer-Pinto, M., Clark, G. F., Dafforn, K. A., Brassil, W. A., Becker, A., & Johnston, E. L. (accepted). Coastal urban lighting has ecological consequences for multiple trophic levels under the sea. *Science of the Total Environment*.
- Bonthoux, S., Brun, M., Di Pietro, F., Greulich, S., & Bouche-Pillon, S. (2014). How can wastelands promote biodiversity in cities? A review. *Landscape and Urban Planning*, 132, 79-88. doi:10.1016/j.landurbplan.2014.08.010
- Boulton, A. J., Brock, M. A., Robson, B. J., Ryder, D. S., Chambers, J. M., & Davis, J. A. (2015). *Australian Freshwater Ecology: Processes and Management. 2nd edition*. Chichester, U.K.: Wiley Blackwell.
- Braaker, S., Ghazoul, J., Obrist, M. K., & Moretti, M. (2014). Habitat connectivity shapes urban arthropod communities: the key role of green roofs. *Ecology*, 95(4), 1010-1021. doi:10.1890/13-0705.1
- Brown, A. C., & McLachlan, A. (2002). Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. *Environmental Conservation*, 29(1), 62-77. doi:10.1017/s037689290200005x
- Brown, G. P., Phillips, B. L., Webb, J. K., & Shine, R. (2006). Toad on the road: use of roads as dispersal corridors by cane toads (*Bufo marinus*) at an invasion front in tropical Australia. *Biological Conservation*, 133(1), 88-94. doi:10.1016/j.biocon.2006.05.020
- Browne, M. A., & Chapman, M. G. (2011). Ecologically informed engineering reduces loss of intertidal biodiversity on artificial shorelines. *Environmental Science & Technology*, 45(19), 8204-8207. doi:10.1021/es201924b
- Browne, M. A., & Chapman, M. G. (2014). Mitigating against the loss of species by adding artificial intertidal pools to existing seawalls. *Marine Ecology Progress Series*, 497, 119-129. doi:10.3354/meps10596
- Broyer, J., Sukhanova, O., & Mischenko, A. (2016). How to sustain meadow passerine populations in Europe through alternative mowing management. *Agriculture Ecosystems & Environment*, 215, 133-139. doi:10.1016/j.agee.2015.09.019

- Bulleri, F. (2005a). Experimental evaluation of early patterns of colonisation of space on rocky shores and seawalls. *Marine Environmental Research*, 60(3), 355-374.  
doi:10.1016/j.marenvres.2004.12.002
- Bulleri, F. (2005b). Role of recruitment in causing differences between intertidal assemblages on seawalls and rocky shores. *Marine Ecology Progress Series*, 287, 53-64.  
doi:10.3354/meps287053
- Bulleri, F., & Chapman, M. G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology*, 47(1), 26-35.  
doi:10.1111/j.1365-2664.2009.01751.x
- Bunn, S. E., Davies, P. M., Kellaway, D. M., & Prosser, I. P. (1998). Influence of invasive macrophytes on channel morphology and hydrology in an open tropical lowland stream, and potential control by riparian shading. *Freshwater Biology*, 39(1), 171-178.  
doi:10.1046/j.1365-2427.1998.00264.x
- Burdick, D. M., & Short, F. T. (1999). The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. *Environmental Management*, 23(2), 231-240.  
doi:10.1007/s002679900182
- Burghardt, K. T., Tallamy, D. W., & Shriver, W. G. (2009). Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conservation Biology*, 23(1), 219-224.  
doi:10.1111/j.1523-1739.2008.01076.x
- Campbell, A. H., Marzinelli, E. M., Verges, A., Coleman, M. A., & Steinberg, P. D. (2014). Towards restoration of missing underwater forests. *PLoS ONE*, 9(1), e84106.  
doi:10.1371/journal.pone.0084106
- Carlton, J. T., & Geller, J. B. (1993). Ecological roulette - the global transport of nonindigenous marine organisms. *Science*, 261(5117), 78-82.
- Caryl, F. M., Lumsden, L. F., van der Ree, R., & Wintle, B. A. (2016). Functional responses of insectivorous bats to increasing housing density support 'land-sparing' rather than 'land-sharing' urban growth strategies. *Journal of Applied Ecology*, 53(1), 191-201.  
doi:10.1111/1365-2664.12549
- Castelle, A. J., Johnsn, A. W., & Conolly, C. (1994). Wetland and stream buffer size requirements - a review. *Journal of Environmental Quality*, 23(5), 878-882.
- Castelletta, M., Thiollay, J.-M., & Sodhi, N. S. (2005). The effects of extreme forest fragmentation on the bird community of Singapore Island. *Biological Conservation*, 121(1), 135-155. doi:10.1016/j.biocon.2004.03.033
- Catterall, C. P., Cousin, J. A., Piper, S., & Johnson, G. (2010). Long-term dynamics of bird diversity in forest and suburb: decay, turnover or homogenization? *Diversity and Distributions*, 16(4), 559-570. doi:10.1111/j.1472-4642.2010.00665.x
- Catterall, C. P., Green, R. J., & Jones, D. N. (1989). Occurrence of birds in relation to plants in a sub-tropical city. *Australian Wildlife Research*, 16(3), 289-305.
- Catterall, C. P., Green, R. J., & Jones, D. N. (1991). Habitat use by birds across a forest-suburb interface in Brisbane - implications for corridors. *Nature conservation*, 2, 247-258.
- Chace, J. F., & Walsh, J. J. (2006). Urban effects on native avifauna: a review. *Landscape and Urban Planning*, 74(1), 46-69. doi:10.1016/j.landurbplan.2004.08.007
- Chapin, F. S., Power, M. E., Pickett, S. T. A., Freitag, A., Reynolds, J. A., Jackson, R. B., Lodge, D. M., Duke, C., Collins, S. L., Power, A. G., & Bartuska, A. (2011). Earth stewardship: science for action to sustain the human-earth system. *Ecosphere*, 2(8).  
doi:10.1890/es11-00166.1

- Chapman, M. G. (2006). Intertidal seawalls as habitats for molluscs. *Journal of Molluscan Studies*, 72, 247-257. doi:10.1093/mollus/eyl069
- Chapman, M. G., & Blockley, D. J. (2009). Engineering novel habitats on urban infrastructure to increase intertidal biodiversity. *Oecologia*, 161(3), 625-635. doi:10.1007/s00442-009-1393-y
- Chapman, M. G., & Bulleri, F. (2003). Intertidal seawalls - new features of landscape in intertidal environments. *Landscape and Urban Planning*, 62(3), 159-172. doi:10.1016/s0169-2046(02)00148-2
- Chapman, M. G., & Underwood, A. J. (2011). Evaluation of ecological engineering of "armoured" shorelines to improve their value as habitat. *Journal of Experimental Marine Biology and Ecology*, 400(1-2), 302-313. doi:10.1016/j.jembe.2011.02.025
- Chown, S., & Duffy, G. (2015). Thermal physiology and urbanization: perspectives on exit, entry and transformation rules. *Functional Ecology*, 29(7), 902-912.
- Christie, F. J., Cassis, G., & Hochuli, D. F. (2010). Urbanization affects the trophic structure of arboreal arthropod communities. *Urban Ecosystems*, 13(2), 169-180. doi:10.1007/s11252-009-0115-x
- Christie, F. J., & Hochuli, D. F. (2005). Elevated levels of herbivory in urban landscapes: are declines in tree health more than an edge effect? *Ecology and Society*, 10(1), 10.
- Cincotta, R. P., Wisniewski, J., & Engelman, R. (2000). Human population in the biodiversity hotspots. *Nature*, 404(6781), 990-992. doi:10.1038/35010105
- City of Melbourne (2014). *Urban Forest Strategy: making a great city greener 2012-2032*.
- Clark, G. F., Kelaher, B. P., Dafforn, K. A., Coleman, M. A., Knott, N. A., Marzinelli, E. M., & Johnston, E. L. (2015). What does impacted look like? High diversity and abundance of epibiota in modified estuaries. *Environmental Pollution*, 196, 12-20. doi:10.1016/j.envpol.2014.09.017
- Cleary, G. P., Parsons, H., Davis, A., Coleman, B. R., Jones, D. N., Miller, K. K., & Weston, M. A. (2016). Avian assemblages at bird baths: a comparison of urban and rural bird baths in Australia. *PLoS ONE*, 11(3), e0150899. doi:10.1371/journal.pone.0150899
- Clergeau, P., Jokimaki, J., & Savard, J. P. L. (2001). Are urban bird communities influenced by the bird diversity of adjacent landscapes? *Journal of Applied Ecology*, 38(5), 1122-1134. doi:10.1046/j.1365-2664.2001.00666.x
- Clynick, B. G. (2008). Characteristics of an urban fish assemblage: distribution of fish associated with coastal marinas. *Marine Environmental Research*, 65(1), 18-33. doi:10.1016/j.marenvres.2007.07.005
- Clynick, B. G., Chapman, M. G., & Underwood, A. J. (2008). Fish assemblages associated with urban structures and natural reefs in Sydney, Australia. *Austral Ecology*, 33(2), 140-150. doi:10.1111/j.1442-9993.2007.01802.x
- Codarin, A., Wysocki, L. E., Ladich, F., & Picciulin, M. (2009). Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). *Marine Pollution Bulletin*, 58(12), 1880-1887.
- Coleman, M. A., Kelaher, B. P., Steinberg, P. D., & Millar, A. J. K. (2008). Absence of a large brown macroalga on urbanized rocky reefs around Sydney, Australia, and evidence for historical decline. *Journal of Phycology*, 44(4), 897-901. doi:10.1111/j.1529-8817.2008.00541.x
- Concepcion, E. D., Obrist, M. K., Moretti, M., Altermatt, F., Baur, B., & Nobis, M. P. (2016). Impacts of urban sprawl on species richness of plants, butterflies, gastropods and birds:

- not only built-up area matters. *Urban Ecosystems*, 19(1), 225-242. doi:10.1007/s11252-015-0474-4
- Connell, S. D. (2001). Urban structures as marine habitats: an experimental comparison of the composition and abundance of subtidal epibiota among pilings, pontoons and rocky reefs. *Marine Environmental Research*, 52(2), 115-125. doi:10.1016/s0141-1136(00)00266-x
- Connell, S. D., & Glasby, T. M. (1999). Do urban structures influence local abundance and diversity of subtidal epibiota? A case study from Sydney Harbour, Australia. *Marine Environmental Research*, 47(4), 373-387. doi:10.1016/s0141-1136(98)00126-3
- Cooke, B. C., Jones, A. R., Goodwin, I. D., & Bishop, M. J. (2012). Nourishment practices on Australian sandy beaches: a review. *Journal of Environmental Management*, 113, 319-327. doi:10.1016/j.jenvman.2012.09.025
- Coombee, M. A., La Marca, E. C., Naylor, L. A., & Thompson, R. C. (2015). Getting into the groove: opportunities to enhance the ecological value of hard coastal infrastructure using fine-scale surface textures. *Ecological Engineering*, 77, 314-323. doi:10.1016/j.ecoleng.2015.01.032
- Cooper, C. B., Dickinson, J., Phillips, T., & Bonney, R. (2007). Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society*, 12(2), 11.
- Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change-Human and Policy Dimensions*, 26, 152-158. doi:10.1016/j.gloenvcha.2014.04.002
- Croak, B. M., Pike, D. A., Webb, J. K., & Shine, R. (2010). Using artificial rocks to restore nonrenewable shelter sites in human-degraded systems: colonization by fauna. *Restoration Ecology*, 18(4), 428-438. doi:10.1111/j.1526-100X.2008.00476.x
- Cunnington, G. M., & Fahrig, L. (2010). Plasticity in the vocalizations of anurans in response to traffic noise. *Acta Oecologica-International Journal of Ecology*, 36(5), 463-470. doi:10.1016/j.actao.2010.06.002
- Dafforn, K. A., Glasby, T. M., Airoidi, L., Rivero, N. K., Mayer-Pinto, M., & Johnston, E. L. (2015). Marine urbanization: an ecological framework for designing multifunctional artificial structures. *Frontiers in Ecology and the Environment*, 13(2), 82-90. doi:10.1890/140050
- Dafforn, K. A., Glasby, T. M., & Johnston, E. L. (2009). Links between estuarine condition and spatial distributions of marine invaders. *Diversity and Distributions*, 15(5), 807-821. doi:10.1111/j.1472-4642.2009.00587.x
- Dafforn, K. A., Glasby, T. M., & Johnston, E. L. (2012). Comparing the invasibility of experimental "reefs" with field observations of natural reefs and artificial structures. *PLoS ONE*, 7(5), e38124. doi:10.1371/journal.pone.0038124
- Dafforn, K. A., Kelaher, B. P., Simpson, S. L., Coleman, M. A., Hutchings, P. A., Clark, G. F., Knott, N. A., Doblin, M. A., & Johnston, E. L. (2013). Polychaete richness and abundance enhanced in anthropogenically modified estuaries despite high concentrations of toxic contaminants. *PLoS ONE*, 8(9), e77018. doi:10.1371/journal.pone.0077018
- Dafforn, K. A., Mayer-Pinto, M., Morris, R. L., & Waltham, N. J. (2015). Application of management tools to integrate ecological principles with the design of marine infrastructure. *Journal of Environmental Management*, 158, 61-73. doi:10.1016/j.jenvman.2015.05.001
- Dallimer, M., Rouquette, J. R., Skinner, A. M. J., Armsworth, P. R., Maltby, L. M., Warren, P. H., & Gaston, K. J. (2012). Contrasting patterns in species richness of birds, butterflies and

- plants along riparian corridors in an urban landscape. *Diversity and Distributions*, 18(8), 742-753. doi:10.1111/j.1472-4642.2012.00891.x
- Daly, T. (2013). Coastal saltmarsh. *NSW Department of Primary Industries*, March 2013, Primefact 1256, First edition.
- Daniels, G. D., & Kirkpatrick, J. B. (2006). Does variation in garden characteristics influence the conservation of birds in suburbia? *Biological Conservation*, 133(3), 326-335. doi:10.1016/j.biocon.2006.06.011
- Davenport, J., & Davenport, J. L. (2006). The impact of tourism and personal leisure transport on coastal environments: a review. *Estuarine Coastal and Shelf Science*, 67(1-2), 280-292. doi:10.1016/j.ecss.2005.11.026
- Davies, P. J., Ives, C. D., Findlay, S. J., & Taylor, M. P. (2011). Urban rivers and riparian systems - directions and recommendations for legislators, policy makers, developers and community users. *Environmental and Planning Law Journal*, 28(5), 313-331.
- Davies, P. J., & Wright, I. A. (2014). A review of policy, legal, land use and social change in the management of urban water resources in Sydney, Australia: a brief reflection of challenges and lessons from the last 200 years. *Land Use Policy*, 36, 450-460. doi:10.1016/j.landusepol.2013.09.009
- Davies, P. J., Wright, I. A., Findlay, S. J., Jonasson, O. J., & Burgin, S. (2010). Impact of urban development on aquatic macroinvertebrates in south eastern Australia: degradation of in-stream habitats and comparison with non-urban streams. *Aquatic Ecology*, 44(4), 685-700. doi:10.1007/s10452-009-9307-y
- Davies, T. W., Bennie, J., Inger, R., De Ibarra, N. H., & Gaston, K. J. (2013). Artificial light pollution: are shifting spectral signatures changing the balance of species interactions? *Global Change Biology*, 19(5), 1417-1423. doi:10.1111/gcb.12166
- Davies, T. W., Duffy, J. P., Bennie, J., & Gaston, K. J. (2014). The nature, extent, and ecological implications of marine light pollution. *Frontiers in Ecology and the Environment*, 12(6), 347-355. doi:10.1890/130281
- Davis, A., Major, R. E., & Taylor, C. E. (2013). Housing shortages in urban regions: aggressive interactions at tree hollows in forest remnants. *PLoS ONE*, 8(3), e59332. doi:10.1371/journal.pone.0059332
- Davis, A., Major, R. E., & Taylor, C. E. (2014). Distribution of tree-hollows and hollow preferences by parrots in an urban landscape. *Emu*, 114(4), 295-303. doi:10.1071/mu13065
- Davis, A., Major, R. E., & Taylor, C. E. (2015). The association between nectar availability and nectarivore density in urban and natural environments. *Urban Ecosystems*, 18(2), 503-515. doi:10.1007/s11252-014-0417-5
- Davis, A., Taylor, C. E., & Major, R. E. (2012). Seasonal abundance and habitat use of Australian parrots in an urbanised landscape. *Landscape and Urban Planning*, 106(2), 191-198. doi:10.1016/j.landurbplan.2012.03.005
- Davis, J. L., Currin, C. A., O'Brien, C., Raffenburg, C., & Davis, A. (2015). Living shorelines: coastal resilience with a blue carbon benefit. *PLoS ONE*, 10(11), e0142595. doi:10.1371/journal.pone.0142595
- Davis, R. A., Gole, C., & Roberts, J. D. (2013). Impacts of urbanisation on the native avifauna of Perth, Western Australia. *Urban Ecosystems*, 16(3), 427-452. doi:10.1007/s11252-012-0275-y

- de Soto, N. A., Delorme, N., Atkins, J., Howard, S., Williams, J., & Johnson, M. (2013). Anthropogenic noise causes body malformations and delays development in marine larvae. *Scientific Reports*, 3, art: 2831.
- Demers, M. C. A., Davis, A. R., & Knott, N. A. (2013). A comparison of the impact of 'seagrass-friendly' boat mooring systems on *Posidonia australis*. *Marine Environmental Research*, 83, 54-62. doi:10.1016/j.marenvres.2012.10.010
- Deslous-Paoli, J. M., Souchu, P., Mazouni, N., Juge, C., & Dagault, F. (1998). Relations milieu-ressources: impact de la conchyliculture sur un environnement lagunaire Méditerranéen (Thau). *Oceanologica Acta*, 21(6), 831-843.
- Deutsch, C. A., Tewksbury, J. J., Huey, R. B., Sheldon, K. S., Ghalambor, C. K., Haak, D. C., & Martin, P. R. (2008). Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences of the United States of America*, 105(18), 6668-6672. doi:10.1073/pnas.0709472105
- Dobson, A. P., Bradshaw, A. D., & Baker, A. J. M. (1997). Hopes for the future: restoration ecology and conservation biology. *Science*, 277(5325), 515-522. doi:10.1126/science.277.5325.515
- Dominoni, D. M., Carmona-Wagner, E. O., Hofmann, M., Kranstauber, B., & Partecke, J. (2014). Individual-based measurements of light intensity provide new insights into the effects of artificial light at night on daily rhythms of urban-dwelling songbirds. *Journal of Animal Ecology*, 83(3), 681-692. doi:10.1111/1365-2656.12150
- Douvere, F. (2008). The importance of marine spatial planning in advancing ecosystem-based sea use management. *Marine Policy*, 32(5), 762-771. doi:10.1016/j.marpol.2008.03.021
- Drakare, S., Lennon, J. J., & Hillebrand, H. (2006). The imprint of the geographical, evolutionary and ecological context on species-area relationships. *Ecology Letters*, 9(2), 215-227. doi:10.1111/j.1461-0248.2005.00848.x
- Drinkwater, K. F., & Frank, K. T. (1994). Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation-Marine and Freshwater Ecosystems*, 4(2), 135-151. doi:10.1002/aqc.3270040205
- Drinnan, I. N. (2005). The search for fragmentation thresholds in a southern Sydney suburb. *Biological Conservation*, 124(3), 339-349. doi:10.1016/j.biocon.2005.01.040
- Dugan, J. E., Hubbard, D. M., Rodil, I. F., Revell, D. L., & Schroeter, S. (2008). Ecological effects of coastal armoring on sandy beaches. *Marine Ecology*, 29(Supplementary S1), 160-170. doi:10.1111/j.1439-0485.2008.00231.x
- Dunn, R. R., Gavin, M. C., Sanchez, M. C., & Solomon, J. N. (2006). The pigeon paradox: dependence of global conservation on urban nature. *Conservation Biology*, 20(6), 1814-1816. doi:10.1111/j.1523-1739.2006.00533.x
- Dunton, K. H., & Schonberg, S. V. (2002). Assessment of propeller scarring in seagrass beds of the South Texas coast. *Journal of Coastal Research*, 37, 100-110.
- Eamus, D., Macinnis-Ng, C. M. O., Hose, G. C., Zeppel, M. J. B., Taylor, D. T., & Murray, B. R. (2005). Ecosystem services: an ecophysiological examination. *Australian Journal of Botany*, 53(1), 1-19. doi:10.1071/bt04119
- Einav, R., Harussi, K., & Perry, D. (2003). The footprint of the desalination processes on the environment. *Desalination*, 152(1), 141-154.
- Eisenbeis, G., & Hänel, A. (2009). Light pollution and the impact of artificial night lighting on insects. In M. J. McDonnell, A. K. Hahs, & J. H. Breuste (Eds.), *Ecology of Cities and Towns* (pp. 243-263). Cambridge: Cambridge University Press.

- Elmqvist, T., Colding, J., Barthel, S., Borgstrom, S., Duit, A., Lundberg, J., Andersson, E., Ahrne, K., Ernstson, H., Folke, C., & Bengtsson, J. (2004). The dynamics of social-ecological systems in urban landscapes - Stockholm and the National Urban Park, Sweden. In C. Alfsen-Norodom, B. D. Lane, & M. Corry (Eds.), *Urban biosphere and society: partnership of cities* (Vol. 1023, pp. 308-322). Annals of the New York Academy of Sciences.
- Evans, A. J., Firth, L. B., Hawkins, S. J., Morris, E. S., Goudge, H., & Moore, P. J. (2015). Drill-cored rock pools: an effective method of ecological enhancement on artificial structures. *Marine and Freshwater Research*, *67*, 123-130. doi:http://dx.doi.org/10.1071/MF14244
- Evans, K. L., Hatchwell, B. J., Parnell, M., & Gaston, K. J. (2010). A conceptual framework for the colonisation of urban areas: the blackbird *Turdus merula* as a case study. *Biological Reviews*, *85*(3), 643-667. doi:10.1111/j.1469-185X.2010.00121.x
- Evans, W. A., Davies, P. J., & McRae, C. (2016). The occurrence of methyl, ethyl, propyl, and butyl parabens in the urban rivers and stormwaters of Sydney, Australia. *Environmental Science-Water Research & Technology*, *2*(4), 733-742. doi:10.1039/c5ew00240k
- Faeth, S. H., Warren, P. S., Shochat, E., & Marussich, W. A. (2005). Trophic dynamics in urban communities. *BioScience*, *55*(5), 399-407. doi:10.1641/0006-3568(2005)055[0399:tdiuc]2.0.co;2
- Fahrig, L. (2001). How much habitat is enough? *Biological Conservation*, *100*(1), 65-74. doi:10.1016/s0006-3207(00)00208-1
- Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology Evolution and Systematics*, *34*, 487-515. doi:10.1146/annurev.ecolsys.34.011802.132419
- Fenoglio, M. S., Videla, M., Salvo, A., & Valladares, G. (2013). Beneficial insects in urban environments: parasitism rates increase in large and less isolated plant patches via enhanced parasitoid species richness. *Biological Conservation*, *164*, 82-89. doi:10.1016/j.biocon.2013.05.002
- Fernandez-Juricic, E. (2000). Avifaunal use of wooded streets in an urban landscape. *Conservation Biology*, *14*(2), 513-521. doi:10.1046/j.1523-1739.2000.98600.x
- Firth, L. B., Thompson, R. C., Bohn, K., Abbiati, M., Airoidi, L., Bouma, T. J., Bozzeda, F., Ceccherelli, V. U., Colangelo, M. A., Evans, A., Ferrario, F., Hanley, M. E., Hinz, H., Hoggart, S. P. G., Jackson, J. E., Moore, P., Morgan, E. H., Perkol-Finkel, S., Skov, M. W., Strain, E. M., Belzen, J. v., & Hawkins, S. J. (2014). Between a rock and a hard place: environmental and engineering considerations when designing coastal defence structures. *Coastal Engineering*, *87*, 122-135.
- Fischer, J., & Lindenmayer, D. B. (2002). The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 2. Paddock trees as stepping stones. *Biodiversity and Conservation*, *11*(5), 833-849. doi:10.1023/a:1015318328007
- FitzGibbon, S. I., Putland, D. A., & Goldizen, A. W. (2007). The importance of functional connectivity in the conservation of a ground-dwelling mammal in an urban Australian landscape. *Landscape Ecology*, *22*(10), 1513-1525. doi:10.1007/s10980-007-9139-x
- Fitzpatrick, J., & Kirkman, H. (1995). Effects of prolonged shading stress on growth and survival of seagrass *Posidonia australis* in Jervis Bay, New South Wales, Australia. *Marine Ecology Progress Series*, *127*(1-3), 279-289. doi:10.3354/meps127279
- Foley, M. M., Halpern, B. S., Micheli, F., Armsby, M. H., Caldwell, M. R., Crain, C. M., Prahler, E., Rohr, N., Sivas, D., Beck, M. W., Carr, M. H., Crowder, L. B., Duffy, J. E., Hacker, S. D., McLeod, K. L., Palumbi, S. R., Peterson, C. H., Regan, H. M., Ruckelshaus, M. H., Sandifer,

- P. A., & Steneck, R. S. (2010). Guiding ecological principles for marine spatial planning. *Marine Policy*, 34(5), 955-966. doi:10.1016/j.marpol.2010.02.001
- Fonseca, M. S., & Bell, S. S. (1998). Influence of physical setting on seagrass landscapes near Beaufort, North Carolina, USA. *Marine Ecology Progress Series*, 171, 109-121.
- Frankham, R. (1996). Relationship of genetic variation to population size in wildlife. *Conservation Biology*, 10(6), 1500-1508. doi:10.1046/j.1523-1739.1996.10061500.x
- French, K., Major, R., & Hely, K. (2005). Use of native and exotic garden plants by suburban nectarivorous birds. *Biological Conservation*, 121(4), 545-559. doi:10.1016/j.biocon.2004.06.004
- Fuller, R. A., & Gaston, K. J. (2009). The scaling of green space coverage in European cities. *Biology Letters*, 5(3), 352-355. doi:10.1098/rsbl.2009.0010
- Gaston, K. J., Bennie, J., Davies, T. W., & Hopkins, J. (2013). The ecological impacts of nighttime light pollution: a mechanistic appraisal. *Biological Reviews*, 88(4), 912-927. doi:10.1111/brv.12036
- Gaston, K. J., Davies, T. W., Bennie, J., & Hopkins, J. (2012). Review: reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology*, 49(6), 1256-1266. doi:10.1111/j.1365-2664.2012.02212.x
- Gaston, K. J., Davies, Z. G., & Edmondson, J. L. (2010). Urban environments and ecosystem functions. In K. J. Gaston (Ed.), *Urban ecology*. Cambridge: Cambridge University Press.
- Gaston, K. J., Duffy, J. P., Gaston, S., Bennie, J., & Davies, T. W. (2014). Human alteration of natural light cycles: causes and ecological consequences. *Oecologia*, 176(4), 917-931. doi:10.1007/s00442-014-3088-2
- Gaston, K. J., Smith, R. M., Thompson, K., & Warren, P. H. (2005). Urban domestic gardens (II): experimental tests of methods for increasing biodiversity. *Biodiversity and Conservation*, 14(2), 395-413. doi:10.1007/s10531-004-6066-x
- Gibb, H., & Hochuli, D. F. (1999). Nesting analysis of arthropod assemblages in habitat fragments in the Sydney region. *The Other*, 99, 77-81.
- Gibb, H., & Hochuli, D. F. (2002). Habitat fragmentation in an urban environment: large and small fragments support different arthropod assemblages. *Biological Conservation*, 106(1), 91-100. doi:10.1016/s0006-3207(01)00232-4
- Gibbons, P., & Lindenmayer, D. B. (2002). *Tree hollows and wildlife conservation in Australia*. Collingwood, Victoria: CSIRO publishing.
- Gillanders, B. M., Able, K. W., Brown, J. A., Eggleston, D. B., & Sheridan, P. F. (2003). Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. *Marine Ecology Progress Series*, 247, 281-295. doi:10.3354/meps247281
- Gittman, R. K., Peterson, C. H., Currin, C. A., Fodrie, F. J., Piehler, M. F., & Bruno, J. F. (2016). Living shorelines can enhance the nursery role of threatened estuarine habitats. *Ecological Applications*, 26(1), 249-263. doi:10.1890/14-0716
- Glasby, T. M. (1999). Differences between subtidal epibiota on pier pilings and rocky reefs at marinas in Sydney, Australia. *Estuarine Coastal and Shelf Science*, 48(2), 281-290. doi:10.1006/ecss.1998.0417
- Glasby, T. M., & Connell, S. D. (1999). Urban structures as marine habitats. *Ambio*, 28, 595-598.
- Glasby, T. M., Connell, S. D., Holloway, M. G., & Hewitt, C. L. (2007). Nonindigenous biota on artificial structures: could habitat creation facilitate biological invasions? *Marine Biology*, 151(3), 887-895. doi:10.1007/s00227-006-0552-5

- Goddard, M. A., Dougill, A. J., & Benton, T. G. (2010). Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology & Evolution*, *25*(2), 90-98. doi:http://dx.doi.org/10.1016/j.tree.2009.07.016
- Godefroid, S., & Koedam, N. (2007). Urban plant species patterns are highly driven by density and function of built-up areas. *Landscape Ecology*, *22*(8), 1227-1239. doi:10.1007/s10980-007-9102-x
- Goldsborough, W., & Meritt, D. (2001). *Oyster gardening for restoration and education* (Vol. UM-SG-SGEP-99-05): Prepared by: Maryland Sea Grant College Program for the Oyster Alliance.
- Goldsbrough, C. L., Hochuli, D. F., & Shine, R. (2003). Invertebrate biodiversity under hot rocks: habitat use by the fauna of sandstone outcrops in the Sydney region. *Biological Conservation*, *109*(1), 85-93. doi:10.1016/s0006-3207(02)00139-8
- Gomes, D. G. E., Page, R. A., Geipel, I., Taylor, R. C., Ryan, M. J., & Halfwerk, W. (2016). Bats perceptually weight prey cues across sensory systems when hunting in noise. *Science*, *353*(6305), 1277-1280. doi:10.1126/science.aaf7934
- Goodsell, P. J. (2009). Diversity in fragments of artificial and natural marine habitats. *Marine Ecology Progress Series*, *384*, 23-31. doi:10.3354/meps08037
- Goodsell, P. J., Chapman, M. G., & Underwood, A. J. (2007). Differences between biota in anthropogenically fragmented habitats and in naturally patchy habitats. *Marine Ecology Progress Series*, *351*, 15-23. doi:10.3354/meps07144
- Grarock, K., Lindenmayer, D. B., Wood, J. T., & Tidemann, C. R. (2013). Does human-induced habitat modification influence the impact of introduced species? A case study on cavity-nesting by the introduced common myna (*Acridotheres tristis*) and two Australian native parrots. *Environmental Management*, *52*(4), 958-970. doi:10.1007/s00267-013-0088-7
- Gregg, J. W., Jones, C. G., & Dawson, T. E. (2003). Urbanization effects on tree growth in the vicinity of New York City. *Nature*, *424*(6945), 183-187. doi:10.1038/nature01728
- Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J. G., Bai, X. M., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, *319*(5864), 756-760. doi:10.1126/science.1150195
- Groffman, P. M., Dorsey, A. M., & Mayer, P. M. (2005). N processing within geomorphic structures in urban streams. *Journal of the North American Benthological Society*, *24*(3), 613-625.
- Gruebler, M. U., Schuler, H., Horch, P., & Spaar, R. (2012). The effectiveness of conservation measures to enhance nest survival in a meadow bird suffering from anthropogenic nest loss. *Biological Conservation*, *146*(1), 197-203. doi:10.1016/j.biocon.2011.12.019
- Guarnieri, G., Terlizzi, A., Bevilacqua, S., & Fraschetti, S. (2009). Local vs regional effects of substratum on early colonization stages of sessile assemblages. *Biofouling*, *25*(7), 593-604. doi:10.1080/08927010903013656
- Haddad, N. M., Brudvig, L. A., Damschen, E. I., Evans, D. M., Johnson, B. L., Levey, D. J., Orrock, J. L., Resasco, J., Sullivan, L. L., Tewksbury, J. J., Wagner, S. A., & Weldon, A. J. (2014). Potential negative ecological effects of corridors. *Conservation Biology*, *28*(5), 1178-1187. doi:10.1111/cobi.12323
- Hahs, A. K., McDonnell, M. J., McCarthy, M. A., Vesk, P. A., Corlett, R. T., Norton, B. A., Clemants, S. E., Duncan, R. P., Thompson, K., Schwartz, M. W., & Williams, N. S. G. (2009). A global synthesis of plant extinction rates in urban areas. *Ecology Letters*, *12*(11), 1165-1173. doi:10.1111/j.1461-0248.2009.01372.x

- Hale, J. D., Fairbrass, A. J., Matthews, T. J., Davies, G., & Sadler, J. P. (2015). The ecological impact of city lighting scenarios: exploring gap crossing thresholds for urban bats. *Global Change Biology*, *21*(7), 2467-2478. doi:10.1111/gcb.12884
- Hamer, A. J., & McDonnell, M. J. (2008). Amphibian ecology and conservation in the urbanising world: a review. *Biological Conservation*, *141*(10), 2432-2449. doi:10.1016/j.biocon.2008.07.020
- Hamer, A. J., & McDonnell, M. J. (2010). The response of herpetofauna to urbanization: inferring patterns of persistence from wildlife databases. *Austral Ecology*, *35*(5), 568-580. doi:10.1111/j.1442-9993.2009.02068.x
- Hamer, A. J., & Parris, K. M. (2011). Local and landscape determinants of amphibian communities in urban ponds. *Ecological Applications*, *21*(2), 378-390. doi:10.1890/10-0390.1
- Hancock, N., Harris, R., Broadhurst, L., & Hughes, L. (2016). *Climate-ready vegetation – A guide for natural resources managers*. Australian Network for Plan Conservation Inc. Available at [http://anpc.asn.au/resources/climate\\_ready\\_revegetation](http://anpc.asn.au/resources/climate_ready_revegetation).
- Hanford, J. K., Crowther, M. S., & Hochuli, D. F. (2016). Effectiveness of vegetation-based biodiversity offset metrics as surrogates for ants. *Conservation Biology*, *Early view*, doi: 10.1111/cobi.12794.
- Harrison, S., & Bruna, E. (1999). Habitat fragmentation and large-scale conservation: what do we know for sure? *Ecography*, *22*(3), 225-232. doi:10.1111/j.1600-0587.1999.tb00496.x
- Hassall, C., & Anderson, S. (2015). Stormwater ponds can contain comparable biodiversity to unmanaged wetlands in urban areas. *Hydrobiologia*, *745*(1), 137-149. doi:10.1007/s10750-014-2100-5
- Hassall, C., Hollinshead, J., & Hull, A. (2011). Environmental correlates of plant and invertebrate species richness in ponds. *Biodiversity and Conservation*, *20*(13), 3189-3222. doi:10.1007/s10531-011-0142-9
- Hastings, K., Hesp, P., & Kendrick, G. A. (1995). Seagrass loss associated with boat moorings at Rottnest Island, Western Australia. *Ocean & Coastal Management*, *26*(3), 225-246. doi:10.1016/0964-5691(95)00012-q
- Haviland-Howell, G., Frankel, A. S., Powell, C. M., Bocconcelli, A., Herman, R. L., & Sayigh, L. S. (2007). Recreational boating traffic: a chronic source of anthropogenic noise in the Wilmington, North Carolina Intracoastal Waterway. *The Journal of the Acoustical Society of America*, *122*(1), 151-160.
- Helden, A. J., & Leather, S. R. (2004). Biodiversity on urban roundabouts - Hemiptera, management and the species-area relationship. *Basic and Applied Ecology*, *5*(4), 367-377. doi:10.1016/j.baae.2004.06.004
- Henry, H. C., Bishop, M. J., Critchley, L., Bugnot, A. B., Airoidi, L., Mayer-Pinto, M., Sheehan, E. V., Coleman, R. A., Loke, L. H. L., Johnston, E. L., Komyakova, V., Morris, R. L., Strain, E. M. A., Naylor, L. A., & Daffon, K. A. (in press). Identifying the consequences of ocean sprawl for sedimentary habitats. *Journal of Experimental Marine Biology and Ecology*.
- Heterick, B. E., Lythe, M., & Smithyman, C. (2013). Urbanisation factors impacting on ant (Hymenoptera: Formicidae) biodiversity in the Perth metropolitan area, Western Australia: two case studies. *Urban Ecosystems*, *16*(2), 145-173. doi:10.1007/s11252-012-0257-0
- Hewitt, C. L., Campbell, M. L., Thresher, R. E., Martin, R. B., Boyd, S., Cohen, B. F., Currie, D. R., Gomon, M. F., Keough, M. J., Lewis, J. A., Lockett, M. M., Mays, N., McArthur, M. A., O'Hara, T. D., Poore, G. C. B., Ross, D. J., Storey, M. J., Watson, J. E., & Wilson, R. S.

- (2004). Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. *Marine Biology*, 144(1), 183-202. doi:10.1007/s00227-003-1173-x
- HIE UWS (Hawkesbury Institute for the Environment University of Western Sydney). (2015). Summary report on biodiversity surveys for golf courses in the Sydney Basin. *ABC-Golf: accounting for biodiversity and carbon in Sydney's golf courses*, Hawkesbury Institute for the Environment, Western Sydney University.
- Hobbs, R. J., Arico, S., Aronson, J., Baron, J. S., Bridgewater, P., Cramer, V. A., Epstein, P. R., Ewel, J. J., Klink, C. A., Lugo, A. E., Norton, D., Ojima, D., Richardson, D. M., Sanderson, E. W., Valladares, F., Vila, M., Zamora, R., & Zobel, M. (2006). Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*, 15(1), 1-7. doi:10.1111/j.1466-822x.2006.00212.x
- Hobbs, R. J., & Norton, D. A. (1996). Towards a conceptual framework for restoration ecology. *Restoration Ecology*, 4(2), 93-110. doi:10.1111/j.1526-100X.1996.tb00112.x
- Hochuli, D. F., Gibb, H., Burrows, S. E., & Christie, F. J. (2004). Ecology of Sydney's urban fragments: has fragmentation taken the sting out of insect herbivory? In D. Lunney & S. Burgin (Eds.), *Urban wildlife: more than meets the eye*. Sydney: Royal Zoological Society of New South Wales.
- Hogg, I. D., & Norris, R. H. (1991). Effects of runoff from land clearing and urban-development on the distribution and abundance of macroinvertebrates in pool areas of a river. *Australian Journal of Marine and Freshwater Research*, 42(5), 507-518.
- Holloway, M. G., & Connell, S. D. (2002). Why do floating structures create novel habitats for subtidal epibiota? *Marine Ecology Progress Series*, 235, 43-52. doi:10.3354/meps235043
- Horak, J. (2016). Suitability of biodiversity-area and biodiversity-perimeter relationships in ecology: a case study of urban ecosystems. *Urban Ecosystems*, 19(1), 131-142. doi:10.1007/s11252-015-0492-2
- Hostetler, M., Allen, W., & Meurk, C. (2011). Conserving urban biodiversity? Creating green infrastructure is only the first step. *Landscape and Urban Planning*, 100(4), 369-371. doi:10.1016/j.landurbplan.2011.01.011
- Howes, A., Mac Nally, R., Loyn, R., Kath, J., Bowen, M., McAlpine, C., & Maron, M. (2014). Foraging guild perturbations and ecological homogenization driven by a despotic native bird species. *Ibis*, 156(2), 341-354. doi:10.1111/ibi.12136
- Ikin, K., Knight, E., Lindenmayer, D. B., Fischer, J., & Manning, A. D. (2013). The influence of native versus exotic streetscape vegetation on the spatial distribution of birds in suburbs and reserves. *Diversity and Distributions*, 19(3), 294-306. doi:10.1111/j.1472-4642.2012.00937.x
- Isaac, B., Cooke, R., Simmons, D., & Hogan, F. (2008). Predictive mapping of powerful owl (*Ninox strenua*) breeding sites using Geographical Information Systems (GIS) in urban Melbourne, Australia. *Landscape and Urban Planning*, 84(3-4), 212-218. doi:10.1016/j.landurbplan.2007.08.002
- Ives, C. D., Hose, G. C., Nipperess, D. A., & Taylor, M. P. (2011). Environmental and landscape factors influencing ant and plant diversity in suburban riparian corridors. *Landscape and Urban Planning*, 103(3-4), 372-382. doi:10.1016/j.landurbplan.2011.08.009
- Ives, C. D., Lentini, P. E., Threlfall, C. G., Ikin, K., Shanahan, D. F., Garrard, G. E., Bekessy, S. A., Fuller, R. A., Mumaw, L., Rayner, L., Rowe, R., Valentine, L. E., & Kendal, D. (2016). Cities are hotspots for threatened species. *Global Ecology and Biogeography*, 25(1), 117-126. doi:10.1111/geb.12404

- Ives, C. D., Taylor, M. P., Nipperess, D. A., & Hose, G. C. (2013). Effect of catchment urbanization on ant diversity in remnant riparian corridors. *Landscape and Urban Planning*, *110*, 155-163. doi:10.1016/j.landurbplan.2012.11.005
- Jenerette, G. D., Harlan, S. L., Stefanov, W. L., & Martin, C. A. (2011). Ecosystem services and urban heat riskscape moderation: water, green spaces, and social inequality in Phoenix, USA. *Ecological Applications*, *21*(7), 2637-2651.
- Johnston, E. L., Mayer-Pinto, M., & Crowe, T. P. (2015). Chemical contaminant effects on marine ecosystem functioning. *Journal of Applied Ecology*, *52*(1), 140-149.
- Johnston, E. L., & Roberts, D. A. (2009). Contaminants reduce the richness and evenness of marine communities: a review and meta-analysis. *Environmental Pollution*, *157*(6), 1745-1752. doi:10.1016/j.envpol.2009.02.017
- Johst, K., Drechsler, M., Thomas, J., & Settele, J. (2006). Influence of mowing on the persistence of two endangered large blue butterfly species. *Journal of Applied Ecology*, *43*(2), 333-342. doi:10.1111/j.1365-2664.2006.01125.x
- Joo, W., Gage, S. H., & Kasten, E. P. (2011). Analysis and interpretation of variability in soundscapes along an urban-rural gradient. *Landscape and Urban Planning*, *103*(3-4), 259-276. doi:10.1016/j.landurbplan.2011.08.001
- Jung, K., & Kalko, E. K. V. (2010). Where forest meets urbanization: foraging plasticity of aerial insectivorous bats in an anthropogenically altered environment. *Journal of Mammalogy*, *91*(1), 144-153. doi:10.1644/08-mamm-a-313r.1
- Kang, W., Minor, E. S., Park, C. R., & Lee, D. (2015). Effects of habitat structure, human disturbance, and habitat connectivity on urban forest bird communities. *Urban Ecosystems*, *18*(3), 857-870. doi:10.1007/s11252-014-0433-5
- Kaupp, A., Brenneisen, S., Klausnitzer, B., & Nagel, P. (2004). Eco-faunistic characteristics of the beetle fauna of vegetated roofs (Insecta: Coleoptera). *Entomologische Blätter fuer Biologie und Systematik der Käfer*, *100*(1), 47-83.
- Kazemi, F., Beecham, S., & Gibbs, J. (2009). Streetscale bioretention basins in Melbourne and their effect on local biodiversity. *Ecological Engineering*, *35*(10), 1454-1465. doi:10.1016/j.ecoleng.2009.06.003
- Kazemi, F., Beecham, S., & Gibbs, J. (2011). Streetscape biodiversity and the role of bioretention swales in an Australian urban environment. *Landscape and Urban Planning*, *101*(2), 139-148. doi:10.1016/j.landurbplan.2011.02.006
- Kelagher, B. P., Van Den Broek, J., York, P. H., Bishop, M. J., & Booth, D. J. (2013). Positive responses of a seagrass ecosystem to experimental nutrient enrichment. *Marine Ecology Progress Series*, *487*, 15-25. doi:10.3354/meps10364
- Keough, M. J., & Quinn, G. P. (1998). Effects of periodic disturbances from trampling on rocky intertidal algal beds. *Ecological Applications*, *8*(1), 141-161. doi:10.2307/2641317
- Ksiazek, K., Fant, J., & Skogen, K. (2012). An assessment of pollen limitation on Chicago green roofs. *Landscape and Urban Planning*, *107*(4), 401-408. doi:10.1016/j.landurbplan.2012.07.008
- Kuussaari, M., Bommarco, R., Heikkinen, R. K., Helm, A., Krauss, J., Lindborg, R., Ockinger, E., Partel, M., Pino, J., Roda, F., Stefanescu, C., Teder, T., Zobel, M., & Steffan-Dewenter, I. (2009). Extinction debt: a challenge for biodiversity conservation. *Trends in Ecology & Evolution*, *24*(10), 564-571.
- Lake, J. C., & Leishman, M. R. (2004). Invasion success of exotic in natural ecosystems: the role of disturbance, plant attributes and freedom from herbivores. *Biological Conservation*, *117*(2), 215-226. doi:10.1016/s0006-3207(03)00294-5

- Lampe, U., Schmoll, T., Franzke, A., & Reinhold, K. (2012). Staying tuned: grasshoppers from noisy roadside habitats produce courtship signals with elevated frequency components. *Functional Ecology*, 26(6), 1348-1354. doi:10.1111/1365-2435.12000
- Larkin, P. D., Heideman, K. L., Burfeind, D. D., & Stunz, G. W. (2010). The effect of boat propeller scarring intensity on genetic variation in a subtropical seagrass species. *Botanica Marina*, 53(1), 99-102. doi:10.1515/bot.2010.004
- Larkum, A. W. D., & West, R. J. (1990). Long-term changes of seagrass meadows in Botany Bay, Australia. *Aquatic Botany*, 37(1), 55-70. doi:10.1016/0304-3770(90)90064-r
- Latty, T. (2016). Biodiversity and green roof retrofit. In S. J. Wilkinson & T. Dixon (Eds.), *Green roof retrofit: building urban resilience*. Wiley-Blackwell.
- Laurance, W. F. (2008). Theory meets reality: how habitat fragmentation research has transcended island biogeographic theory. *Biological Conservation*, 141(7), 1731-1744. doi:10.1016/j.biocon.2008.05.011
- Laurance, W. F. (2010). Habitat destruction: death by a thousand cuts. In N. S. Sodhi & P. R. Ehrlich (Eds.), *Conservation Biology for All*. Oxford: Oxford University Press.
- Le Roux, D. S., Ikin, K., Lindenmayer, D. B., Bistricher, G., Manning, A. D., & Gibbons, P. (2016). Effects of entrance size, tree size and landscape context on nest box occupancy: considerations for management and biodiversity offsets. *Forest Ecology and Management*, 366, 135-142. doi:10.1016/j.foreco.2016.02.017
- Le Roux, D. S., Ikin, K., Lindenmayer, D. B., Manning, A. D., & Gibbons, P. (2014). The future of large old trees in urban landscapes. *PLoS ONE*, 9(6), e99403. doi:10.1371/journal.pone.0099403
- Le Roux, D. S., Ikin, K., Lindenmayer, D. B., Manning, A. D., & Gibbons, P. (2015). Single large or several small? Applying biogeographic principles to tree-level conservation and biodiversity offsets. *Biological Conservation*, 191, 558-566. doi:10.1016/j.biocon.2015.08.011
- Lechner, A., Keckeis, H., Schludermann, E., Loisl, F., Humphries, P., Glas, M., Tritthart, M., & Habersack, H. (2014). Shoreline configurations affect dispersal patterns of fish larvae in a large river. *ICES Journal of Marine Science*, 71(4), 930-942. doi:10.1093/icesjms/fst139
- Lin, B. B., & Fuller, R. A. (2013). Sharing or sparing? How should we grow the world's cities? *Journal of Applied Ecology*, 50(5), 1161-1168. doi:10.1111/1365-2664.12118
- Lindgarth, M., & Hoskin, M. (2001). Patterns of distribution of macro-fauna in different types of estuarine, soft sediment habitats adjacent to urban and non-urban areas. *Estuarine Coastal and Shelf Science*, 52(2), 237-247. doi:10.1006/ecss.2000.0741
- Lindenmayer, D. B. (2007). Fire and biodiversity. *On borrowed time: Australia's environmental crisis and what we must do about it* (pp. 293-317). Camberwell, Victoria: CSIRO Publishing.
- Litvak, E., Bijoor, N. S., & Pataki, D. E. (2014). Adding trees to irrigated turfgrass lawns may be a water-saving measure in semi-arid environments. *Ecohydrology*, 7(5), 1314-1330. doi:10.1002/eco.1458
- Loke, L. H. L., & Todd, P. A. (2016). Structural complexity and component type increase intertidal biodiversity independently of area. *Ecology*, 97(2), 383-393. doi:10.1890/15-0257.1
- Lomolino, M. V. (1984). Mammalian island bio geography: effects of area, isolation and vagility. *Oecologia*, 61(3), 376-382. doi:10.1007/bf00379638
- Lomov, B., Keith, D. A., Britton, D. R., & Hochuli, D. F. (2006). Are butterflies and moths useful indicators for restoration monitoring? A pilot study in Sydney's Cumberland Plain

- woodland. *Ecological Management and Restoration*, 7(3), 204-210. doi:10.1111/j.1442-8903.2006.00310.x
- Lomov, B., Keith, D. A., & Hochuli, D. F. (2009). Linking ecological function to species composition in ecological restoration: seed removal by ants in recreated woodland. *Austral Ecology*, 34(7), 751-760. doi:10.1111/j.1442-9993.2009.01981.x
- Lomov, B., Keith, D. A., & Hochuli, D. F. (2010). Pollination and plant reproductive success in restored urban landscapes dominated by a pervasive exotic pollinator. *Landscape and Urban Planning*, 96(4), 232-239. doi:10.1016/j.landurbplan.2010.03.009
- Longcore, T., & Rich, C. (2004). Ecological light pollution. *Frontiers in Ecology and the Environment*, 2(4), 191-198. doi:10.2307/3868314
- Lopucki, R., & Kiersztyn, A. (2015). Urban green space conservation and management based on biodiversity of terrestrial fauna - a decision support tool. *Urban Forestry and Urban Greening*, 14(3), 508-518. doi:10.1016/j.ufug.2015.05.001
- Loram, A., Tratalos, J., Warren, P. H., & Gaston, K. J. (2007). Urban domestic gardens (X): the extent & structure of the resource in five major cities. *Landscape Ecology*, 22(4), 601-615. doi:10.1007/s10980-006-9051-9
- Lotze, H. K., Lenihan, H. S., Bourque, B. J., Bradbury, R. H., Cooke, R. G., Kay, M. C., Kidwell, S. M., Kirby, M. X., Peterson, C. H., & Jackson, J. B. C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science*, 312(5781), 1806-1809. doi:10.1126/science.1128035
- Lowe, E. C., Wilder, S. M., & Hochuli, D. F. (2014). Urbanisation at multiple scales is associated with larger size and higher fecundity of an orb-weaving spider. *PLoS ONE*, 9(8), e105480. doi:10.1371/journal.pone.0105480
- Lowe, E. C., Wilder, S. M., & Hochuli, D. F. (2016). Persistence and survival of the spider *Nephila plumipes* in cities: do increased prey resources drive the success of an urban exploiter? *Urban Ecosystems*, 19(2), 705-720.
- Lowe, K. A., Taylor, C. E., & Major, R. E. (2011). Do common mynas significantly compete with native birds in urban environments? *Journal of Ornithology*, 152(4), 909-921. doi:10.1007/s10336-011-0674-5
- Lowry, H., Lill, A., & Wong, B. B. M. (2012). How noisy does a noisy miner have to be? Amplitude adjustments of alarm calls in an avian urban 'adapter'. *PLoS ONE*, 7(1), e29960. doi:10.1371/journal.pone.0029960
- Lucass, C., Eens, M., & Muller, W. (2016). When ambient noise impairs parent-offspring communication. *Environmental Pollution*, 212, 592-597. doi:10.1016/j.envpol.2016.03.015
- Luck, G. W. (2007). A review of the relationships between human population density and biodiversity. *Biological Reviews*, 82(4), 607-645. doi:10.1111/j.1469-185X.2007.00028.x
- Lucrezi, S., Schlacher, T. A., & Robinson, W. (2010). Can storms and shore armouring exert additive effects on sandy-beach habitats and biota? *Marine and Freshwater Research*, 61(9), 951-962. doi:10.1071/mf09259
- Lutterschmidt, W. I., & Hutchison, V. H. (1997). The critical thermal maximum: data to support the onset of spasms as the definitive end point. *Canadian Journal of Zoology-Revue Canadienne De Zoologie*, 75(10), 1553-1560. doi:10.1139/z97-782
- Lyytimäki, J., Petersen, L. K., Normander, B., & Bezák, P. (2008). Nature as a nuisance? Ecosystem services and disservices to urban lifestyles. *Environmental Sciences*, 5(3), 161-172.

- MacArthur, R. H., & Wilson, E. O. (1963). An equilibrium theory of insular zoogeography. *Evolution*, *17*(4), 373-387. doi:10.2307/2407089
- Maclvor, J. S., & Packer, L. (2015). 'Bee hotels' as tools for native pollinator conservation: a premature verdict? *PLoS ONE*, *10*(3). doi:10.1371/journal.pone.0122126
- Major, R. E., & Parsons, H. (2010). What do museum specimens tell us about the impact of urbanisation? A comparison of the recent and historical bird communities of Sydney. *Emu*, *110*(1), 92-103. doi:10.1071/mu09058
- Maneerat, S., & Daude, E. (2016). A spatial agent-based simulation model of the dengue vector *Aedes aegypti* to explore its population dynamics in urban areas. *Ecological Modelling*, *333*, 66-78. doi:10.1016/j.ecolmodel.2016.04.012
- Manning, A. D., Gibbons, P., & Lindenmayer, D. B. (2009). Scattered trees: a complementary strategy for facilitating adaptive responses to climate change in modified landscapes? *Journal of Applied Ecology*, *46*(4), 915-919. doi:10.1111/j.1365-2664.2009.01657.x
- Manning, L. M., Peterson, C. H., & Bishop, M. J. (2014). Dominant macrobenthic populations experience sustained impacts from annual disposal of fine sediments on sandy beaches. *Marine Ecology Progress Series*, *508*, 1-15. doi:10.3354/meps10870
- Maron, M., Grey, M. J., Catterall, C. P., Major, R. E., Oliver, D. L., Clarke, M. F., Loyn, R. H., Mac Nally, R., Davidson, I., & Thomson, J. R. (2013). Avifaunal disarray due to a single despotic species. *Diversity and Distributions*, *19*(12), 1468-1479. doi:10.1111/ddi.12128
- Maron, M., Ives, C. D., Kujala, H., Bull, J. W., Maseyk, F. J. F., Bekessy, S., Gordon, A., Watson, J. E. M., Lentini, P. E., Gibbons, P., Possingham, H. P., Hobbs, R. J., Keith, D. A., Wintle, B. A., & Evans, M. C. (2016). Taming a wicked problem: resolving controversies in biodiversity offsetting. *BioScience*, *66*(6), 489-498. doi:10.1093/biosci/biw038
- Marzluff, J. M. (2005). Island biogeography for an urbanizing world: how extinction and colonization may determine biological diversity in human-dominated landscapes. *Urban Ecosystems*, *8*(2), 157-177. doi:10.1007/s11252-005-4378-6
- Marzluff, J. M., & Ewing, K. (2001). Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. *Restoration Ecology*, *9*(3), 280-292. doi:10.1046/j.1526-100x.2001.009003280.x
- Mason, J., Moorman, C., Hess, G., & Sinclair, K. (2007). Designing suburban greenways to provide habitat for forest-breeding birds. *Landscape and Urban Planning*, *80*(1-2), 153-164. doi:10.1016/j.landurbplan.2006.07.002
- Matteson, K. C., Ascher, J. S., & Langellotto, G. A. (2008). Bee richness and abundance in New York city urban gardens. *Annals of the Entomological Society of America*, *101*(1), 140-150. doi:10.1603/0013-8746(2008)101[140:braain]2.0.co;2
- Mayer-Pinto, M., Johnston, E. L., Hutchings, P. A., Marzinelli, E. M., Ahyong, S. T., Birch, G., Booth, D. J., Creese, R. G., Doblin, M. A., Figueira, W., Gribben, P. E., Pritchard, T., Roughan, M., Steinberg, P. D., & Hedge, L. H. (2015). Sydney Harbour: a review of anthropogenic impacts on the biodiversity and ecosystem function of one of the world's largest natural harbours. *Marine and Freshwater Research*, *66*(12), 1088-1105. doi:10.1071/mf15157
- McAfee, D., Cole, V. J., & Bishop, M. J. (2016). Latitudinal gradients in ecosystem engineering by oysters vary across habitats. *Ecology*, *97*(4), 929-939. doi:10.1890/15-0651.1
- McCarthy, T. K., Frankiewicz, P., Cullen, P., Blaszkowski, M., O'Connor, W., & Doherty, D. (2008). Long-term effects of hydropower installations and associated river regulation on River Shannon eel populations: mitigation and management. *Hydrobiologia*, *609*, 109-124. doi:10.1007/s10750-008-9395-z

- McDonald, T., Jonson, J., & Dixon, K. W. (2016). National standards for the practice of ecological restoration in Australia. *Restoration Ecology*, 24(S1), S4-S32.
- McDonnell, M. J., & Hahs, A. K. (2008). The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: current status and future directions. *Landscape Ecology*, 23(10), 1143-1155. doi:10.1007/s10980-008-9253-4
- McDonnell, M. J., & Hahs, A. K. (2015). Adaptation and adaptedness of organisms to urban environments. In D. J. Futuyma (Ed.), *Annual Review of Ecology, Evolution, and Systematics*, 46, 261-280. Palo Alto: Annual Reviews.
- McKenzie, L. A., Brooks, R., & Johnston, E. L. (2011). Heritable pollution tolerance in a marine invader. *Environmental Research*, 111(7), 926-932. doi:10.1016/j.envres.2010.12.007
- McKenzie, L. A., Brooks, R. C., & Johnston, E. L. (2012). A widespread contaminant enhances invasion success of a marine invader. *Journal of Applied Ecology*, 49(4), 767-773. doi:10.1111/j.1365-2664.2012.02158.x
- McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*, 127(3), 247-260. doi:10.1016/j.biocon.2005.09.005
- McKinney, M. L. (2008). Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosystems*, 11(2), 161-176. doi:10.1007/s11252-007-0045-4
- Millennium Ecosystem Assessment (MEA). (2005). *Ecosystems and human well-being: synthesis*. Washington, DC, USA: Island Press.
- Meillere, A., Brischoux, F., Parenteau, C., & Angelier, F. (2015). Influence of urbanization on body size, condition, and physiology in an urban exploiter: a multi-component approach. *PLoS ONE*, 10(8), e0135685. doi:10.1371/journal.pone.0135685
- Meineke, E. K., Dunn, R. R., Sexton, J. O., & Frank, S. D. (2013). Urban warming drives insect pest abundance on street trees. *PLoS ONE*, 8(3), e59687. doi:10.1371/journal.pone.0059687
- Miller, M. W. (2006). Apparent effects of light pollution on singing behavior of American robins. *Condor*, 108(1), 130-139. doi:10.1650/0010-5422(2006)108[0130:aeolpo]2.0.co;2
- Montague, M. J., Danek-Gontard, M., & Kunc, H. P. (2013). Phenotypic plasticity affects the response of a sexually selected trait to anthropogenic noise. *Behavioral Ecology*, 24(2), 342-348. doi:10.1093/beheco/ars169
- Morris, R. L. (2016). *Retrofitting biodiversity: ecological engineering for management of urbanised systems*. PhD thesis. University of Sydney, Australia.
- Morrison, D. A., Cary, G. J., Pengelly, S. M., Ross, D. G., Mullins, B. J., Thomas, C. R., & Anderson, T. S. (1995). Effects of fire frequency on plant-species composition of sandstone communities in the Sydney region - inter-fire interval and time-since-fire. *Australian Journal of Ecology*, 20(2), 239-247. doi:10.1111/j.1442-9993.1995.tb00535.x
- Mortberg, U., & Wallentinus, H. G. (2000). Red-listed forest bird species in an urban environment - assessment of green space corridors. *Landscape and Urban Planning*, 50(4), 215-226. doi:10.1016/s0169-2046(00)00090-6
- Munsch, S. H., Cordell, J. R., Toft, J. D., & Morgan, E. E. (2014). Effects of seawalls and piers on fish assemblages and juvenile salmon feeding behavior. *North American Journal of Fisheries Management*, 34(4), 814-827. doi:10.1080/02755947.2014.910579
- Munshi-South, J. (2012). Urban landscape genetics: canopy cover predicts gene flow between white-footed mouse (*Peromyscus leucopus*) populations in New York City. *Molecular Ecology*, 21(6), 1360-1378. doi:10.1111/j.1365-294X.2012.05476.x

- Murray, C. G., Kasel, S., Loyn, R. H., Hepworth, G., & Hamilton, A. J. (2013). Waterbird use of artificial wetlands in an Australian urban landscape. *Hydrobiologia*, 716(1), 131-146. doi:10.1007/s10750-013-1558-x
- Naeem, S. (1998). Species redundancy and ecosystem reliability. *Conservation Biology*, 12(1), 39-45. doi:10.1046/j.1523-1739.1998.96379.x
- Naeem, S., & Li, S. B. (1997). Biodiversity enhances ecosystem reliability. *Nature*, 390(6659), 507-509. doi:10.1038/37348
- Nassauer, J. I. (1988). The aesthetics of horticulture - neatness as a form of care. *Hortscience*, 23(6), 973-977.
- Nassauer, J. I. (1992). The appearance of ecological-systems as a matter of policy. *Landscape Ecology*, 6(4), 239-250. doi:10.1007/bf00129702
- Navara, K. J., & Nelson, R. J. (2007). The dark side of light at night: physiological, epidemiological, and ecological consequences. *Journal of Pineal Research*, 43(3), 215-224. doi:10.1111/j.1600-079X.2007.00473.x
- Nebel, S., Porter, J. L., & Kingsford, R. T. (2008). Long-term trends of shorebird populations in eastern Australia and impacts of freshwater extraction. *Biological Conservation*, 141(4), 971-980. doi:10.1016/j.biocon.2008.01.017
- Neylan, J. (2007). *Improving the environmental management of New South Wales golf courses*. Sydney: Department of Environment and Climate Change NSW.
- Ng, C. S. L., Lim, S. C., Ong, J. Y., Teo, L. M. S., Chou, L. M., Chua, K. E., & Tan, K. S. (2015). Enhancing the biodiversity of coastal defence structures: transplantation of nursery-reared reef biota onto intertidal seawalls. *Ecological Engineering*, 82, 480-486. doi:10.1016/j.ecoleng.2015.05.016
- Niemelä, J., & Kotze, D. J. (2009). Carabid beetle assemblages along urban to rural gradients: a review. *Landscape and Urban Planning*, 92(2), 65-71. doi:10.1016/j.landurbplan.2009.05.016
- Nixon, S. W. (1995). Coastal marine eutrophication - a definition, social causes, and future concerns. *Ophelia*, 41, 199-219.
- Noel, S., Ouellet, M., Galois, P., & Lapointe, F. J. (2007). Impact of urban fragmentation on the genetic structure of the eastern red-backed salamander. *Conservation Genetics*, 8(3), 599-606. doi:10.1007/s10592-006-9202-1
- Noriega, R., Schlacher, T. A., & Smeuninx, B. (2012). Reductions in ghost crab populations reflect urbanization of beaches and dunes. *Journal of Coastal Research*, 28(1), 123-131. doi:10.2112/jcoastres-d-09-00173.1
- Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: a framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, 134, 127-138. doi:10.1016/j.landurbplan.2014.10.018
- Noss, R. F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, 4(4), 355-364.
- NSW Office of Environment and Heritage (2013). Ecological consequences of high frequency fires - key threatening process listing. Available at [www.environment.nsw.gov.au/threatenedspecies/EcologicalConsequencesFiresKTPListing.htm](http://www.environment.nsw.gov.au/threatenedspecies/EcologicalConsequencesFiresKTPListing.htm)
- NSW Rural Fire Service (2006). *Planning for bush fire protection*. Available at [www.rfs.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0008/4400/Complete-Planning-for-Bush-Fire-Protection-2006.pdf](http://www.rfs.nsw.gov.au/__data/assets/pdf_file/0008/4400/Complete-Planning-for-Bush-Fire-Protection-2006.pdf)

- O'Grady, J. J., Reed, D. H., Brook, B. W., & Frankham, R. (2004). What are the best correlates of predicted extinction risk? *Biological Conservation*, *118*(4), 513-520. doi:10.1016/j.biocon.2003.10.002
- Oldham, C. E., Lavery, P. S., McMahon, K., Pattiaratchi, C., & Chiffings, T. (2010). *Seagrass wrack dynamics in Geographe Bay, Western Australia. Report to Western Australia Department of Transport, and Shire of Bussleton*. Available at [https://www.ecu.edu.au/\\_\\_data/assets/pdf\\_file/0008/728774/Seagrass-Wrack-Dynamics-LR.pdf](https://www.ecu.edu.au/__data/assets/pdf_file/0008/728774/Seagrass-Wrack-Dynamics-LR.pdf)
- Olguin, H. F., Salibian, A., & Puig, A. (2000). Comparative sensitivity of *Scenedesmus acutus* and *Chlorella pyrenoidosa* as sentinel organisms for aquatic ecotoxicity assessment: studies on a highly polluted urban river. *Environmental Toxicology*, *15*(1), 14-22.
- Ono, K., & Simenstad, C. A. (2014). Reducing the effect of overwater structures on migrating juvenile salmon: an experiment with light. *Ecological Engineering*, *71*, 180-189. doi:10.1016/j.ecoleng.2014.07.010
- Orth, R. J., Carruthers, T. J. B., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., Hughes, A. R., Kendrick, G. A., Kenworthy, W. J., Olyarnik, S., Short, F. T., Waycott, M., & Williams, S. L. (2006). A global crisis for seagrass ecosystems. *BioScience*, *56*(12), 987-996. doi:10.1641/0006-3568(2006)56[987:agcfse]2.0.co;2
- Ossola, A., Hahs, A. K., Nash, M. A., & Livesley, S. J. (2016). Habitat complexity enhances comminution and decomposition processes in urban ecosystems. *Ecosystems*, *19*(5), 927-941. doi:10.1007/s10021-016-9976-z
- Oulton, L. J. (2016). *Evaluation of the efficacy of stormwater treatment devices for reducing water borne ecological and human health risks*. PhD thesis. Macquarie University, Sydney.
- Palmer, G. C., Fitzsimons, J. A., Antos, M. J., & White, J. G. (2008). Determinants of native avian richness in suburban remnant vegetation: implications for conservation planning. *Biological Conservation*, *141*(9), 2329-2341. doi:10.1016/j.biocon.2008.06.025
- Parris, K. M., Velik-Lord, M., & North, J. M. A. (2009). Frogs call at a higher pitch in traffic noise. *Ecology and Society*, *14*(1), 25.
- Parsons, H., French, K., & Major, R. E. (2008). The vegetation requirements of superb fairy-wrens (*Malurus cyaneus*) in non-urban edge and urbanised habitats. *Emu*, *108*(4), 283-291. doi:10.1071/mu07060
- Parsons, H., Major, R. E., & French, K. (2006). Species interactions and habitat associations of birds inhabiting urban areas of Sydney, Australia. *Austral Ecology*, *31*(2), 217-227. doi:10.1111/j.1442-9993.2006.01584.x
- Pattiaratchi, C., Wijeratne, S., & Bosserelle, C. (2011). Sand and seagrass wrack modelling in Port Geographe, south-western Australia. In *Coasts and Ports 2011: Diverse and Developing: Proceedings of the 20th Australasian Coastal and Ocean Engineering Conference and the 13th Australasian Port and Harbour Conference* (p. 564). Engineers Australia.
- Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. *Annual Review of Ecology and Systematics*, *32*, 333-365. doi:10.1146/annurev.ecolsys.32.081501.114040
- Pauw, A., & Hawkins, J. A. (2011). Reconstruction of historical pollination rates reveals linked declines of pollinators and plants. *Oikos*, *120*(3), 344-349. doi:10.1111/j.1600-0706.2010.19039.x

- Pavao-Zuckerman, M. A., & Coleman, D. C. (2007). Urbanization alters the functional composition, but not taxonomic diversity, of the soil nematode community. *Applied Soil Ecology*, *35*(2), 329-339. doi:10.1016/j.apsoil.2006.07.008
- Pearce, H., & Walters, C. L. (2012). Do green roofs provide habitat for bats in urban areas? *Acta Chiropterologica*, *14*(2), 469-478. doi:10.3161/150811012x661774
- Penone, C., Machon, N., Julliard, R., & Le Viol, I. (2012). Do railway edges provide functional connectivity for plant communities in an urban context? *Biological Conservation*, *148*(1), 126-133. doi:10.1016/j.biocon.2012.01.041
- Perkol-Finkel, S., Ferrario, F., Nicotera, V., & Airoidi, L. (2012). Conservation challenges in urban seascapes: promoting the growth of threatened species on coastal infrastructures. *Journal of Applied Ecology*, *49*(6), 1457-1466. doi:10.1111/j.1365-2664.2012.02204.x
- Perkol-Finkel, S., & Sella, I. (2015). Blue is the new green: ecological enhancement of concrete based coastal and marine infrastructure. *Ecological Engineering*, *84*, 260-272. doi:10.1016/j.ecoleng.2015.09.016
- Peterson, C. H., & Bishop, M. J. (2005). Assessing the environmental impacts of beach nourishment. *BioScience*, *55*(10), 887-896. doi:10.1641/0006-3568(2005)055[0887:ateiob]2.0.co;2
- Peterson, C. H., Bishop, M. J., D'Anna, L. M., & Johnson, G. A. (2014). Multi-year persistence of beach habitat degradation from nourishment using coarse shelly sediments. *Science of the Total Environment*, *487*, 481-492. doi:10.1016/j.scitotenv.2014.04.046
- Philpott, S. M., Cotton, J., Bichier, P., Friedrich, R. L., Moorhead, L. C., Uno, S., & Valdez, M. (2014). Local and landscape drivers of arthropod abundance, richness, and trophic composition in urban habitats. *Urban Ecosystems*, *17*(2), 513-532. doi:10.1007/s11252-013-0333-0
- Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., & Costanza, R. (2001). Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecology and Systematics*, *32*, 127-157. doi:10.1146/annurev.ecolsys.32.081501.114012
- Pilkey, O. H., & Wright, H. L. I. (1988). Seawalls versus beaches. *Journal of Coastal Research*, *4*, 41-64.
- Piper, S. D., & Catterall, C. P. (2003). A particular case and a general pattern: hyperaggressive behaviour by one species may mediate avifaunal decreases in fragmented Australian forests. *Oikos*, *101*(3), 602-614. doi:10.1034/j.1600-0706.2003.12292.x
- Polasky, S., Nelson, E., Camm, J., Csuti, B., Fackler, P., Lonsdorf, E., Montgomery, C., White, D., Arthur, J., Garber-Yonts, B., Haight, R., Kagan, J., Starfield, A., & Tobalske, C. (2008). Where to put things? Spatial land management to sustain biodiversity and economic returns. *Biological Conservation*, *141*(6), 1505-1524. doi:10.1016/j.biocon.2008.03.022
- Potapova, M., & Charles, D. F. (2003). Distribution of benthic diatoms in US rivers in relation to conductivity and ionic composition. *Freshwater Biology*, *48*(8), 1311-1328. doi:10.1046/j.1365-2427.2003.01080.x
- Povey, A., & Keough, M. J. (1991). Effects of trampling on plant and animal populations on rocky shores. *Oikos*, *61*(3), 355-368. doi:10.2307/3545243
- Primack, R. B. (2010). *Essentials of conservation biology*. (2nd ed.). Sunderland, MA, USA: Sinauer Associates.
- Reese, A. T., Savage, A., Youngsteadt, E., McGuire, K. L., Kolling, A., Watkins, O., Frank, S. D., & Dunn, R. R. (2016). Urban stress is associated with variation in microbial species

- composition-but not richness-in Manhattan. *The ISME Journal*, 10(3), 751-760. doi:10.1038/ismej.2015.152
- Rhodes, J. R., Lunney, D., Callaghan, J., & McAlpine, C. A. (2014). A few large roads or many small ones? How to accommodate growth in vehicle numbers to minimise impacts on wildlife. *PLoS ONE*, 9(3), e91093. doi:e9109310.1371/journal.pone.0091093
- Robinson, C., Suggett, D. J., Cherukuru, N., Ralph, P. J., & Doblin, M. A. (2014). Performance of fast repetition rate fluorometry based estimates of primary productivity in coastal waters. *Journal of Marine Systems*, 139, 299-310. doi:10.1016/j.jmarsys.2014.07.016
- Roche, D. V., Cardilini, A. P. A., Lees, D., Maguire, G. S., Dann, P., Sherman, C. D. H., & Weston, M. A. (2016). Human residential status and habitat quality affect the likelihood but not the success of lapwing breeding in an urban matrix. *Science of the Total Environment*, 556, 189-195. doi:10.1016/j.scitotenv.2016.03.008
- Rochman, C. M., Browne, M. A., Underwood, A. J., van Franeker, J. A., Hompson, R. C. T., & Amaral-Zettler, L. A. (2016). The ecological impacts of marine debris: unraveling the demonstrated evidence from what is perceived. *Ecology*, 97(2), 302-312. doi:10.1890/14-2070.1
- Rolls, R. J. (2011). The role of life-history and location of barriers to migration in the spatial distribution and conservation of fish assemblages in a coastal river system. *Biological Conservation*, 144(1), 339-349. doi:10.1016/j.biocon.2010.09.011
- Rose, S., & Fairweather, P. G. (1997). Changes in floristic composition of urban bushland invaded by *Pittosporum undulatum* in northern Sydney, Australia. *Australian Journal of Botany*, 45(1), 123-149. doi:10.1071/bt95058
- Roy, A. H., Rosemond, A. D., Paul, M. J., Leigh, D. S., & Wallace, J. B. (2003). Stream macroinvertebrate response to catchment urbanisation (Georgia, USA). *Freshwater Biology*, 48(2), 329-346. doi:10.1046/j.1365-2427.2003.00979.x
- Ruffell, J., Clout, M. N., & Didham, R. K. (2016). The matrix matters, but how should we manage it? Estimating the amount of high-quality matrix required to maintain biodiversity in fragmented landscapes. *Ecography, early view*, DOI: 10.1111/ecog.02097. doi:10.1111/ecog.02097
- Ruiz, G. M., & Carlton, J. T. E. (2003). *Invasive species: vectors and management strategies*. Washington, DC: Island publishers.
- Rupprecht, C. D. D., & Byrne, J. A. (2014). Informal urban green-space: comparison of quantity and characteristics in Brisbane, Australia and Sapporo, Japan. *PLoS ONE*, 9(6), e99784. doi:10.1371/journal.pone.0099784
- Rupprecht, C. D. D., Byrne, J. A., Garden, J. G., & Hero, J. M. (2015). Informal urban green space: a trilingual systematic review of its role for biodiversity and trends in the literature. *Urban Forestry and Urban Greening*, 14(4), 883-908. doi:10.1016/j.ufug.2015.08.009
- Saintilan, N. (2013). Rehabilitation and management of saltmarsh habitats. In S. Paul (Ed.), *Workbook for managing urban wetlands in Australia*. eBook available through [www.sopa.nsw.gov.au/education/WETeBook/](http://www.sopa.nsw.gov.au/education/WETeBook/): Sydney Olympic Park Authority.
- Saintilan, N., & Williams, R. J. (1999). Mangrove transgression into saltmarsh environments in south-east Australia. *Global Ecology and Biogeography*, 8(2), 117-124. doi:10.1046/j.1365-2699.1999.00133.x
- Saintilan, N., Wilson, N. C., Rogers, K., Rajkaran, A., & Krauss, K. W. (2014). Mangrove expansion and salt marsh decline at mangrove poleward limits. *Global Change Biology*, 20(1), 147-157. doi:10.1111/gcb.12341

- Sandström, U. G., Angelstam, P., & Khakee, A. (2006). Urban comprehensive planning: identifying barriers for the maintenance of functional habitat networks. *Landscape and Urban Planning*, *75*, 43-57.
- Scheffers, B. R., & Paszkowski, C. A. (2016). Large body size for metamorphic wood frogs in urban stormwater wetlands. *Urban Ecosystems*, *19*(1), 347-359. doi:10.1007/s11252-015-0495-z
- Schwartz, M. W., Brigham, C. A., Hoeksema, J. D., Lyons, K. G., Mills, M. H., & van Mantgem, P. J. (2000). Linking biodiversity to ecosystem function: implications for conservation ecology. *Oecologia*, *122*(3), 297-305. doi:10.1007/s004420050035
- Schwartz, M. W., Jurjavcic, N. L., & O'Brien, J. M. (2002). Conservation's disenfranchised urban poor. *BioScience*, *52*(7), 601-606. doi:10.1641/0006-3568(2002)052[0601:csdup]2.0.co;2
- Sewell, S. R., & Catterall, C. P. (1998). Bushland modification and styles of urban development: their effects on birds in south-east Queensland. *Wildlife Research*, *25*(1), 41-63. doi:10.1071/wr96078
- Shannon, G., McKenna, M. F., Angeloni, L. M., Crooks, K. R., Fristrup, K. M., Brown, E., Warner, K. A., Nelson, M. D., White, C., Briggs, J., McFarland, S., & Wittemyer, G. (2016). A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews*, *91*, 982-1005.
- Sheer, M. B., & Steel, E. A. (2006). Lost watersheds: barriers, aquatic habitat connectivity, and salmon persistence in the Willamette and Lower Columbia River basins. *Transactions of the American Fisheries Society*, *135*(6), 1654-1669. doi:10.1577/t05-221.1
- Short, F. T., & Wyllie-Echeverria, S. (1996). Natural and human-induced disturbance of seagrasses. *Environmental Conservation*, *23*(1), 17-27.
- Shwartz, A., Muratet, A., Simon, L., & Julliard, R. (2013). Local and management variables outweigh landscape effects in enhancing the diversity of different taxa in a big metropolis. *Biological Conservation*, *157*, 285-292. doi:10.1016/j.biocon.2012.09.009
- Shwartz, A., Shirley, S., & Kark, S. (2008). How do habitat variability and management regime shape the spatial heterogeneity of birds within a large Mediterranean urban park? *Landscape and Urban Planning*, *84*(3-4), 219-229. doi:10.1016/j.landurbplan.2007.08.003
- Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., & Popper, A. N. (2010). A noisy spring: the impact of globally rising underwater sound levels on fish. *Trends in Ecology & Evolution*, *25*(7), 419-427.
- Slater, P. J. (1995). The interaction of bird communities with vegetation and season in Brisbane Forest Park. *Emu*, *95*, 194-207.
- Smith, J., & Lill, A. (2008). Importance of eucalypts in exploitation of urban parks by rainbow and musk lorikeets. *Emu*, *108*(2), 187-195. doi:10.1071/mu07062
- Smith, R. M., Gaston, K. J., Warren, P. H., & Thompson, K. (2005). Urban domestic gardens (V): relationships between landcover composition, housing and landscape. *Landscape Ecology*, *20*(2), 235-253. doi:10.1007/s10980-004-3160-0
- Smith, R. M., Gaston, K. J., Warren, P. H., & Thompson, K. (2006). Urban domestic gardens (VIII): environmental correlates of invertebrate abundance. *Biodiversity and Conservation*, *15*(8), 2515-2545. doi:10.1007/s10531-005-2784-y
- Snyder, B., & Kaiser, M. J. (2009). Ecological and economic cost-benefit analysis of offshore wind energy. *Renewable Energy*, *34*(6), 1567-1578. doi:10.1016/j.renene.2008.11.015

- Soga, M., Yamaura, Y., Koike, S., & Gaston, K. J. (2014). Land sharing vs. land sparing: does the compact city reconcile urban development and biodiversity conservation? *Journal of Applied Ecology*, *51*(5), 1378-1386. doi:10.1111/1365-2664.12280
- Somero, G. N. (2012). The physiology of global change: linking patterns to mechanisms. *Annual Review of Marine Science*, *4*, 39-61. doi:10.1146/annurev-marine-120710-100935
- Soulsbury, C. D., & White, P. C. L. (2015). Human-wildlife interactions in urban areas: a review of conflicts, benefits and opportunities. *Wildlife Research*, *42*(7), 541-553. doi:10.1071/wr14229
- Srivastava, D. S., & Vellend, M. (2005). Biodiversity-ecosystem function research: is it relevant to conservation? *Annual Review of Ecology Evolution and Systematics*, *36*, 267-294. doi:10.1146/annurev.ecolsys.36.102003.152636
- Stachowicz, J. J., Fried, H., Osman, R. W., & Whitlatch, R. B. (2002). Biodiversity, invasion resistance, and marine ecosystem function: reconciling pattern and process. *Ecology*, *83*(9), 2575-2590.
- Stagoll, K., Lindenmayer, D. B., Knight, E., Fischer, J., & Manning, A. D. (2012). Large trees are keystone structures in urban parks. *Conservation Letters*, *5*(2), 115-122. doi:10.1111/j.1755-263X.2011.00216.x
- Stagoll, K., Manning, A. D., Knight, E., Fischer, J., & Lindenmayer, D. B. (2010). Using bird-habitat relationships to inform urban planning. *Landscape and Urban Planning*, *98*(1), 13-25. doi:10.1016/j.landurbplan.2010.07.006
- Stevens, R. G., & Zhu, Y. (2015). Electric light, particularly at night, disrupts human circadian rhythmicity: is that a problem? *Philosophical Transactions of the Royal Society B-Biological Sciences*, *370*(1667), 20140120. doi:10.1098/rstb.2014.0120
- Stone, E. L., Jones, G., & Harris, S. (2009). Street lighting disturbs commuting bats. *Current Biology*, *19*(13), 1123-1127. doi:10.1016/j.cub.2009.05.058
- Stott, I., Soga, M., Inger, R., & Gaston, K. J. (2015). Land sparing is crucial for urban ecosystem services. *Frontiers in Ecology and the Environment*, *13*(7), 387-393. doi:10.1890/140286
- Straka, T. M., Lentini, P. E., Lumsden, L. F., Wintle, B. A., & van der Ree, R. (2016). Urban bat communities are affected by wetland size, quality, and pollution levels. *Ecology and Evolution*, *6*(14), 4761-4774. doi:10.1002/ece3.2224
- Sushinsky, J. R., Rhodes, J. R., Possingham, H. P., Gill, T. K., & Fuller, R. A. (2013). How should we grow cities to minimize their biodiversity impacts? *Global Change Biology*, *19*(2), 401-410. doi:10.1111/gcb.12055
- Sutherland, M. D., Dafforn, K. A., Scanes, P., Potts, J., Simpson, S. L., Sim, V. X.-Y., & Johnston, E. L. (in press). Links between contaminant hotspots in low flow estuarine systems and altered sediment biogeochemical processes. *Estuarine, Coastal and Shelf Science*.
- Tait, C. J., Daniels, C. B., & Hill, R. S. (2005). Changes in species assemblages within the Adelaide Metropolitan Area, Australia, 1836-2002. *Ecological Applications*, *15*(1), 346-359. doi:10.1890/04-0920
- Taylor, A. R., & Knight, R. L. (2003). Wildlife responses to recreation and associated visitor perceptions. *Ecological Applications*, *13*(4), 951-963. doi:10.1890/1051-0761(2003)13[951:wrtraa]2.0.co;2
- Taylor, L., Taylor, C., & Davis, A. (2013). The impact of urbanisation on avian species: the inextricable link between people and birds. *Urban Ecosystems*, *16*(3), 481-498. doi:10.1007/s11252-012-0283-y
- Taylor, P. D., Fahrig, L., Henein, K., & Merriam, G. (1993). Connectivity is a vital element of landscape structure. *Oikos*, *68*(3), 571-573. doi:10.2307/3544927

- Tennesen, J. B., Parks, S. E., & Langkilde, T. (2014). Traffic noise causes physiological stress and impairs breeding migration behaviour in frogs. *Conservation Physiology*, 2(1). doi:10.1093/conphys/cou032
- Tewksbury, J. J., Levey, D. J., Haddad, N. M., Sargent, S., Orrock, J. L., Weldon, A., Danielson, B. J., Brinkerhoff, J., Damschen, E. I., & Townsend, P. (2002). Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences of the United States of America*, 99(20), 12923-12926. doi:10.1073/pnas.202242699
- Thomason, J. C., Letissier, M. D. A., Thomason, P. O., & Field, S. N. (2002). Optimising settlement tiles: the effects of surface texture and energy, orientation and deployment duration upon the fouling community. *Biofouling*, 18(4), 293-304. doi:10.1080/0892701021000034409
- Thompson, K., Austin, K. C., Smith, R. M., Warren, P. H., Angold, P. G., & Gaston, K. J. (2003). Urban domestic gardens (I): putting small-scale plant diversity in context. *Journal of Vegetation Science*, 14(1), 71-78. doi:10.1111/j.1654-1103.2003.tb02129.x
- Threlfall, C. G., Law, B., & Banks, P. B. (2012). Sensitivity of insectivorous bats to urbanization: Implications for suburban conservation planning. *Biological Conservation*, 146(1), 41-52. doi:10.1016/j.biocon.2011.11.026
- Threlfall, C. G., Law, B., & Banks, P. B. (2013). The urban matrix and artificial light restricts the nightly ranging behaviour of Gould's long-eared bat (*Nyctophilus gouldi*). *Austral Ecology*, 38(8), 921-930.
- Threlfall, C. G., Mata, L., Mackie, J. A., Hahs, A. K., Stork, N. E., Williams, N. S., & Livesley, S. J. (2017). Increasing biodiversity in urban green spaces through simple vegetation interventions. *Journal of Applied Ecology*.
- Threlfall, C. G., Ossola, A., Hahs, A. K., Williams, N. S. G., Wilson, L., & Livesley, S. J. (2016). Variation in vegetation structure and composition across urban green space types. *Frontiers in Ecology and the Environment*, 4(6). doi: 10.3389/fevo
- Threlfall, C. G., Walker, K., Williams, N. S. G., Hahs, A. K., Mata, L., Stork, N., & Livesley, S. J. (2015). The conservation value of urban green space habitats for Australian native bee communities. *Biological Conservation*, 187, 240-248. doi:10.1016/j.biocon.2015.05.003
- Threlfall, C. G., Williams, N. S. G., Hahs, A. K., & Livesley, S. J. (2016). Approaches to urban vegetation management and the impacts on urban bird and bat assemblages. *Landscape and Urban Planning*, 153, 28-39.
- Tippler, C., Wright, I. A., Davies, P. J., & Hanlon, A. (2014). The influence of concrete on the geochemical qualities of urban streams. *Marine and Freshwater Research*, 65(11), 1009-1017. doi:10.1071/mf13164
- Toft, J. D., Cordell, J. R., Simenstad, C. A., & Stamatiou, L. A. (2007). Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. *North American Journal of Fisheries Management*, 27(2), 465-480. doi:10.1577/m05-158.1
- Tonietto, R., Fant, J., Ascher, J., Ellis, K., & Larkin, D. (2011). A comparison of bee communities of Chicago green roofs, parks and prairies. *Landscape and Urban Planning*, 103(1), 102-108. doi:10.1016/j.landurbplan.2011.07.004
- Tratalos, J., Fuller, R. A., Evans, K. L., Davies, R. G., Newson, S. E., Greenwood, J. J. D., & Gaston, K. J. (2007). Bird densities are associated with household densities. *Global Change Biology*, 13(8), 1685-1695. doi:10.1111/j.1365-2486.2007.01390.x

- Tratalos, J. A., & Austin, T. J. (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, *102*(1), 67-75. doi:10.1016/S0006-3207(01)00085-4
- Turrini, T., Sanders, D., & Knop, E. (2016). Effects of urbanization on direct and indirect interactions in a tri-trophic system. *Ecological Applications*, *26*(3), 664-675. doi:10.1890/14-1787
- Tyrrell, M. C., & Byers, J. E. (2007). Do artificial substrates favor nonindigenous fouling species over native species? *Journal of Experimental Marine Biology and Ecology*, *342*(1), 54-60. doi:10.1016/j.jembe.2006.10.014
- van den Berg, F. T., Thompson, M. B., & Hochuli, D. F. (2015). When hot rocks get hotter: behavior and acclimatization mitigate exposure to extreme temperatures in a spider. *Ecosphere*, *6*(5). doi:10.1890/es14-00436.1
- van der Ree, R., & McCarthy, M. A. (2005). Inferring persistence of indigenous mammals in response to urbanisation. *Animal Conservation*, *8*, 309-319. doi:10.1017/S1367943005002258
- van Grunsven, R. H. A., Donners, M., Boekee, K., Tichelaar, I., van Geffen, K. G., Groenendijk, D., Berendse, F., & Veenendaal, E. M. (2014). Spectral composition of light sources and insect phototaxis, with an evaluation of existing spectral response models. *Journal of Insect Conservation*, *18*(2), 225-231. doi:10.1007/s10841-014-9633-9
- Vasconcelos, R. O., Amorim, M. C. P., & Ladich, F. (2007). Effects of ship noise on the detectability of communication signals in the Lusitanian toadfish. *Journal of Experimental Biology*, *210*(12), 2104-2112.
- Vergnes, A., Le Viol, I., & Clergeau, P. (2012). Green corridors in urban landscapes affect the arthropod communities of domestic gardens. *Biological Conservation*, *145*(1), 171-178. doi:10.1016/j.biocon.2011.11.002
- Vergnes, A., Pellissier, V., Lemperiere, G., Rollard, C., & Clergeau, P. (2014). Urban densification causes the decline of ground-dwelling arthropods. *Biodiversity and Conservation*, *23*(8), 1859-1877. doi:10.1007/s10531-014-0689-3
- Violin, C. R., Cada, P., Sudduth, E. B., Hassett, B. A., Penrose, D. L., & Bernhardt, E. S. (2011). Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. *Ecological Applications*, *21*(6), 1932-1949.
- Vucetich, J. A., Bruskotter, J. T., & Nelson, M. P. (2015). Evaluating whether nature's intrinsic value is an axiom of or anathema to conservation. *Conservation Biology*, *29*(2), 321-332. doi:10.1111/cobi.12464
- Wale, M. A., Simpson, S. D., & Radford, A. N. (2013). Size-dependent physiological responses of shore crabs to single and repeated playback of ship noise. *Biology Letters*, *9*, 20121194.
- Walker, D. I., Lukatelich, R. J., Bastyan, G., & McComb, A. J. (1989). Effect of boat mooring on seagrass beds near Perth, Western Australia. *Aquatic Botany*, *36*(1), 69-77. doi:10.1016/0304-3770(89)90092-2
- Walsh, C. J., Fletcher, T. D., & Ladson, A. R. (2005). Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. *Journal of the North American Benthological Society*, *24*(3), 690-705. doi:10.1899/0887-3593(2005)024[0690:sriuct]2.0.co;2
- Wang, L. Z., Lyons, J., & Kanehl, P. (2001). Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management*, *28*(2), 255-266. doi:10.1007/s0026702409

- Watson, J., Freudenberger, D., & Paull, D. (2001). An assessment of the focal-species approach for conserving birds in variegated landscapes in southeastern Australia. *Conservation Biology*, 15(5), 1364-1373. doi:10.1046/j.1523-1739.2001.00166.x
- Whelan, R. J. (2002). Managing fire regimes for conservation and property protection: an Australian response. *Conservation Biology*, 16(6), 1659-1661. doi:10.1046/j.1523-1739.2002.02091.x
- White, J. G., Antos, M. J., Fitzsimons, J. A., & Palmer, G. C. (2005). Non-uniform bird assemblages in urban environments: the influence of streetscape vegetation. *Landscape and Urban Planning*, 71(2-4), 123-135. doi:10.1016/j.landurbplan.2004.02.006
- Whitehead, A. L., Kujala, H., & Wintle, B. A. (2016). Dealing with cumulative biodiversity impacts in strategic environmental assessment: a new frontier for conservation planning. *Conservation Letters*, Early view, DOI: 10.1111/conl.12260.
- Whitfield, A. K., & Becker, A. (2014). Impacts of recreational motorboats on fishes: a review. *Marine Pollution Bulletin*, 83(1), 24-31. doi:10.1016/j.marpolbul.2014.03.055
- Whitmore, C., Crouch, T. E., & Slotow, R. H. (2002). Conservation of biodiversity in urban environments: invertebrates on structurally enhanced road islands. *African Entomology*, 10(1), 113-126.
- Williams, N. S. G., Lundholm, J., & MacIvor, J. S. (2014). Do green roofs help urban biodiversity conservation? *Journal of Applied Ecology*, 51(6), 1643-1649. doi:10.1111/1365-2664.12333
- Williams, N. S. G., Morgan, J. W., McDonnell, M. J., & McCarthy, M. A. (2005). Plant traits and local extinctions in natural grasslands along an urban-rural gradient. *Journal of Ecology*, 93(6), 1203-1213. doi:10.1111/j.1365-2745.2005.01039.x
- Williamson, M., & Fitter, A. (1996). The varying success of invaders. *Ecology*, 77(6), 1661-1666. doi:10.2307/2265769
- Woinarski, J. C. Z., Burbidge, A. H., Ciomer, S., Harley, D., Legge, S., Lindenmayer, D. B., & Partridge, T. (2015). Fire and biodiversity in Australia. In A. Stow, N. Maclean, & G. I. Holwell (Eds.), *Austral ark: the state of wildlife in Australia and New Zealand*. Cambridge: Cambridge University Press.
- Wood, P. J., & Armitage, P. D. (1997). Biological effects of fine sediment in the lotic environment. *Environmental Management*, 21(2), 203-217. doi:10.1007/s002679900019
- Wright, I. A., Davies, P. J., Findlay, S. J., & Jonasson, O. J. (2011). A new type of water pollution: concrete drainage infrastructure and geochemical contamination of urban waters. *Marine and Freshwater Research*, 62(12), 1355-1361. doi:10.1071/mf10296
- York, P. H., Kelaher, B. P., Booth, D. J., & Bishop, M. J. (2012). Trophic responses to nutrient enrichment in a temperate seagrass food chain. *Marine Ecology Progress Series*, 449, 291-296. doi:10.3354/meps09541
- Young, K. M., Daniels, C. B., & Johnston, G. (2007). Species of street tree is important for southern hemisphere bird trophic guilds. *Austral Ecology*, 32(5), 541-550. doi:10.1111/j.1442-9993.2007.01726.x
- Zaimes, G. N., Schultz, R. C., & Isenhardt, T. M. (2004). Stream bank erosion adjacent to riparian forest buffers, row-crop fields, and continuously-grazed pastures along Bear Creek in central Iowa. *Journal of Soil and Water Conservation*, 59(1), 19-27.



## 4 POLICY AND PLANNING

### DESKTOP REVIEW OF LITERATURE

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2016

## 4.1 Key points

- Land-use planning and development are mostly the responsibility of the NSW Government enacted through various laws and policies.
- The state's apex policy, "NSW: Making it Happen", lacks specific mention of biodiversity management and the protection of natural environmental assets.
- The measurement and reporting of outcomes of existing environmental policies by state and local governments is highly varied and generally poor, making it difficult to evaluate their effectiveness and success.
- Governance affecting urban ecosystems is complex and not well understood.
- The drivers of the decline of urban ecosystems in NSW are unclear. They may involve inherent flaws in current legal and policy frameworks that contribute to the ongoing loss of urban biodiversity; poor implementation and regulation; or other social, political and economic factors that otherwise fail to capture the value of biodiversity in land-use planning and operational decisions.
- The management of the natural environment is not widely considered in the context of liveability, despite the important role of ecosystem services. Linking liveable cities to biodiversity, although not always compatible, is likely to result in stronger urban ecology outcomes.
- There are inherent tensions around land contestability in cities and current values-based socioeconomic development perspectives, which often override environmental protection and management outcomes. This manifests in the framing of development and housing outcomes around the costs of construction rather than urban ecology or liveability outcomes.
- Successful strategies for advancing biodiversity outcomes will rely on the convergence of three elements: 1) clear targets and objectives; 2) establishing a robust understanding of the connection between biodiversity and liveability; and 3) effective public and political engagement.
- The GSC has prepared draft district plans for Sydney covering six districts, based on achieving a productive, liveable and sustainable city. These plans will inform the revision of the metropolitan strategy and local plans and provide an opportunity for advancing urban ecological outcomes.
- Amendments to the *Environmental Planning and Assessment Act 1979* will make metropolitan and district plans statutory documents, which should result in greater legal consideration of the plans' objectives and intentions.
- The *Biodiversity Conservation Act 2016* retains the use of offsetting (BioBanking) to protect certain high-value lands. This market-based scheme has been successful in retaining and protecting certain sites, but evidence of its ecological effectiveness is yet to be established.
- The current revision of State Environmental Planning Policy 19 – Bushland in Urban Areas represents a timely opportunity to strengthen urban ecological outcomes through performance-based controls that can be spatially relevant, such as enabling connections to the green and blue grids.
- Controls on stormwater discharge that affect stream health are applied inconsistently and on a discretionary basis because they are local policies and not a state-based environmental planning instrument.



## 4.2 Introduction

Cities represent complex interactions between human and natural systems. It is well documented that biodiversity is lost as cities expand and increase in population (Chapter 3). The nexus between land-use planning and biodiversity (Chapter 5) requires the integration of strategic or city planning at multiple scales, controls on development, and ongoing education and regulation, thereby ensuring that appropriate laws and policies are enacted through planning decisions and the actions of public and private interests. Policies and planning must be coordinated and applied consistently to protect and manage the cumulative impacts of urban development on biodiversity.

This chapter outlines the history of urban ecosystems and opportunities for advances in cities within the legal and policy context that operates in NSW. The examination is framed by the obligations and opportunities in Sydney, Wollongong and Newcastle to protect and manage existing habitats and, where possible, improve them. Legal frameworks are defined here as laws, legal instruments and policies specifically prescribed or given force by Acts of Parliament, or a power provided by such Acts. The legal and policy system is subject to ongoing revision and review, as illustrated by the gazettal of the *Biodiversity Conservation Act 2016* and release of draft district plans for Sydney in November 2016.

The key terms used in this chapter are defined in Chapter 2. Examples of and opportunities for reform (this chapter, and Chapter 7) are supported by evidence presented in the literature review on urban biodiversity management (Chapter 3) and the integration of biodiversity in built environments (Chapter 5).

## 4.3 Short history of land development and urban ecology implications

The historical development pattern of Sydney, Newcastle and Wollongong includes a period of industrial urbanisation defined by more compact forms of housing with population and industry located close to city centres. The early period of European settlement was dominated by detached and semi-detached houses on small lots with small or no private gardens. Public open spaces were provided by formal parks, which served as places of relief for residents in otherwise dense and proximate relationships between residential and industrial lands.

By the turn of the twentieth century, housing development in Australia had started to shift from a medium-density terrace and small-lot typology to a low-density suburban form, enabled by the mid-1900s by increasing private car ownership. New parklands and other open spaces were based on a garden city model and subsequent greenbelt model promoted by Ebenezer Howard, an English town planner. In Sydney, the approach was seen in various formal parks, the establishment of reserved lands such as recreation areas (e.g. Lane Cove Valley) and the greenbelt, established by the Country of Cumberland Scheme (first envisaged in 1944 and formalized as a planning strategy under the *County Council Local Government (Town and Country Planning) Amendment Act 1945*, gazetted in 1951). The pattern of low-density and car-dominated suburban growth continued through to the 1970s, buoyed by a protracted period of continued economic growth referred to as the 'long boom'. Throughout this period of suburbanisation, significant portions of the remnant bushland were cleared, often initially for agriculture then for new residential subdivisions (NSW Spatial Services, 2016). The industrial focus of Newcastle and Wollongong presented similar land development pressures. The growth of these cities was linked directly to the prosperity and expansion of heavy industries, notably steel manufacturing, which has now left or is in decline, and, the case of Newcastle, its function as a major coal port.

Land development pressures have shifted and intensified since the long boom, and these have had an impact on the area of private open space in low-density housing areas. Lot sizes have been declining steadily (Hall, 2010; Table 7.1) and house sizes have been increasing (Haddow, 2007). These trends have resulted in a higher built-area-to-land ratio, with less soft landscape space and consequently less area to support large trees. Demographically, the number of people per dwelling has been declining, thus requiring more homes per capita (ABS, 2010), and there is more pressure to develop greenfield subdivisions and, more recently, increase densities in existing areas (infill development).

This urban restructuring in the inner- and middle-ring suburbs has led to higher densities and consequently less public and private open space per capita. The demand for housing closer to city centres has been enabled by the urban consolidation policies of state and local governments and delivered by homeowners capitalising on the increased financial value of their large lots, with developers consolidating multiple lots and building more compact low-, medium- and high-density housing. This infill intensification of existing residential housing to higher densities is referred to as 'greyfield' development (Newton, 2010). The impacts of urban consolidation on urban tree canopies are evident: most inner-ring council areas have low tree cover, and many outer-ring council areas also have low levels of canopy cover due to historical clearing associated with agriculture and the smaller lot sizes permitted in recent subdivisions (Figure 4.1). There have also been socio-demographic changes in many suburbs, particularly in traditionally working-class areas close to city centres, which are 'gentrifying' and becoming occupied by a new generation of homeowners, who are also redeveloping and renovating the older housing stock.

A larger-scale view provides additional understanding of development patterns (Figure 4.2), including the role of land reservations made through the national park system in protecting a substantial ecological reserve.

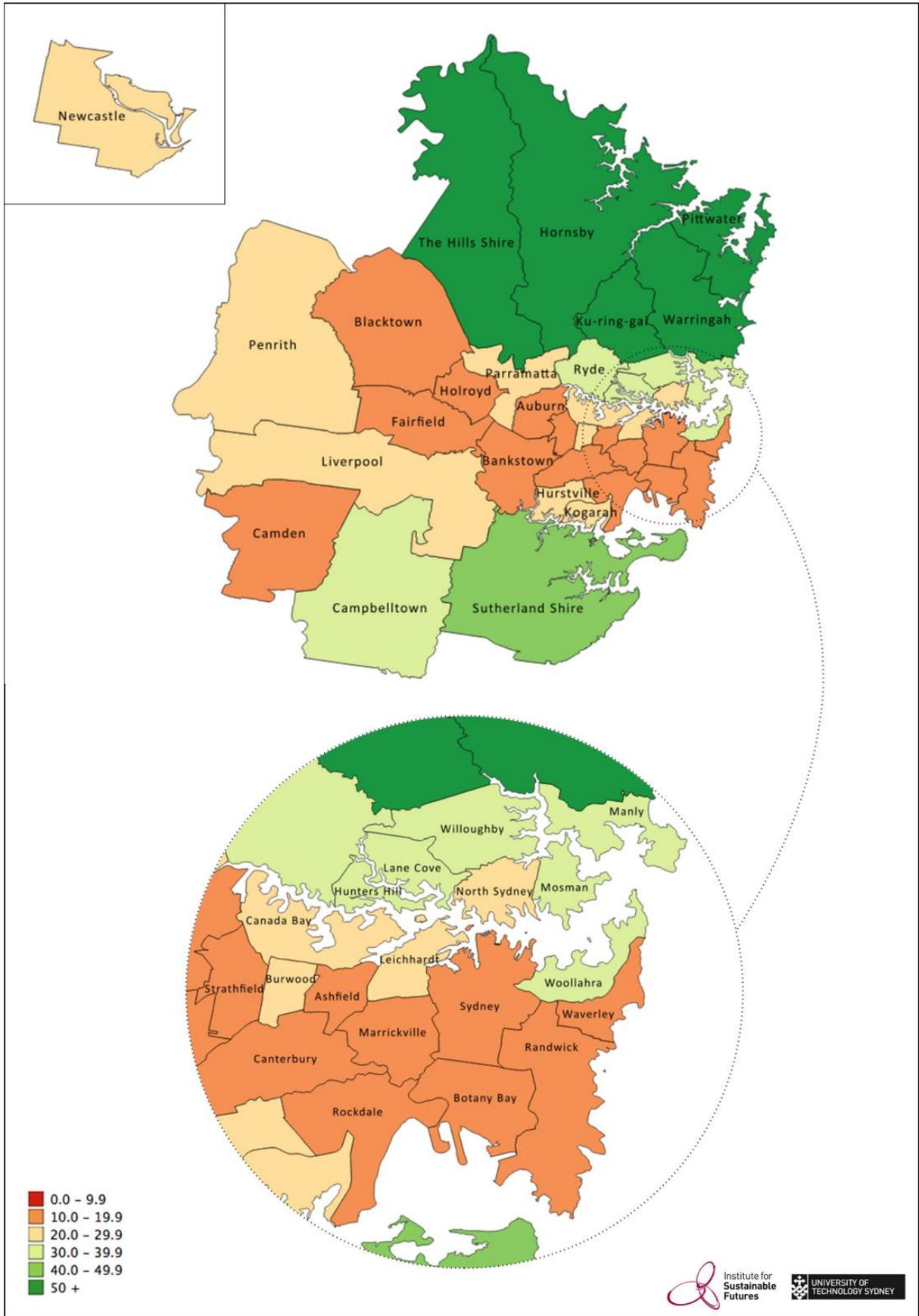
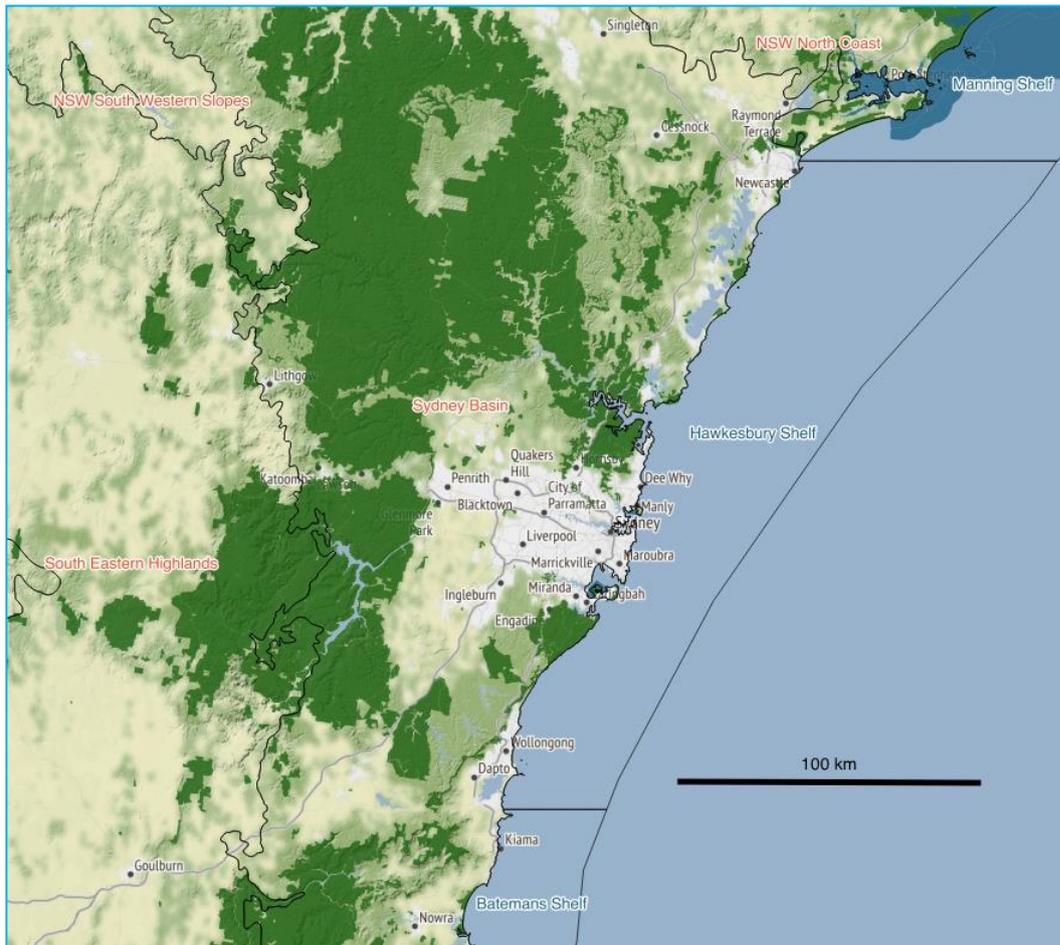


Figure 4.1. Map of percentage tree canopy cover in selected councils in the Sydney metropolitan area. Source: Jacobs *et al.* (2014), p. 16.



**Figure 4.2.** Protected areas and major biogeographic regions in the vicinity of the urban areas of Sydney, Newcastle and Wollongong. Terrestrial protected areas are in dark green and marine protected areas are in dark blue. Names of terrestrial bioregions are in red text and marine bioregions are in blue text. Data sourced from the Commonwealth of Australia Protected Areas Database, 2014. Base map provided by Stamen Design under a Creative Commons Attribution License.

These changes in urban density have accelerated the loss of private open spaces in suburbs and contributed to a decline in urban biodiversity. Since the introduction of the *Environmental Planning and Assessment Act*, NSW’s primary land-use planning legislation, in 1979, enabling planning instruments have been introduced in an attempt to focus strategic and statutory planning processes on the protection and management of the natural environment. The success of these instruments in managing urban ecology in cities and of the supporting policies and practices of federal, state and local governments have been mixed, however, as described in the following sections.

#### 4.4 Policy and legislation

##### Commonwealth context

The Commonwealth does not have direct constitutional powers over land-use planning or matters related to urban ecology. It does, however, use indirect powers through the Australian Constitution on matters of international and national importance (e.g. World Heritage areas), in providing grants, and on intergovernmental collaboration set by the Coalition of Australian Governments (known as COAG).

International conventions pertaining to biodiversity are operationalised into Commonwealth law and policy. The primary Commonwealth legislation is the *Environmental Protection and Biodiversity*

*Conservation Act 1999* (EPBC). This Act enables the Commonwealth to make decisions on land and ecological values where ‘matters of national environmental significance’ are, or may be, affected by a proposed development or other activity. Such matters include World Heritage areas, Ramsar wetlands, and federally listed threatened species and ecological communities.

In certain circumstances, the Commonwealth is the consent authority for development, either by way of strategic environmental assessment or on the basis of individual proposals. The Commonwealth is the consent authority under the EPBC when a development proposal is sent to the Commonwealth for consideration, either as a single development or by way of a strategic environmental assessment. In its planning for the Sydney growth centres, for example, the NSW State Government prepared a strategic environmental assessment for the Commonwealth because the lands under consideration contained a range of ‘matters of national environmental significance’, such as threatened species. In this case, NSW could not proceed with the development of the growth centres or release land for the development of the growth centres without first obtaining Commonwealth approval and complying with any conditions set by the Commonwealth in its determination of the proposal. In and around the major cities in NSW, the EPBC Act may be triggered by a proposed action that may affect a World Heritage area<sup>21</sup> (such as the Blue Mountains), an internationally recognised wetland site (such as the Towra Point and Hunter estuary Ramsar sites<sup>22</sup>), or any place where listed threatened species or threatened ecological communities are located.<sup>23</sup>

Under the Intergovernmental Agreement on the Environment 1992 (Department of Environment and Energy, 1992), streamlined processes related to environmental assessments now exist involving both the Commonwealth and NSW governments. In essence, this agreement seeks to ensure there are no inconsistencies between federal and state policies and assessment processes on the protection of lands or activities relevant to federally listed threatened and endangered species. This agreement and processes has been clarified through a memorandum of understanding and a bilateral agreement between the Commonwealth and NSW governments, in which the NSW Government, on behalf of the Commonwealth, undertakes assessments of proposed developments in accordance with the requirements of the EPBC (Commonwealth of Australia and NSW Government, 2015).

Overall, the interest and intervention by the Commonwealth Government in city planning and function has varied over time. Interventions are largely achieved through policy frameworks that recognise the importance of cities to the nation’s economy, such as the State of Australian Cities Reports produced between 2010 and 2015 (e.g. Department of Infrastructure and Regional Development, 2015) and, more recently, the Smart Cities Plan (Department of the Prime Minister and Cabinet, 2016).

### **Legal and policy framework in NSW**

The NSW legal and policy framework is working towards vertical policy alignment, cascading from objectives articulated in the State Plan (NSW Government, 2016b), which informs all government operations in the state, including those of local government. Various laws, regulations, plans and policies affect decisions about land. This section begins with a vertical view of land-use planning, from the State Plan to the primary piece of planning legislation, the *Environmental Planning and Assessment Act 1979* (EP&A Act). It then broadens horizontally, identifying and explaining the other statutory instruments affecting decision-making on urban ecological values.

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<sup>21</sup> The Department of Environment and Energy maintains a list of Australia’s World Heritage sites at: [www.environment.gov.au/heritage/places/world-heritage-list](http://www.environment.gov.au/heritage/places/world-heritage-list)

<sup>22</sup> Refer to the Department of Environment and Energy website at: [www.environment.gov.au/water/wetlands/ramsar](http://www.environment.gov.au/water/wetlands/ramsar)

<sup>23</sup> Refer to the Species Profile and Threats Database at: [www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl](http://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl)

## State and Premier's priorities

In 2015, the NSW Government identified 30 key reform areas, including 12 'Premier priorities' as part of its NSW: Making it Happen policy announcement (NSW Government, 2016b). None of these key reform areas include consideration of urban ecological values, instead addressing building infrastructure and achieving faster approvals to enable housing construction. The present plan lacks specificity on biodiversity management and the protection of natural environmental assets; state-wide government decision-making, therefore, is informed by no apex policy with consideration of the natural environment. This limits inter- and intra-government strategic planning, assessment processes and operational policies and procedures for addressing the natural environment beyond statutory obligations and creating a governance gap in ecologically based decision-making and practice.

## Land-use planning and development

Decisions on urban land use are mostly taken in consideration of NSW legislation and associated policies. As described below, there is inconsistency among the wide range of relevant laws in their objectives for the conservation, restoration or growth of urban ecosystems in the Sydney region and other cities. The primary legislation governing land-use planning and assessment is the EP&A Act and the *Environmental Planning & Assessment Regulation 2000* under the responsibility of the Minister of Planning. The operation of the Act is informed by the following objects, which have not changed since 1999 (objects involving ecological considerations are in bold):

'(a) to encourage:

**(i) the proper management, development and conservation of natural and artificial resources, including agricultural land, natural areas, forests, minerals, water, cities, towns and villages for the purpose of promoting the social and economic welfare of the community and a better environment,**

(ii) the promotion and co-ordination of the orderly and economic use and development of land,

(iii) the protection, provision and co-ordination of communication and utility services,

(iv) the provision of land for public purposes,

(v) the provision and co-ordination of community services and facilities, and

**(vi) the protection of the environment, including the protection and conservation of native animals and plants, including threatened species, populations and ecological communities, and their habitats, and**

**(vii) ecologically sustainable development, and**

(viii) the provision and maintenance of affordable housing, and

'(b) to promote the sharing of the responsibility for environmental planning between the different levels of government in the State, and

(c) to provide increased opportunity for public involvement and participation in environmental planning and assessment.'

The EP&A Act supports multiple land-use decision-making processes in two main categories: 1) strategic planning at various spatial scales; and 2) controls over development, most commonly as individual projects. The EP&A Act enables decision-making at the state, regional and local levels. Importantly, the

EP&A Act does not operate in isolation, linking with many other statutes, plans and policies. The EP&A Act is administered by the Department of Planning, including the making of land-use plans. Significant jurisdictional reforms and changes to the way in which land-use plans are made are underway. Key changes include the creation of the GSC and the introduction of a new statutory planning focus for the development of regional and district plans for Sydney and local plans for local-government areas. The GSC has responsibility for the Sydney area and the Department of Planning retains its strategic planning role for Wollongong and Newcastle.

### **Metropolitan, district and local planning**

The GSC is constituted under the *Greater Sydney Commission Act 2015* (GSC Act), with the following seven principal objectives (environmental objectives are in bold):

‘(a) to lead metropolitan planning for the Greater Sydney Region,

**‘(b) to promote orderly development in the Greater Sydney Region, integrating social, economic and environmental considerations with regard to the principles of ecologically sustainable development contained in section 6 (2) of the Protection of the Environment Administration Act 1991,**

‘(c) to promote the alignment of Government infrastructure decision-making with land use planning,

‘(d) to promote the supply of housing, including affordable housing,

**‘(e) to encourage development that is resilient and takes into account natural hazards,**

**‘(f) to support ongoing improvement in productivity, liveability and environmental quality,**

‘(g) to provide increased opportunity for public involvement and participation in environmental planning and assessment in the Greater Sydney Region.’

In meeting its objectives, the GSC will make plans and determine development. The Minister for Planning made the Ministerial Statement of Priorities for the Greater Sydney Commission (2016-2018) (NSW Government, 2015) to provide more guidance to the GSC in regard to the Minister’s expectations of the outcomes of its activities. The EP&A Act was amended to align with the formation and roles of the GSC, including plan-making and development determination.

The establishment of the GSC is important in any assessment of the potential for integrating urban ecology

#### **Box 4.1** The Sydney Green Grid

Sydney’s Green Grid is a key strategy in the metropolitan (‘A Plan for Growing Sydney’) and draft district plans for Sydney being prepared by the GSC. The objective of the Sydney Green Grid is to provide a connected and diverse network of green spaces and assets that:

- increases access to open space
- promotes good health and active living
- creates new high-quality public areas and places
- makes the urban environment more green
- enhances green spaces
- promotes green skills in bushland and waterway care and restoration
- improves access to sport and recreation
- delivers better tools for future open-space planning.

The Grid will operate at multiple scales that acknowledge the social and environmental benefits provided by the major national parks that surround Sydney to its local parkland and bushland sites, through to individual street trees in the suburban network.

into the planning system in NSW. An opportunity exists to embed urban ecology policies vertically throughout the hierarchy of planning documents the GSC is preparing to enable the effective and consistent reform of biodiversity protection and management across the Greater Sydney Region.

The governance systems created under the GSC Act are based on a sustainability framework, with three commissioners assigned responsibility for environment, economic and social functions, respectively. Crucially, the membership of the GSC's infrastructure delivery committee includes five state government agencies (Planning and Environment; Transport; Treasury; Health; and Education), with the potential to lead to transformative change in the way in which planning is undertaken and how each agency carries out its activities (GSC, 2016c). The GSC is also placed as an agency to transition planning for the Greater Sydney Region by integrating social, economic and environmental considerations with regard to the principles of ecologically sustainable development and how urban ecology can deliver both direct and indirect co-benefits across the three sustainability themes. This transition and coordinating role has been lacking in city planning in NSW, as identified in 2014 in the review and proposed reform of the EP&A Act (Ruming & Davies, 2014).

The GSC released six draft district plans (Central, North, West Central, West, South West and South) in November 2016 (GSC, 2016b); these set out an agenda for a productive, liveable and sustainable city with the aim of protecting and enhancing the natural environment. Each draft district plan outlines a number of sustainability priorities and actions for the given district. Sustainability aspects of the draft plans draw on Goal 4 of A Plan for Growing Sydney, which aims for the city to be both sustainable and resilient in protecting its natural environment using a balanced approach to land and resource use.

The draft district plans contain specific priority outcomes aligned with the overarching agenda of creating a sustainable city. These priorities are related to the protection and management of remnant vegetation, bushland, green and open spaces and waterways (Tables 4.1) and specify the lead and partner agencies responsible for the priority or action (Table 4.2). The key priorities are discussed below.

- **Enhancing landscapes in districts**

The proposed approach to enhancing landscapes in districts addresses four interconnected aspects: 1) waterways, including both natural and man-made systems; 2) areas of native vegetation and vegetation of value to biodiversity and ecological communities; 3) the implementation of Sydney's Green Grid (as below); and 4) the careful management of the Metropolitan Rural Area.

- **Protecting district waterways**

Protecting waterways is an important priority for districts, particularly to maintain and improve waterway health and water quality. The West Central District emphasises the conservation and protection of the Parramatta River, and the North and Central districts emphasise the preservation of Sydney Harbour's foreshores and waterways.

The GSC identified the review of criteria for monitoring water quality and waterway health as a crucial action for all districts. Specific goals are set for the South Creek area and to achieve excellent environmental performance in the South West, West Central and West districts (which are also priority development areas).

- **Protecting and enhancing biodiversity**

This priority emphasises the need to avoid and minimise impacts on biodiversity. The focus of conservation planning is on opportunities to protect and enhance valuable native vegetation near

national parks. An objective is to obtain better biodiversity conservation outcomes than might be achieved through a site-by-site or project-by-project approach. The new assessment process would involve strategic planning at the landscape level in order to ‘consider opportunities to connect areas of biodiversity, the relationship between different areas and threats to natural features’ as well as ‘the effects of conservation efforts across the landscape’ (GSC, 2016b).

Another objective is to improve or maintain the conservation status of threatened species and communities. An objective of strategic conservation planning is to facilitate urban growth and development, reduce costs and expedite the approval process for development and infrastructure. Although plans aim to provide an ‘equitable model’ for identifying and recovering costs to biodiversity caused by urban growth and development, there is no specific mention of reviewing the biodiversity offset scheme.

- **Delivering Sydney’s Green Grid**

In delivering Sydney’s Green Grid, the draft district plans indicate that priority areas (that is, those areas forming part of or contributing to the Green Grid) can make use of funding programs (e.g. the NSW Metropolitan Green Space program and NSW Environmental Trust grants). The GSC has identified the development of support tools and methodologies as an action for improving local open-space planning in the districts. The Central District Plan makes special mention of maximising public benefits from the innovative use of golf courses, including an action to ‘identify opportunities for shared golf courses and open space’. This may provide opportunities for advancing urban ecological outcomes.

- **Creating efficient districts**

District plans include an action to embed the NSW Climate Change Policy Framework<sup>24</sup> into the planning process in conjunction with support for low-carbon initiatives as a way of increasing the resource-use efficiency of districts and minimising waste. The development of environmental performance targets and benchmarks is outlined as an action across all districts. Waste management is highlighted as an issue to be supported at the district level through the identification of land for future waste recycling and reuse.

- **Planning for resilient districts**

The UHI effect and air and noise pollution were identified as key issues for resilience. A suggested action is the review of guidelines on air-quality and noise measures, especially for developments near transport infrastructure. For the UHI effect, the GSC proposes integrating UHI mitigation into the planning of urban-renewal projects and priority growth areas across the districts.

The West Central, West and South West draft district plans identify addressing flood hazards in the Hawkesbury Nepean Valley as a priority, and the South West draft district plan includes a priority of protecting the ‘natural beauty of the visual landscape’ (GSC, 2016b). All districts feature, as a priority, assisting local communities to develop a better understanding of natural hazards and specific actions to reduce risks. Although not mentioned in the draft plans, this may have adverse outcomes for urban ecosystems in Sydney if this is to be achieved through the use of Warragamba Dam as a flood-control structure, which might involve raising the height of the dam and consequently flooding significant upstream areas of the national park.

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<sup>24</sup> See NSW Office of Environment and Heritage (2016b).

A sustainability priority in all draft district plans except for the Central District is to consider environmental, social and economic values in planning and to generally discourage urban development in the Metropolitan Rural Area. The relevant planning authorities need to undertake strategic planning in accordance with these sustainability priorities, and they should adopt a design-led approach to planning (emphasising design quality, liveability and a sense of community). Planning proposals that affect land in rural or environmental zones are not to be supported by authorities unless the land is identified as an urban investigation area in a regional or district plan. Further exception can be made if the land is part of, or is identified through strategic planning as, a rural residential development that protects the values of the area and considers environmental, social and economic values. These recommendations are particularly relevant for the long-term survival of many endangered ecological communities and threatened species that rely on natural areas in Sydney's west.

The Central District plan stands out as different to the Metropolitan Rural Area<sup>25</sup> (where urban development is discouraged). The Central District plan includes the consideration of environmental values in planning as a specific priority for a sustainable city. Although urban densification and restricting urban sprawl are seen as positive means for preserving open spaces in the peri-urban area, a planning strategy of densification can limit new greening opportunities in the inner cities (Frantzeskaki & Tilie, 2014) and will be more effective for biodiversity if it is promoted alongside natural/green retrofitting (Beatley, 2011).

The district plans (especially the Central District plan) could benefit from explicitly prioritising the implementation of green infrastructure and retrofitting. The plans do note a need to upgrade the districts' ageing grid of grey infrastructure (focusing on opportunities in urban-renewal areas). The plans also mention WSUD measures as a means for enhancing vegetation growth and protecting waterways, complementing other strategic visions such as the Parramatta River Catchment Group's goal of a swimmable Parramatta River by 2025.

Of note is the concept of developing and delivering the Sydney Green Grid Project, which seeks to conserve, improve and expand the network of open spaces as part of the city's strategic planning. To maximise the impact of this initiative, broader environmental, health, social and economic outcomes should be accounted for as co-benefits of a greener Sydney (as discussed in Chapter 5). The way in which the Sydney Green Grid will function as a strategic planning or on-the-ground process is uncertain, although it will likely draw on the experiences of the Southern Sydney Regional Organization of Councils and work across the Parramatta Local Government Area (see Chapter 3 and the functional requirements of biocorridors).

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<sup>25</sup> The Metropolitan Rural Area is defined as the Greater Sydney Region's non-urban areas and includes 'rural towns and villages, farmland, floodplains, national parks and areas of wilderness' because these contribute primarily to local growth (GSC, 2016b). The Metropolitan Rural Area is mapped out in all district plans (except the Central District), and urban development is discouraged in those areas.

**Table 4.1.** GSC sustainability priorities. Non-shaded cells indicate overlap across districts, and the overarching/general priorities are in italics. Cells shaded in the same colour indicate overlap between districts. Priorities unique to a district are in bold.

Central	North	West Central	West	South West	South
• <i>Enhancing the Central District in its landscape</i>	• <i>Enhancing the North District in its landscape</i>	• <i>Enhancing the West Central District in its landscape</i>	• <i>Enhancing the West District in its landscape</i>	• <i>Enhancing the South West District in its landscape</i>	• <i>Enhancing the South District in its landscape</i>
<i>S1: Protecting the district's waterways</i>	<i>S1: Protecting the district's waterways</i>	<i>S1: Protecting the district's waterways</i>	<i>S1: Protecting the district's waterways</i>	<b>S1: Protecting the natural beauty of the visual landscape</b>	<i>S1: Protecting the district's waterways</i>
S1: Maintain and improve water quality and waterway health	S1: Maintain and improve water quality and waterway health	S1: Maintain and improve water quality and waterway health	S1: Maintain and improve water quality and waterway health	S1: Improve protection of ridgelines and scenic areas	S1: Maintain and improve water quality and waterway health
• <i>Managing coastal landscapes</i>	• <i>Managing coastal landscapes</i>	• <i>Managing the district's estuaries</i>	• <i>Managing the district's estuaries</i>	• <i>Managing the district's estuaries</i>	• <i>Managing coastal landscapes</i>
S2: Protect and conserve the values of Sydney Harbour	S2: Protect and conserve the values of Sydney Harbour	S2: Protect and conserve the values of the Parramatta River and Sydney Harbour	<i>S2: Protecting and enhancing biodiversity</i>	<i>S2: Protecting the District's waterways</i>	<i>S2: Protecting and enhancing biodiversity</i>
S3: Enhance access to Sydney Harbour foreshore and waterways	S3: Enhance access to Sydney Harbour foreshore and waterways	S3: Enhance access to the Parramatta River and Sydney Harbour foreshore and waterways	S2: Avoid and minimise impacts on biodiversity	S2: Maintain or restore water quality and waterway health	S2: Avoid and minimise impacts on biodiversity
<i>S4: Protecting and enhancing biodiversity</i>	<i>S4: Protecting and enhancing biodiversity</i>	<i>S4: Protecting and enhancing biodiversity</i>	<i>S3-5: Delivering Sydney's Green Grid</i>	<i>S3: Protecting and enhancing biodiversity</i>	<i>S3, S4: Delivering Sydney's Green Grid</i>
S4: Avoid and minimise impacts on biodiversity	S4: Avoid and minimise impacts on biodiversity	S4: Avoid and minimise impacts on biodiversity	S3: Align strategic planning to the vision for the Green Grid	S3: Avoid and minimise impacts on biodiversity	S3: Align strategic planning to the vision for the Green Grid
<i>S5-8: Delivering Sydney's Green Grid</i>	<i>S5-7: Delivering Sydney's Green Grid</i>	<i>S5-7: Delivering Sydney's Green Grid</i>	S4: Protect, enhance and extend the urban canopy	<i>S4, S5: Delivering Sydney's Green Grid</i>	S4: Protect, enhance and extend the urban canopy
S5: Align strategic planning to the vision for the Green Grid	S5: Align strategic planning to the vision for the Green Grid	S5: Align strategic planning to the vision for the Green Grid	S5: Improve protection of ridgelines and scenic areas	S4: Align strategic planning to the vision for the Green Grid	S5: Improve protection of ridgelines and scenic areas
<b>S6: Maximise benefits to the public from the innovative use of golf courses</b>	S6: Protect, enhance and extend the urban canopy	S6: Protect, enhance and extend the urban canopy	<i>S6-8: Managing the Metropolitan Rural Area</i>	S5: Protect, enhance and extend the urban canopy	<i>S6-8: Managing the Metropolitan Rural Area</i>
S7: Protect, enhance and extend the urban canopy	S7: Improve protection of ridgelines and scenic areas	S7: Improve protection of ridgelines and scenic areas	S6: Discourage urban development in the Metropolitan Rural Area	<i>S6-8: Managing the Metropolitan Rural Area</i>	S6: Discourage urban development in the Metropolitan Rural Area
S8: Improve protection of ridgelines and scenic areas	<i>S8-10: Managing the Metropolitan Rural Area</i>	<i>S8-10: Managing the Metropolitan Rural Area</i>	S7: Consider environmental, social and economic values	S6: Discourage urban development in the Metropolitan	S7: Consider environmental, social and economic values

			when planning in the Metropolitan Rural Area	Rural Area	when planning in the Metropolitan Rural Area
<i>S9 Creating an efficient district</i>	S8: Discourage urban development in the Metropolitan Rural Area	S8: Discourage urban development in the Metropolitan Rural Area	S8: Provide for rural residential development while protecting the values of the Metropolitan Rural Area	S7: Consider environmental, social and economic values when planning in the Metropolitan Rural Area	S8: Provide for rural residential development while protecting the values of the Metropolitan Rural Area
S9: Support opportunities for district waste management	S9: Consider environmental, social and economic values when planning in the Metropolitan Rural Area	S9: Consider environmental, social and economic values when planning in the Metropolitan Rural Area	<i>S9 Creating an efficient West District</i>	S8: Provide for rural residential development while protecting the values of the Metropolitan Rural Area	<i>S9 Creating an efficient South District</i>
<i>S10-12: Planning for a resilient Central District</i>	S10: Provide for rural residential development while protecting the values of the Metropolitan Rural Area	S10: Provide for rural residential development while protecting the values of the Metropolitan Rural Area	S9: Support opportunities for district waste management	<i>S9 Creating an efficient South West District</i>	S9: Support opportunities for district waste management
S10: Mitigate the urban heat island effect	<i>S11: Creating an efficient North District</i>	<i>S11: Creating an efficient West Central District</i>	<i>S10-13: Planning for a resilient West District</i>	S9: Support opportunities for district waste management	<i>S10-13: Planning for a resilient South District</i>
S11: Integrate land-use and transport planning to consider emergency evacuation needs	S11: Support opportunities for district waste management	S11: Support opportunities for district waste management	S10: Mitigate the urban heat island effect	<i>S10-13: Planning for a resilient South West District</i>	S10: Mitigate the urban heat island effect
S12: Assist local communities to develop a coordinated understanding of natural hazards and responses that reduce risk	<i>S12:-15: Planning for a resilient North District</i>	<i>S12:-15: Planning for a resilient West Central District</i>	S11: Integrate land-use and transport planning to consider emergency evacuation needs	S10: Mitigate the urban heat island effect	S11: Integrate land-use and transport planning to consider emergency evacuation needs
	S12: Mitigate the urban heat island effect	S12: Mitigate the urban heat island effect	S12: Use buffers to manage the impacts of rural activities on noise, odour and air quality	S11: Integrate land-use and transport planning to consider emergency evacuation needs	S12: Use buffers to manage the impacts of rural activities on noise, odour and air quality
	S13: Integrate land-use and transport planning to consider emergency evacuation needs	S13: Integrate land-use and transport planning to consider emergency evacuation needs	S13: Assist local communities to develop a coordinated understanding of natural hazards and responses that reduce risk	S12: Use buffers to manage the impacts of rural activities on noise, odour and air quality	S13: Assist local communities to develop a coordinated understanding of natural hazards and responses that reduce risk
	S14: Use buffers to manage the impacts of rural activities on	S14: Use buffers to manage the impacts of rural activities on	<i>S16: Managing flood hazards in the Hawkesbury-Nepean Valley</i>	S13: Assist local communities to develop a coordinated	

noise, odour and air quality	noise, odour and air quality		understanding of natural hazards and responses that reduce risk
S15: Assist local communities too develop a coordinated understanding of natural hazards and responses that reduce risk	S15: Assist local communities to develop a coordinated understanding of natural hazards and responses that reduce risk		<i>S18: Managing flood hazards in the Hawkesbury-Nepean Valley</i>
	<i>S16: Managing flood hazards in the Hawkesbury Nepean Valley</i>		

Table 4.2. Actions for GSC sustainability priorities. Non-shaded cells indicate overlap across all districts. Actions specific to a single district are in bold. Cells shaded in the same colour indicate overlap between districts.

**Abbreviations:** DPE: Department of Planning and Environment; EPA: Environmental Protection Agency; GSC: Greater Sydney Commission; OEH: Office of Environment and Heritage; SW: Sydney Water; TfNSW: Transport for NSW; WSPT: Western Sydney Parkland Trust

Central	Lead	Partners	North	Lead	Partners	West Central	Lead	Partners	West	Lead	Partners	South West	Lead	Partners	South	Lead	Partners
S1: Review criteria for monitoring water quality and waterway health	OEH	GSC	S1: Review criteria for monitoring water quality and waterway health	OEH	GSC	S1: Review criteria for monitoring water quality and waterway health	OEH	GSC	S1: Review criteria for monitoring water quality and waterway health	OEH	GSC	<b>S1: Protect the qualities of the Scenic Hills landscape</b>	GSC	DPE, councils	S1: Review criteria for monitoring water quality and waterway health	OEH	GSC
S2: Update information on areas of high environmental value	OEH, DPE	Councils	S2: Update information on areas of high environmental value	OEH, DPE	Councils	<b>S2: Protect the South Creek environment and use development approaches to achieve excellent environment performance</b>	GSC	EPA	<b>S2: Protect the South Creek environment and use development approaches to achieve excellent environment performance</b>	GSC	EPA	S2: Review criteria for monitoring water quality and waterway health	OEH	GSC	S2: Update information on areas of high environmental value	OEH, DPE	Councils
S3: Use funding programs to deliver the Central District Green Grid priorities	GSC, TfNSW, OEH	Councils	S3: Use funding programs to deliver the Central District Green Grid priorities	GSC, TfNSW, OEH	Councils	<b>S3: Develop a strategic conservation plan for western Sydney</b>	OEH, DPE	GSC	<b>S3: Improve the management of waterways in priority growth areas</b>	DPE	GSC	<b>S3: Protect the South Creek environment and development approaches to achieve excellent environment performance</b>	GSC	EPA	S3: Use funding programs to deliver the South District Green Grid priorities	GSC, TfNSW, OEH	Councils
S4: Develop support tools and methodologies for local open-space planning	GSC		S4: Develop support tools and methodologies for local open-space planning	GSC		S4: Update information on areas of high environmental value	OEH, DPE	Councils	<b>S4: Develop a strategic conservation plan for western Sydney</b>	OEH, DPE	GSC	<b>S4: Improve the management of waterways in priority growth areas</b>	DPE	GSC	S4: Develop support tools and methodologies for local open-space planning	GSC	
<b>S5: Identify opportunities for shared golf courses and open space</b>	GSC	TfNSW, Office of Sport Sydney	S5: Update the Urban Green Cover in NSW Technical Guidelines to respond to solar access to roofs	OEH, DPE		S5: Use funding programs to deliver the West Central District Green Grid priorities	GSC, TfNSW, OEH	Councils	S5: Update information on areas of high environmental value	OEH, DPE	Councils	<b>S5: Monitor water levels and water quality in Thirlmere Lakes</b>	OEH		S5: Update the Urban Green Cover in NSW Technical Guidelines to respond to solar access to roofs	OEH, DPE	

S6: Update the Urban Green Cover in NSW Technical Guidelines to respond to solar access to roofs	OEH, DPE	Councils	S6: Identify land for future waste reuse and recycling	EPA, DPE	Councils	S6: Develop support tools and methodologies for local open-space planning	GSC	Blacktown Council, SW, Water NSW	S6: Use funding programs to deliver the West District Green Grid priorities	GSC, TNSW, OEH	Councils	S6: Develop a strategic conservation plan for western Sydney	OEH, DPE	GSC	S6: Identify land for future waste reuse and recycling	EPA, DPE	Councils
S7: Identify land for future waste reuse and recycling	EPA, DPE	Councils	S7: Embed the NSW Climate Change Policy Framework into local planning decisions	GSC	GSC	<b>S7: Create new recreational opportunities at Prospect Reservoir</b>	GSC, WSPT		S7: Develop support tools and methodologies for local open-space planning	GSC	Councils	S7: Update information on areas of high environmental value	Councils	GSC	S7: Embed the NSW Climate Change Policy Framework into local planning decisions	GSC	Councils, OEH
S8: Embed the NSW Climate Change Policy Framework into local planning decisions	GSC		S8: Support the development of initiatives for a sustainable low carbon future	GSC, DPE, councils		S8: Update the Urban Green Cover in NSW Technical Guidelines to respond to solar access to roofs	OEH, DPE		S8: Update the Urban Green Cover in NSW Technical Guidelines to respond to solar access to roofs	OEH, DPE	Councils	S8: Use funding priorities to deliver the South West District Green Grid priorities	Councils		S8: Support the development of initiatives for a sustainable low carbon future	GSC, Councils, DPE	
S9: Support the development of initiatives for a sustainable low-carbon future	GSC, DPE, councils		S9: Support the development of environmental performance targets and benchmarks	GSC, DPE, councils		S9: Identify land for future waste reuse and recycling	EPA, DPE	Councils	S9: Identify land for future waste reuse and recycling	EPA, DPE	Councils	S9: Develop support tools and methodologies for local open-space planning	GSC		S9: Support the development of environmental performance targets and benchmarks	GSC	NSW Climate Council, Australian Government, utility providers
S10: Support the development of environmental performance targets and benchmarks	GSC, DPE, councils		S10: Incorporate the mitigation of the urban heat island effect into planning for urban renewal projects and priority growth areas	DPE		S10: Embed the NSW Climate Change Policy Framework into local planning decisions	GSC	Councils, OEH	S10: Embed the NSW Climate Change Policy Framework into local planning decisions	GSC	Councils, OEH	S10: Update the Urban Green Cover in NSW Technical Guidelines to respond to solar access to roofs	OEH, DPE		S10: Incorporate the management of urban heat into planning for urban renewal projects and priority growth areas	DPE	
S11: Incorporate the mitigation of the urban heat island effect into planning for urban renewal projects and priority growth areas	DPE		S11: Review the guidelines for air quality and noise measures for development near rail corridors and busy roads	EPA, DPE		S11: Support the development of initiatives for a sustainable low-carbon future	GSC, DPE, councils		S11: Support the development of initiatives for a sustainable low-carbon future	GSC, DPE, Councils	Councils	S11: Identify land for future waste reuse and recycling	EPA, DPE		S11: Review the guidelines for air quality and noise measures for development near rail corridors and busy roads	EPA, DPE	

S12: Review the guidelines for air quality and noise measures for development near rail corridors and busy roads	EPA, DPE	S12: Identify and map potential high-impact areas for noise and air pollution	DPE, councils EPA	S12: Support the development of environmental performance targets and benchmarks	GSC, DPE, councils NSW Climate Council, Australian Government, utility providers	S12: Support the development of environmental performance targets and benchmarks	GSC	S12: Embed the NSW Climate Change Policy Framework into local planning decisions	GSC Councils, OEH	S12: Identify and map potential high-impact areas for noise and air pollution	EPA DPE, councils	
S13: Identify and map potential high-impact areas for noise and air pollution	EPA			S13: Incorporate the mitigation of the urban heat island effect into planning for urban renewal projects and priority growth areas	DPE	S13: Incorporate the mitigation of the urban heat island effect into planning for urban renewal projects and priority growth areas	DPE	S13: Support the development of initiatives for a sustainable low-carbon future	GSC, councils, DPE			
				S14: Review the guidelines for air quality and noise measures for development near rail corridors and busy roads	EPA, DPE	S14: Review the guidelines for air quality and noise measures for development near rail corridors and busy roads	EPA, DPE	S14: Support the development of environmental performance targets and benchmarks	GSC			NSW Climate Council, Australian Government, utility providers
				S15: Identify and map potential high-impact areas for noise and air pollution	EPA, DPE	S15: Identify and map potential high-impact areas for noise and air pollution	DPE, Councils	S15: Incorporate the mitigation of the urban heat island effect into planning for urban renewal projects and priority growth areas	DPE			
				S16: Address flood-risk issues in the Hawkesbury-Nepean Valley	DPE, INSW	S16: Address flood-risk issues in the Hawkesbury-Nepean Valley	GSC, councils	S16: Review the guidelines for air quality and noise measures for development near rail corridors and busy roads	EPA, DPE			
								S17: Identify and map potential high-impact areas for noise and air pollution	EPA			DPE, councils

S18: Address flood-risk issues in the Hawkesbury- Nepean Valley	DPE, INSW GSC, councils
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In maintaining and improving waterway health and quality, the draft district plans state that 'relevant planning authorities and managers of public land should ... consider more water sensitive approaches to managing stormwater to meet the water quality and quantity targets, including harvesting and re-use of water and management of riparian corridors' (GSC, 2016b). Lake Illawarra features in the district plans as a case study on delivering water-sensitive growth using the Illawarra-Shoalhaven Regional Plan's risk-based framework as a strategic planning tool. Recommendations on policies and regulations for WSUD in Sydney should consider the review of opportunities by the Cooperative Centre for Water Sensitive Cities (CRCWSC, 2016), as well as the review of the NSW planning framework for WSUD by Choi and McIlrath (2016).

After finalisation, the district plans will be reviewed every five years, and they will form an integral part of a vertically consistent strategic planning process, upwards to the Strategic Plan for the Greater Sydney Region, which includes the review of A Plan for Growing Sydney, and downwards to council local environment plans (LEPs). Of note is the concept of developing and delivering the Sydney Green Grid Project, which seeks to conserve, improve and expand the network of open spaces as part of the city's strategic planning. Reviews of this project must be undertaken within a multifunctional perspective linking the environmental, health, social and economic benefits. At the local level, LEPs and supporting plans and policies must be consistent with higher-level documents. A barrier to the application of urban ecology is the lack of consistency of local plans and policies between council areas, notwithstanding the considerable variability in operational decisions on the management of natural assets. There is a crucial need for all levels of planning (metropolitan, district and local) to consider geographic scales and how best to coordinate and deliver biodiversity outcomes – from the regional level through to individual lots.

The GSC is responsible for the monitoring and evaluation of planning in Sydney, and it will be developing the Greater Sydney Dashboard interactive information hub. The metrics are unknown, but evaluation processes involving a hierarchy of biodiversity inputs and outputs will be required if urban ecological outcomes are to be achieved.

It is unknown whether the GSC or another agency will be responsible for evaluating the success of the design-led approach outlined in the district plans. The draft district plans indicate which actions and new collaborations the GSC will be responsible for delivering and leading. For example:

'To support the efficient and effective alignment of land use planning and infrastructure:

'the Commission will prepare an Annual Infrastructure Priority List in conjunction with Infrastructure NSW to support the productivity, liveability and sustainability of the District as it grows, consistent with Action 1.11.6 of A Plan for Growing Sydney.'

The city's transition to ecologically sustainable development principles will require ongoing adaptation to respond to past and current impacts and anticipated future changes (Meadowcroft, 2009). A successful transition requires various elements, including:

- Long-term planning that considers the future development and impact scenarios and how these could be managed.
- The review and amendment of current practices contributing to the deterioration of urban ecosystems. Typically, these are deeply embedded or business-as-usual practices that strongly resist change to established 'path dependencies'.

- Support for interactive and collaborate practices among stakeholders with interests in or impacts on an issue, although who typically are not solely responsible for it (e.g. most catchment management issues).
- The use of technology and innovation as both learning opportunities and agents of change.
- The embedding of adaptive learning and management processes, which will include setting targets and establishing monitoring and evaluation systems.
- Assigning responsibility to and setting a high priority within government to enable action and change.

City planning could focus on the GSC's three pillars of creating a productive, liveable and sustainable city and the state government goal of creating a liveable city (NSW Department of Planning and Environment, 2014).<sup>26</sup> This goal has a greater focus on urban ecology but is not focused on a single outcome, such as the past focus on jobs and housing targets (GSC, 2016d).

Strategic planning must link known areas of high biodiversity with a view to protecting remnant bushland and other important terrestrial, riparian and aquatic ecosystems. It must also adopt a management approach that seeks opportunities to recreate or re-establish natural systems or corridors.

Corridors should be part of a hierarchy based on their importance, functional requirements and mechanisms for supporting regional, district and local connections. A policy hierarchy exists for the management of riparian areas (NSW Department of Primary Industries, 2012b), although that policy was framed around the priority of housing supply (Ives *et al.*, 2013) rather than the provision of ecosystem services and the long-term protection of riparian habitats (Davies *et al.*, 2011; Ives *et al.*, 2013).

Significantly, recent amendments to the EP&A Act will, for the first time, make the regional plan for Sydney a statutory document. In the past, these strategic plans have been guides only; they are now enabled by statutory provisions in the EP&A Act for the preparation of plans to deliver on objectives (such as those discussed below), Ministerial directions (s117 of the EP&A Act) and regulations. Statutory regional plans will hold greater weight, and embedding urban ecology principles and objectives in them will provide further 'scaffolding' for the vertical and horizontal integration of environmental outcomes in land-use decision-making. The preparation of a strategic plan for the Greater Sydney Region is likely to commence in 2017; the Ministerial Statement of Priorities for the Greater Sydney Commission (2016–2018) (NSW Government, 2015) requires that the GSC prepares this plan, along with its review of A Plan for Growing Sydney, the Long Term Masterplan 2012, and Rebuilding NSW – State Infrastructure Strategy 2014, to align land-use planning and infrastructure.

**A Plan for Growing Sydney: the apex strategic plan for Sydney**

A Plan for Growing Sydney has four goals, the most relevant to urban ecology of which are Goal 3: 'A great place to live with communities that are strong, healthy and well connected', and Goal 4: 'A sustainable and resilient city that protects the natural environment and has a balanced approach to the use of land and resources'. Both goals contain directions to guide decisions with the aim of protecting and promoting biodiversity in the Greater Sydney Region. These directions are as follows:

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<sup>26</sup>Goal 3 in the current NSW metropolitan strategy.

- Goal 3, Direction 3.2, is aimed at creating a network of interlinked, multipurpose open and green spaces across Sydney (NSW Department of Planning and Environment 2014, Action 3.2.1). Included in this is the delivery of the Sydney Green Grid Project and the investigation and application of options and Environmental Trust funds to urban habitat and bushland renewal projects (Action 3.2.2). Importantly, the Environmental Trust has noted its inability to significantly drive the issue beyond the drafting of rules and regulations. This highlights the discrepancy that can occur between policy and practical application.
- Direction 4.1, 'Protect our natural environment and biodiversity', contains several actions related to urban ecology, including increasing the use of biodiversity certification and 'biodiversity banking'; the management of bushland on private lands in areas of high conservation value, including biodiversity corridors; the continued use of existing planning instruments to protect biodiversity in protected areas, acknowledging that adverse impacts on natural values can arise from the planning and development process; the identification of the Metropolitan Rural Area as a buffer zone between populations and protected areas and other natural assets, while recognising the need for access to productive resources (actions 4.1.1 and 4.1.2); and actions to integrate the management of the marine estate with land-use decisions (Action 4.1.3).

A Plan for Growing Sydney has actions relating to natural hazard management (Direction 4.2) and the application of the Urban Green Cover Technical Guidelines (Action 4.3.1). The plan also identifies a new planning 'area' in Sydney – the Metropolitan Rural Area.<sup>27</sup> Relatively little information is available on the purpose of this area, but it is land identified in the plan that falls between developed and protected areas. The plan indicates that a specific strategy is required for this area to protect natural assets, given the anticipated large population growth in Sydney's west, which will also link to the proposed Western Sydney Airport development at Badgerys Creek (Box 4.2). In the GSC's draft district plans (see discussion above), however, most of the land concerned with the airport development in the Northwest, West and South West districts is categorised as urban areas, which are considered priority growth areas, and only some are areas set aside as Metropolitan Rural Area (**Figure 4.3**).

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<sup>27</sup> The GSC's draft district plans also use the Metropolitan Rural Area as a way of identifying transitional land to act as a buffer between urban and rural areas.

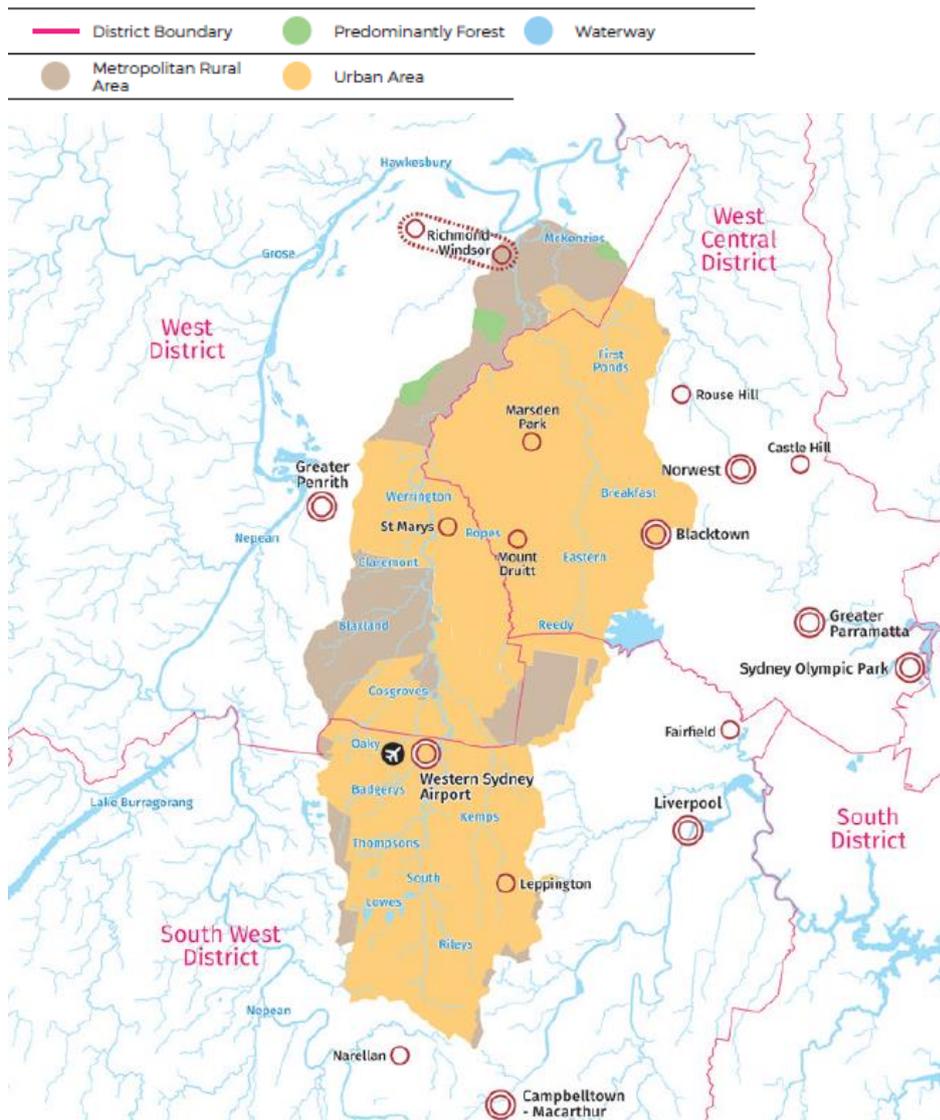


Figure 4.3. South Creek catchment map. Source: GSC (2016b).

A Plan for Growing Sydney aims to balance growth with support for a network of open spaces and green spaces (Direction 3.2) and protecting the natural environment and biodiversity (Direction 4.1). Managing the impacts of development on the environment (Direction 4.3) at the regional, precinct and site scales will require good planning (NSW Department of Planning and Environment, 2014). The NSW Government is committed to developing ‘green cover design principles’ ‘to inform how to incorporate vegetated, permeable and reflective surfaces into urban settings, address thermal loading in the built environment, and provide co-benefits such as reduced energy costs for cooling, stormwater management, cleaner air and biodiversity habitat. The NSW Government will apply the Urban Green Cover in NSW Technical Guidelines in priority precincts (NSW Department of Planning and Environment 2014), although questions about how these will be enforced, their relationship with supporting policies such as environmental planning instruments, and how they will consider scale and the city’s geography (such as the location of corridors) remain unresolved. Updating the Urban Green Cover in NSW Technical Guidelines is a key action in all draft district plans, framed as a means for responding to solar access to roofs. The impact of the guidelines on biodiversity, which is mentioned briefly as a ‘potential benefit’ of urban green cover, is uncertain.

The GSC has released A Draft Amendment to Update A Plan for Growing Sydney, which sets out the development of the regional strategy; it will be on public exhibition until the end of March 2017 (GSC, 2016a). The draft amendment outlines the vision of Greater Sydney as a mega-metropolis consisting of three cities: **Western City**, which includes greater Penrith, Liverpool and Campbelltown–Macarthur; **Central City**, comprising greater Parramatta and the Olympic Peninsula; and **Eastern City**, which comprises the economic and coastal corridor running from the Northern Beaches Hospital Precinct to Port Botany.

The federal and state governments have agreed to develop the Western Sydney City Deal with local councils. Although the deal is set to drive new economic opportunities through the highly anticipated development of Western Sydney Airport and surrounding areas, it also pledges ‘better planning and density done well’ to provide for housing and to ‘support clean air, green spaces, vibrant arts and cultural initiatives’ (GSC, 2016a). Incorporating green infrastructure as a means for reducing air pollution (as well as to buffer against noise and visual pollution from infrastructure projects) and the UHI effect and to promote liveable urban densification presents a unique opportunity, but it needs to be explicitly prioritised over grey-infrastructure approaches.

More generally, the draft amendment (similarly to the draft district plans) outlines a plan for a sustainable Greater Sydney (Figure 4.4). Specific priorities are given to landscape (via the improvement of waterway health as well as protecting, extending and enhancing biodiversity), creating an efficient city (through the mitigation of environmental impacts by using resources more efficiently and promoting renewable energy sources), and, building on the ‘100 Resilient Cities Network’, a resilient city (by identifying and adapting to climate change and strengthening social, organisational and infrastructure capacity).

**Box 4.2. Western Sydney Airport**

Badgerys Creek has been announced as the site for the Western Sydney Airport. The impact of the construction includes the removal of around 318 ha of native vegetation as well as the removal of aquatic and wetland habitats, contributing to the fragmentation of native vegetation in the region (Department of Infrastructure and Regional Development, 2016). Threatened species of flora, fauna and ecological communities listed in Commonwealth and NSW legislation will be directly affected. The Australian Government has committed to a biodiversity offset package of up to \$180 million, as well as the establishment of a 117-ha onsite environmental conservation zone.



Figure 4.4. The GSC’s vision for a sustainable Greater Sydney. Source: GSC (2016a).

**Hunter Region Plan**

The Hunter Region Plan (NSW Department of Planning & Environment, 2015) is in its submission review period. It outlines the following four goals for the Greater Hunter Region:

- 1) Grow Australia’s next major city.
- 2) Grow the largest regional economy in Australia.

- 3) Protect and connect natural environments.
- 4) Support robust regional communities.

Of these, the goal most relevant to urban ecology and biodiversity is Goal 3 ('Protect and connect natural environments'). Direction 3.1 ('Protect the natural environment and biodiversity') and Direction 3.2 ('Secure the health of water resources and coastal landscapes') contain actions related to the protection of biodiversity (actions 3.1.1–3.1.2 and 3.2.2–3.2.3 in NSW Department of Planning & Environment, 2015). The Hunter Regional Plan's companion document, A Plan for Growing Hunter City, contains specific provisions related to urban ecology and biodiversity generally. Action 1.2.2 ('Investigate new land release areas to deliver housing in the longer term') mentions that the assessment of new land-release areas should be based on the potential impacts on the environment and biodiversity and the delivery of sustainable communities (NSW Department of Planning & Environment, 2015, Action 1.2.2). The planning and delivery of the Hunter City Green Grid – the development of an open-space network with green corridors and tree-lined streets – is listed as an intended action (NSW Department of Planning & Environment, 2015, Action 1.4.3).

#### Illawarra-Shoalhaven Regional Plan

The Illawarra-Shoalhaven Regional Plan (NSW Department of Planning and Environment, 2015) was approved in November 2015. It has five goals:

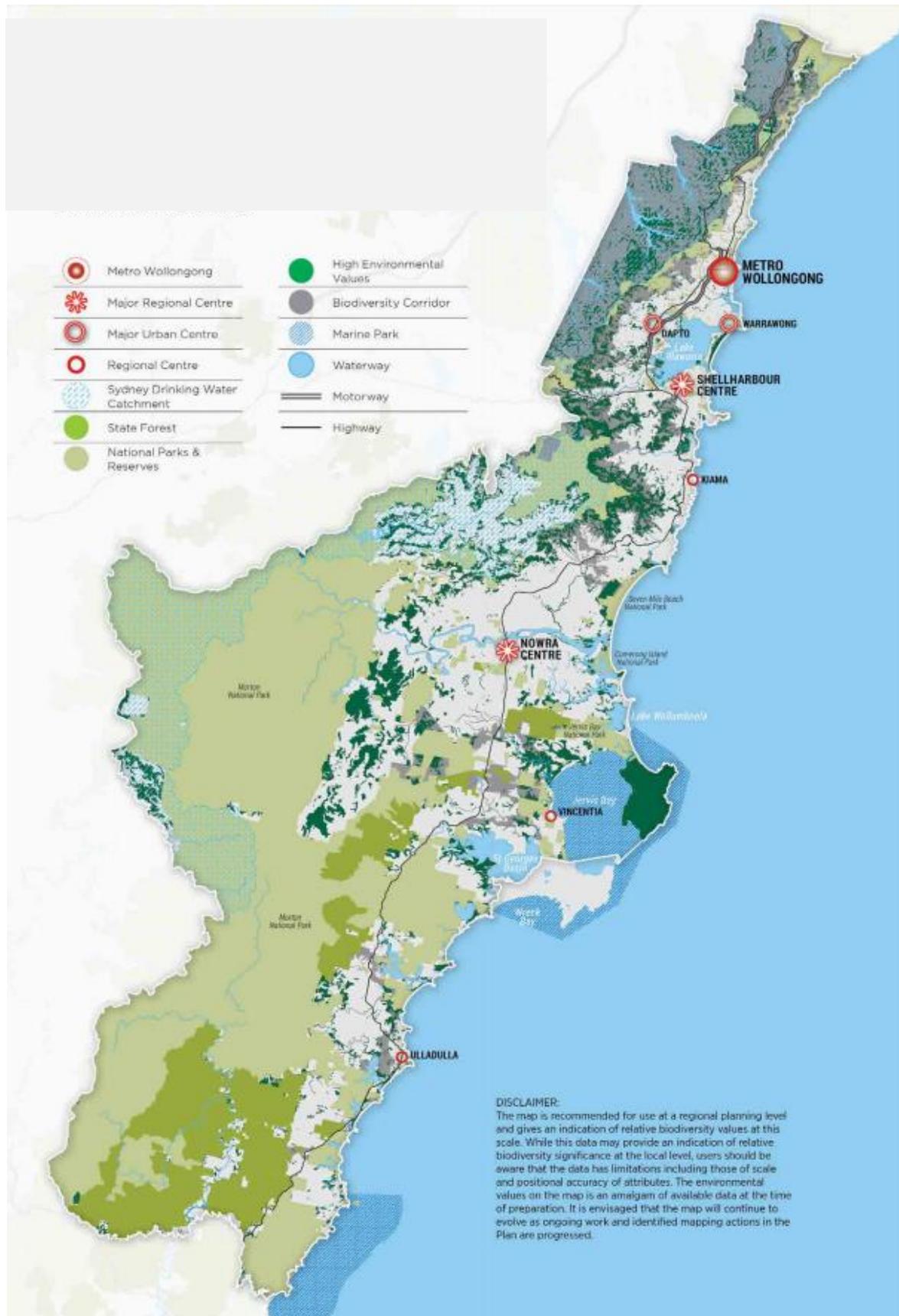
- 1) A prosperous Illawarra-Shoalhaven.
- 2) A region with a variety of housing choices, with homes that meet needs and lifestyles.
- 3) A region with communities that are strong, healthy and well-connected.
- 4) A region that makes appropriate use of agricultural and resource lands.
- 5) A region that protects and enhances the natural environment.

The main goals pertaining to urban ecology and biodiversity are Goal 3 and Goal 5.

Under Direction 3.3, the NSW Government will encourage councils to use the 'Neighbourhood Planning Principles' when preparing LEPs and DCPs for new release areas, as well as in strategic planning for town centres. The Neighbourhood Planning Principles contain clauses targeting the maintenance of conservation lands in and around development sites to protect biodiversity and provide open space, as well the minimisation of impacts on the health of aquatic systems.

Under Direction 5.1, High Environmental Values maps (**Figure 4.5**) will be used to identify environmental assets and areas of high environmental value that need to be protected, and to adjust developments in these areas to avoid or mitigate potential impacts (NSW Department of Planning and Environment, 2015, Action 5.1.1). Direction 5.1 also contains specific actions related to the protection of biodiversity and riparian lands.

**Figure 4.5.** Illawarra-Shoalhaven’s environmental values: demonstrating relative biodiversity values and significance in the Illawarra-Shoalhaven region. It is envisaged that the map will evolve as the region’s plan progresses. Source: NSW Department of Planning and Environment (2015b).



Action 5.1.3 ('Protect the region's biodiversity corridors in local planning controls') is intended to maintain and enhance biodiversity corridors to protect and enhance the ecology of the region. Under the action, councils will need to 'clarify the location of a biodiversity corridor when planning new development and consider other appropriate land uses within the corridor to maintain and, where possible, enhance ecological connectivity' (NSW Department of Planning and Environment, 2015, Action 5.1.3).

Action 5.1.4 ('Create a consistent approach to protect important riparian areas in planning and development controls') is intended to 'maintain water quality, and provide habitat and links for native species and communities' (NSW Department of Planning and Environment, 2015, Action 5.1.4). As part of the intended action, the NSW Government will review all riparian management outcomes in the region to ensure they are applied consistently in LEPs.

### **Other plan-making under the EP&A Act**

Part 3 of the EP&A Act enables plan-making, including environmental planning instruments (EPIs) and DCPs. EPIs are the primary regulatory instruments for development in NSW; they prescribe the types of development that can be undertaken and the circumstances in which they can take place. EPIs are mandatory matters of consideration for development assessment under s79C (1)(a)(i) of the EP&A Act. They are statutory and therefore carry the weight of the law.

There are two types of EPI: 'state environment planning policies' (SEPPs) and LEPs. Regional environmental plans are deemed to be SEPPs under an amendment to the EP&A Act in 2008 as a way of simplifying the planning system.

### **State environmental planning policies**

There is a multitude of SEPPs, but they can be classified as either setting state-wide objectives or development controls that may apply to a single lot or to a multitude of lots. **Table 4.3** identifies and summarises the current SEPPs relevant to urban ecology (Appendix A provides a deeper consideration of those SEPPs). SEPPs are considered superior to LEPs; where there is an inconsistency between a SEPP and a LEP, the SEPP prevails.

**Table 4.3** Basic outline and aims of relevant SEPPs. Source of abstracts: NSW Department of Planning and Environment (2016).

SEPP title	Abstract (NSW Department of Planning and Environment, 2016)	Objectives	Comments	Links
State Environmental Planning Policy No 19—Bushland in Urban Areas	<i>‘Protects and preserves bushland within certain urban areas, as part of the natural heritage or for recreational, educational and scientific purposes. The policy is designed to protect bushland in public open space zones and reservations, and to ensure that bush preservation is given a high priority when local environmental plans for urban development are prepared.’</i>	Aims to protect bushland (from habitats and natural landforms to wildlife corridors and endangered fauna and flora) within urban areas for their aesthetics and their value as natural heritage and recreational, education and scientific resources	Frames bushland preservation priority in LEPs for urban development	<a href="#">State Environmental Planning Policy No 19—Bushland in Urban Areas</a>
State Environmental Planning Policy (State Significant Precincts) 2005	<i>‘Defines certain developments that are major projects to be assessed under Part 3A of the Environmental Planning and Assessment Act 1979 and determined by the Minister for Planning. It also provides planning provisions for State significant sites. In addition, the SEPP identifies the council consent authority functions that may be carried out by joint regional planning panels (JRPPs) and classes of regional development to be determined by JRPPs. Note: this SEPP was formerly known as State Environmental Planning Policy (Major Projects) 2005.’</i>	Aims to facilitate development, redevelopment and/or the protection of significant urban, coastal and regional sites with specific economic, environmental and/or social value to the state	This policy prevails if there are inconsistencies with other environmental planning instruments (even if the other instruments were created before or after this one)	<a href="#">State Environmental Planning Policy (State Significant Precincts) 2005</a>
State Environmental Planning Policy (State and Regional Development) 2011	<i>‘The aims of this Policy are to identify development that is State significant development or State significant infrastructure and critical State significant infrastructure and to confer functions on joint regional planning panels to determine development applications.’</i>	Aims to identify state-significant development, or infrastructure and critical infrastructure that are state-significant. Joint regional planning panels are granted functions for the determination of development applications	This policy prevails if there are inconsistencies with other environmental planning instruments (even if the other instruments were created before or after this one)	<a href="#">State Environmental Planning Policy (State and Regional Development) 2011</a>
State Environmental Planning Policy (Urban Renewal) 2010	<i>‘The aims of this Policy are to establish the process for assessing and identifying sites as urban renewal precincts, to facilitate the orderly and economic development and redevelopment of sites in and around urban renewal precincts, and to facilitate delivery of the objectives of any applicable government State, regional or metropolitan strategies connected with the renewal of urban areas that are accessible by public transport.’</i>	Aims to institute site assessment and identification processes for urban renewal precincts	This policy prevails if there are inconsistencies with other environmental planning instruments	<a href="#">State Environmental Planning Policy (Urban Renewal) 2010</a>
State Environmental Planning Policy (Western Sydney Parklands) 2009	<i>‘The aim of the policy is to put in place planning controls that will enable the Western Sydney Parklands Trust to develop the Western Parklands into multi-use urban parkland for the region of western Sydney.’</i>	Aims to establish planning controls for the Western Sydney Parklands Trust to develop the Western Parklands into multi-use urban parkland	Includes aims for the protection and enhancement of natural systems (flora/fauna species and communities as well as riparian corridors) and ensuring that the Western Parklands are developed	<a href="#">State Environmental Planning Policy (Western Sydney Parklands) 2009</a>

in an ecologically sustainable way

State Environmental Planning Policy (Exempt and Complying Development Codes) 2008	<i>'Streamlines assessment processes for development that complies with specified development standards. The policy provides exempt and complying development codes that have State-wide application, identifying, in the General Exempt Development Code, types of development that are of minimal environmental impact that may be carried out without the need for development consent; and, in the General Housing Code, types of complying development that may be carried out in accordance with a complying development certificate as defined in the <a href="#">Environmental Planning and Assessment Act 1979</a>.'</i>	Aims to streamline development assessment processes with specific standards for development. Is related to other SEPPs and LEPs	Identifies specific types of development with minimal environmental impacts that do not require development consent	<a href="#">State Environmental Planning Policy (Exempt and Complying Development Codes) 2008</a> <a href="#">Exempt development Complying development</a>
State Environmental Planning Policy (Infrastructure) 2007	<i>'Provides a consistent planning regime for infrastructure and the provision of services across NSW, along with providing for consultation with relevant public authorities during the assessment process. The SEPP supports greater flexibility in the location of infrastructure and service facilities along with improved regulatory certainty and efficiency.'</i>	Aims to facilitate the delivery of infrastructure across the state	Identifies environmental assessment categories into which types of infrastructure fall (certain developments of minimal environmental impacts are identified as exempt from the policy)	<a href="#">State Environmental Planning Policy (Infrastructure) 2007</a>
State Environmental Planning Policy (Sydney Region Growth Centres) 2006	<i>'Provides for the coordinated release of land for residential, employment and other urban development in the North West and South West growth centres of the Sydney Region (in conjunction with Environmental Planning and Assessment Regulation relating to precinct planning).'</i>	Aims to provide controls for the sustainability of land with conservation value in growth centres as well as development controls to protect the health of waterways and enhance natural values	Specifically aims to provide land-use and development controls that contribute to biodiversity conservation	<a href="#">State Environmental Planning Policy (Sydney Region Growth Centres) 2006</a> <a href="#">growthcentres.planning.nsw.gov.au</a>
State Environmental Planning Policy (Building Sustainability Index – BASIX) 2004	<i>'This SEPP operates in conjunction with Environmental Planning and Assessment Amendment (Building Sustainability Index: BASIX) Regulation 2004 to ensure the effective introduction of BASIX in NSW. The SEPP ensures consistency in the implementation of BASIX throughout the State by overriding competing provisions in other environmental planning instruments and development control plans, and specifying that SEPP 1 does not apply in relation to any development standard arising under BASIX. The draft SEPP was exhibited together with draft Regulation amendment in 2004.'</i>	Aims to ensure consistency in implementing the BASIX scheme for sustainable residential development in NSW	State-wide application	<a href="#">State Environmental Planning Policy (Building Sustainability Index: BASIX) 2004</a>  <a href="#">BASIX website</a>
State Environmental	<i>'The policy has been made under the Environmental Planning and</i>	Aims to protect and preserve beach	Where development is carried	

Planning Policy No. 71—Coastal Protection	<i>Assessment Act 1979 to ensure that development in the NSW coastal zone is appropriate and suitably located, to ensure that there is a consistent and strategic approach to coastal planning and management and to ensure there is a clear development assessment framework for the coastal zone.'</i>	environments, native coastal vegetation and the marine environment of NSW. Also aims to encourage strategic coastal management	out in sensitive coastal locations, those applications must be referred to the Director-General for comment	
State Environmental Planning Policy No. 65—Design Quality of Residential Apartment Development	<i>'Raises the design quality of residential apartment development across the state through the application of a series of design principles. Provides for the establishment of Design Review Panels to provide independent expert advice to councils on the merit of residential apartment development. The accompanying regulation requires the involvement of a qualified designer throughout the design, approval and construction stages.'</i>	Aims to improve design quality for residential apartment developments in NSW. Includes aims for reducing energy consumption and providing environmentally and socially sustainable housing	This policy prevails where inconsistencies are found in other environmental planning instruments	<a href="#">State Environmental Planning Policy No 65—Design Quality of Residential Apartment Development</a>
State Environmental Planning Policy No 62—Sustainable Aquaculture	<i>'Encourages the sustainable expansion of the industry in NSW. The policy implements the regional strategies already developed by creating a simple approach to identify and categorise aquaculture development on the basis of its potential environmental impact. The SEPP also identifies aquaculture development as a designated development only where there are potential environmental risks.'</i>	Aims to develop sustainable aquaculture practices through minimum standards and a graduated environmental assessment regime and generally to expand permissible zones for aquaculture development	Relevant state-wide	<a href="#">State Environmental Planning Policy No 62—Sustainable Aquaculture</a>
State Environmental Planning Policy No 59—Central Western Sydney Regional Open Space and Residential (Repealed)	<i>'Rezones and coordinates the planning and development of certain land in the central west of Sydney. The policy provides for residential development in suitable areas on a precinct-by-precinct basis to help accommodate Sydney's population growth. It also provides for optimal environmental and planning outcomes, including the conservation of areas of high biodiversity, heritage, scenic or cultural value, implementation of good urban design, and providing for the extraction of resources from existing quarries in an environmentally acceptable manner. Note. The title of this SEPP was amended by SEPP (Western Sydney Employment Area) 2009 published 21 August 2009.'</i>	Aimed to rezone certain lands for urban development, coordinating planning and development	Aims to provide ideal environmental and planning outcomes via: implementation of good urban design; environmentally adequate operation of extractive industries; conserving areas of high biodiversity, heritage/cultural or scenic value, especially areas of remnant vegetation; and encouraging higher public transport usage and achievement of air-quality goals in NSW's Action for Air: the New South Wales Government's 25-year Air Quality Management Plan	<a href="#">State Environmental Planning Policy No 59—Central Western Sydney Regional Open Space and Residential</a>
State Environmental	<i>'Encourages the conservation and management of natural</i>	Aims to boost the quality of conservation	Includes a number of local	<a href="#">State Environmental</a>

Planning Policy No 44—Koala Habitat Protection	<i>vegetation areas that provide habitat for koalas to ensure permanent free-living populations will be maintained over their present range. The policy applies to 107 local government areas. Councils cannot approve development in an area affected by the policy without an investigation of core koala habitat. The policy provides the state-wide approach needed to enable appropriate development to continue, while ensuring there is ongoing protection of koalas and their habitat.'</i>	and management of vegetated areas that provide habitat for koalas as well as to reverse koala population decline and ensure permanent free-living populations	government areas in the study area <sup>28</sup>	<a href="#">Planning Policy No 44-Koala Habitat Protection</a>
State Environmental Planning Policy No 32—Urban Consolidation (Redevelopment of Urban Land) (Repealed)	<i>'States the Government's intention to ensure that urban consolidation objectives are met in all urban areas throughout the State. The policy focuses on the redevelopment of urban land that is no longer required for the purpose it is currently zoned or used, and encourages councils to pursue their own urban consolidation strategies to help implement the aims and objectives of the policy. Councils will continue to be responsible for the majority of rezonings. The policy sets out guidelines for the Minister to follow when considering whether to initiate a regional environmental plan (REP) to make particular sites available for consolidated urban redevelopment. Where a site is rezoned by an REP, the Minister will be the consent authority.'</i>	Aims to provide a policy for improving social, economic and environmental welfare in the state	Includes an aim to reduce urban sprawl on the fringes of existing urban areas	<a href="#">State Environmental Planning Policy No 32—Urban Consolidation (Redevelopment of Urban Land)</a>
State Environmental Planning Policy No 26—Littoral Rainforests	<i>'Protects littoral rainforests, a distinct type of rainforest well suited to harsh salt-laden and drying coastal winds. The policy requires that the likely effects of proposed development be thoroughly considered in an environmental impact statement. The policy applies to 'core' areas of littoral rainforest as well as a 100 metre wide 'buffer' area surrounding these core areas, except for residential land and areas to which SEPP No. 14 - Coastal Wetlands applies. Eighteen local government areas with direct frontage to the Pacific Ocean are affected, from Tweed in the north to Eurobodalla in the south.'</i>	Aims to preserve littoral rainforest areas in their natural state via a mechanism that considers applications for potentially damaging developments in those areas		<a href="#">State Environmental Planning Policy No 26—Littoral Rainforests</a>
State Environmental Planning Policy No. 14—Coastal	<i>'Ensures coastal wetlands are preserved and protected for environmental and economic reasons. The policy applies to local government areas outside the Sydney metropolitan area that front</i>	Aims to ensure the preservation and protection of coastal wetlands for the State's environmental and economic		<a href="#">State Environmental Planning Policy No</a>

<sup>28</sup> See Schedule 1 for full list (includes Sydney Metropolitan Areas, Wollongong, Newcastle and Lake Macquarie). Does not include land dedicated or reserved under the *National Parks and Wildlife Act 1974* or the *Forestry Act 1916* (as a state forest or flora reserve).

Wetlands	<p><i>the Pacific Ocean. The policy identifies over 1300 wetlands of high natural value from Tweed Heads to Broken Bay and from Wollongong to Cape Howe. Land clearing, levee construction, drainage work or filling may only be carried out within these wetlands with the consent of the council and the agreement of the Secretary of the Department of Planning and Environment. Such development also requires an environmental impact statement to be lodged with a development application. The policy is continually reviewed. It has, for example, been amended to omit or include areas, clarify the definition of the land to which the policy applies and to allow minimal clearing along boundaries for fencing and surveying.'</i></p>	interests	<a href="#">14—Coastal Wetlands</a>
State Environmental Planning Policy No. 1—Development Standards	<p><i>'Makes development standards more flexible. It allows councils to approve a development proposal that does not comply with a set standard where this can be shown to be unreasonable or unnecessary.'</i></p>	Provides flexibility in applying planning controls, especially where full compliance is unrealistic, unnecessary or contradictory with other environmental planning instruments	<a href="#">State Environmental Planning Policy No 1—Development Standards</a>

## Local environmental plans

LEPs are statutory land-use plans for local government areas (LGAs). LEPs are prepared by local councils and need to be approved and signed by the NSW Minister for Planning (or delegate) or relevant planning authority, including the GSC for the Greater Sydney Region. LEP must be developed in accordance with the prescribed process, including the preparation of a planning proposal and community consultation (EP&A Act, s59).

All councils in NSW have prepared LEPs using a standard template (known as 'standard instrument LEPs').<sup>29</sup> Standard instrument LEPs contain common definitions, land-use zones and administrative matters. When a standard instrument is made or amended it must be consistent with SEPPs. When an LEP seeks to address an inconsistency within a SEPP or a gap produced by a SEPP, or when a SEPP does not apply under certain circumstances, the LEP must include the variation in clause 1.9.

A standard instrument LEP has five major parts:

- 1) Preliminary – sets out requirements for name, aims, land to which plan applies, and other EPI-specific information.
- 2) Permitted or prohibited development – sets out the zoning and development requirements, including the land-use table.
- 3) Exempt and complying development – sets out exempt and complying development categories.
- 4) Principal development standards – sets out the structure for development standards, most of which are optional for each LEP.
- 5) Miscellaneous provisions – sets out the requirements for the acquisition authority, classification and reclassification of public land (in an LGA), as well as any additional sections (such as 5.9AA: 'Trees or vegetation not prescribed by development control plan').

The standard instrument LEP also contains five schedules for any required inclusions.

Under the EP&A Act, councils can include additional provisions in their standard instrument LEPs, as long as they do not conflict with existing mandatory provisions set out in the standard instrument. In this sense, the standard instrument sets the minimum requirements for operational LEPs. Additional provisions may also be included where these generally do not conflict with a SEPP; these may relate to minimum areas for landscaping but are not uniformly included or applied in a LEP.

Several aspects of the standard instrument LEP promote urban ecology and biodiversity principles. For example, clause 3.3.1 states that exempt or complying development does not apply in any environmentally sensitive area.

The standard instrument LEP contains four environmental zones that may be seen as providing a higher level of protection to what can be described as the core biodiversity assets of cities. The zones are: E1 'national parks and nature reserves'; E2 'environmental conservation'; E3 'environmental management'; and E4 'environmental living'. Each zone has specific objectives and prohibitions for conserving or managing land use. The land surrounding the zones and the corridors connecting them tend to have lower levels of biodiversity protection by way of the land-use zones and the permissibility of activities therein.

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<sup>29</sup> This refers to councils before amalgamation; at the time of writing, no amalgamated councils had consolidated their LEPs.

The standard instrument LEP contains optional clause 5.9 and compulsory clause 5.9AA, which replace tree preservation orders. Clause 5.9 enables a DCP (explained below) to contain lines for the preservation of trees and other vegetation. Clause 5.9AA allows trees or vegetation not covered by clause 5.9 to be ringbarked, cut down, lopped, removed, injured or destroyed without consent. Combined, these provisions signify a significant decrease in the protection of trees and other vegetation at the local government level. The extent to which these provisions protect and preserve trees and vegetation across an urban landscape at spatial (across various LGAs) and temporal scales (development application stage and throughout the life of the building) is unknown. The use of remotely based mapping and imagery could be used to quantify changes in vegetation over time. At a more detailed level, it would be necessary to triangulate such data with development consents and other regulatory actions to ascertain and distinguish between permitted and illegal clearing.

### Development control plans

DCPs are subordinate documents written by local governments to guide or facilitate development and give effect to environmental planning instruments (SEPPs or LEPs) that apply to a development. The contents of DCPs must not contain standards more onerous than those in the relevant EPs. DCP provisions can be broad in their application, and they can vary from council to council. DCPs are not legally binding on consent authorities. They are matters for consideration when assessing applications for development (NSW Government, 1979, s79(1)(iii)) and they may inform how a development is conditionally approved (with such conditions enforceable under the EP&A Act). DCPs are usually made by council resolution (NSW Government, 2000, reg 21), but they may be ordered to be created, altered or revoked under the EP&A Act (NSW Government, 1979, s75F).

A desktop survey of local-government DCPs identified examples of good practice that promote urban ecology (**Table 4.4**). Notably, councils that included environmentally orientated controls tended to have many examples of good practice. Moreover, the controls contained in those DCPs tended to reflect specific outcomes or needs of the local area and community, such as aspiring to have clean waterways or to maintain the 'green' character of a suburb.

**Table 4.4.** Summary of leading examples of urban ecology controls in council DCPs

Aspect	Provision	Reference
<b>Tree canopy</b>	15% canopy cover of a site within ten years of completion of a development	City of Sydney (2012b, Part 3.5.2)
	One tree per four car spaces in ground parking levels	
	Trees should provide at least 50% canopy cover over landscaped areas at maturity	North Sydney Council (2013, p. 9, Part 1.5.8)
Plant the largest-growing and longest-lived tree species appropriate to the site conditions		
<b>Deep soil zones</b>	30% (minimum dimensions 4m x 4m) for deep soil planting zone (for most multi-unit dwelling developments)	City of Parramatta (2011, Part 3.1.3)
	Deep soil zones should adjoin the deep soil zones of neighbouring properties where practicable so as to provide for a contiguous area of deep soil and vegetation	City of Parramatta (2011, Part

		3.3.1)
<b>Biodiversity landscaping adjacent to core bushland areas</b>	Properties abutting environmental conservation (E2) zoned land to be landscaped with local indigenous species to protect bushland and wildlife corridors and soften the interface between the natural landscape and the urban environment	City of Parramatta (2011, Part 3.3.1)
<b>Greenweb</b>	<p>Trees adjacent to threatened ecological communities are to be retained as a buffer. This does not apply to trees listed in the council's Weed Management Policy</p> <p>Species used for planting in or directly adjacent to Greenweb areas should be of local provenance</p> <p>Vegetation retention and rehabilitation must be designed to enhance and link existing vegetation and habitat within the site and within adjacent sites, biodiversity corridors and riparian lands</p> <p>Planting on land identified as 'Support for Core Biodiversity Lands' is to consist of: 100% locally native tree and understorey species within core riparian zones; not less than 70% locally native tree species and 30% locally native understorey species for all other areas; species that reflect the relevant vegetation communities within the area; and a mix of groundcover shrubs and trees and is to exclude monocultures</p>	Ku-ring-gai Council (2016, Section B Part 18)
<b>No net loss of biodiversity</b>	<p>No net loss of significant vegetation or habitat may be achieved by:</p> <ul style="list-style-type: none"> <li>• retention and protection of existing significant vegetation and habitat; or</li> <li>• informal compensatory measures: planting and habitat creation, especially where it improves connectivity; rehabilitation of degraded areas; or translocation of plants or soils</li> </ul> <p>Any proposal involving an offsetting mechanism, on or off site, must be in accordance with the following principles: 1) avoid, minimise and mitigate; 2) improve or maintain overall biodiversity; 3) like for like; 4) supplement existing protection and management; 5) enforceability; 6) the precautionary principle</p>	Ku-ring-gai Council (2016, Section B Part 18)
<b>Green roof</b>	Development applications for all new buildings and alterations and additions to existing buildings that involve the creation of new roof spaces that are generally flat must submit roof plans demonstrating how the new available roof space will contribute to the achievement of at least three of the following six objectives: 1) provide accessible roof space providing increased amenity for the occupants and visitors of the building; 2) improve the aesthetics and amenity of the urban environment (this particularly relates to the appearance of the roof when viewed from surrounding buildings); 3) provide space to accommodate renewable energy production; 4) improve stormwater management by controlling both the quality and flow of stormwater; 5) increase biodiversity by the use of plant material, and in particular to promote food production where appropriate; and 6) protect the building structure by increasing its thermal protection, which will also help reduce internal heating and cooling requirements	North Sydney Council (2013, Part 1.6.10)
<b>Stormwater controls</b>	Stormwater treatment targets for: residential development with five or more dwellings; commercial and industrial; subdivisions including five or more lots,	City of Parramatta (2011, Part

<p>and other developments where the roof area is great than 150m<sup>2</sup>:</p> <ul style="list-style-type: none"> <li>▪ Gross pollutants – 90% reduction in the post-development mean annual load of total gross pollutant load (greater than 5mm)</li> <li>▪ Total suspended solids – 85% reduction in the post development mean annual load of total suspended solids</li> <li>▪ Total phosphorus – 60% reduction in the post development mean annual load of total phosphorus</li> <li>▪ Total nitrogen – 45% reduction in the post development mean annual load of total nitrogen</li> </ul> <p>Hydrocarbons, motor oils, oil and grease – no visible oils for flows up to 50% of the one-year average recurrence interval peak flow specific for service stations, depots, vehicle body repair workshops, vehicle repair stations, vehicle sales or hire premises, car parks associated with retail premises, places of public worship, tourist and visitor accommodation, registered clubs and pubs</p>	<p>3 Table 3.1, adopted from the UPRCT WSUD Technical Guidelines for Western Sydney)</p>
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Common themes of good practice in these DCPs include the following:

1. They provide explicit targets or **minimum performance standards**. For many of the controls, these could be codified in a decision-support system as used for energy and water conservation via the BASIX SEPP and for stormwater quality through the model for urban stormwater improvement conceptualisation (also referred to as MUSIC) developed by eWater.
2. They recognise the importance of **scale, significance and connectivity**, for example using spatial mapping to identify important or ‘core’ natural areas and connecting corridors (as used by the Sutherland Shire and Ku-ring-gai councils). These spatially based approaches are already used in state policy for asset protection in the mapping of bushfire-prone lands mapping and the application of the 10/50 rule.
3. Many are based on sound **ecological principles** with supporting controls. There is an effort to demonstrate an evidence base as justification for the policy (notwithstanding the ‘guidance’ and non-enforceability nature of DCPs) and in turn the imposition of controls as part of development consent.

Like many policies, the effectiveness of DCP controls is often not measured or reported, a problem compounded by the discretionary nature of DCPs in the planning system. To ascertain the value of these ‘best practice’ controls in achieving their stated objectives, monitoring and evaluation within and between councils is necessary. Such an evaluation should be designed to reveal changes in actual development outcomes on the ground but also the political and institutional support for the policy. Questions to be addressed would be: Did the controls form part of the consent? Were they enforced as part of the building certification process? Have they maintained their effectiveness and impact over time?

Landscape plans could provide a foundation for improving urban ecological outcomes in the development application and, subject to conditional consent, the construction and approval phases. Requirements for landscaping could cover aspects such as setting minimum landscape areas, the

configuration of landscape areas (e.g. to support canopy trees or provide corridors to and within a lot), types of vegetation or species, and the provision of habitats for targeted species (see **Table 4.4**).

Although most development applications assessed under the EP&A Act require landscape plans or similar, not all require that the plans are prepared by a 'suitably qualified' person, and this 'best practice' could be pursued at the local government or even state level (via an environmental planning instrument) to increase the importance of landscaping and its contribution to urban ecology. A number of mandatory documents to be submitted with different types of development applications, such as BASIX certificates, stormwater plans and 'safety by design' plans, are required to be prepared by 'suitably qualified' consultants. The Parramatta Council requires landscape plans prepared by suitably qualified persons for a range of development types, such as dual occupation development, residential flat buildings, and developments abutting the public recreation zone, the environmental conservation zone and the natural waterways zone (City of Parramatta, 2011, pp. 50-74, P3.3).

For the purposes of comparison, **Box 4.3** provides a review of various council DCPs in relation to urban ecology controls, showing a high degree of variability between councils. Councils that have been amalgamated, such as Canterbury and Bankstown, will need to consolidate their planning controls in the near future, presenting an opportunity to reform and implement best practices to enhance urban biodiversity outcomes. As with many laws, policies, plans and controls, the relationship between what is required by whom at the development application stage, and what is implemented on the ground after consent, is largely unknown; this is an important and under-researched area of planning regulatory review.

**Box 4.3.** Development control plans with guidelines relating to urban ecology

**North Sydney Council DCP**

The North Sydney DCP contains several provisions directly related to urban ecology principles. The aims of the DCP specify that it should 'ensure ... development [that] is economically, socially and environmentally sustainable' (North Sydney Council, 2013, s 1.6(c)), and the general objectives for residential, commercial and mixed development all state 'innovative sustainable design to reduce energy and water consumption, [that] meets or exceeds sustainability requirements' should be incorporated (North Sydney Council, 2013, s 1.1.1 O9; s 2.1.1 O11; s 3.1.1 O6). Controls on landscaping have the encouragement of 'biodiversity conservation and ecological processes' (North Sydney Council, 2013, s 1.5.6 O1(k); s 1.5.8 O3; s 3.4.5 O1(k)) as part of its objectives, and provision for the encouragement of incorporating green walls into developments by Council, where appropriate (North Sydney Council, 2013, s 1.5.8 P11; s 3.4.7, p11).

There is a specific provision on the incorporation of green roofs in residential developments (North Sydney Council, 2013, s 1.6.10). Its objectives are to:

- Provide accessible roof space providing increased amenity for the occupants and visitors of buildings.
- Improve the aesthetics and amenity of the urban environment (this particularly relates to the appearance of the roof when viewed from surrounding buildings).
- Provide space to accommodate renewable energy production.
- Improve stormwater management by controlling both the quality and flow of stormwater.
- Increase biodiversity by the use of plant material, and in particular to promote food production where appropriate.
- Protect the building structure by increasing its thermal protection, which will also help reduce internal heating and cooling requirements.

The provisions of this section require that development applications for all new, generally flat-roofed

buildings and all alterations that involve the creation of new flat roof space must submit a roof plan demonstrating how the available roof space will contribute to three of the above objectives. In so doing, applicants must show the parts of the roof that will be used as a green roof immediately after construction or in the near future.

This section is replicated for commercial and mixed-use development (North Sydney Council, 2013, s 2.6.12; s 3.5.11). For these types of developments, however, the provisions are not limited to 'generally flat' roof spaces.

#### **Canterbury-Bankstown Council DCP**

The Canterbury-Bankstown Council DCP contains relatively little in the way of firm policies promoting or enforcing urban ecology. Despite the objectives of the DCP having specific regard for ecologically sustainable development, remnant vegetation and flora and fauna, and the site analysis principles referring specifically to urban ecology principles such as microclimate, tree canopy and habitat values, the DCP contains no other mentions of urban ecology-specific or associated environmental concepts in its zone controls.

#### **Blacktown City Council DCP**

The Blacktown DCP has little in the way of specific provisions regarding urban ecology. Ecologically sustainable development is mentioned as part of the DCP's general objectives (Blacktown City Council, 2015, part A cl 1.4(i)), and landscaping guidelines for both residential and industrial areas specify that ecological diversity and environmentally sustainable design principles should be considered (Blacktown City Council, 2015, part C cl 1.5; part E cl 6.3), but there are no specific provisions on these concepts. Area-specific sections of the DCP outline aims to protect riparian corridors and environmental sustainability (e.g. Blacktown City Council, 2015, part L cls 1.7.1a, c–d; part M cls 1b, 1.4). No provisions give effect to these or other urban ecology-related principles.

#### **Parramatta City Council DCP**

The Parramatta DCP has specific provisions related to urban ecology and biodiversity. Section 2.4.2.2 states that development should 'contribute to the protection and rehabilitation of waterways in order to improve waterway health and to develop and maintain ecologically sustainable waterways' (City of Parramatta, 2011, cl 2.4.2.2 O1). As a result, developments are generally required to make provisions for buffer areas and, where a development abuts a waterway, landscaping with local indigenous species is required to protect bushland and wildlife corridors and soften the natural–urban interface (City of Parramatta, 2011, p1, p2).

Part 2 of the DCP contains a section specifically on biodiversity (City of Parramatta, 2011, cl 2.4.7). Its objectives include:

- Minimising the impact of development on the city's biodiversity by:
  - minimising the removal of indigenous vegetation and naturally occurring soils
  - conserving existing significant indigenous and native trees
  - encouraging planting of indigenous and native plants and trees on private property
- Retention and protection of areas of existing biodiversity value, particularly key vegetation links and fauna corridors.

Within Part 2, several controls positively contribute to the protection of urban ecosystems. Provision 1 requires development to 'be sited and designed to minimise the impact on indigenous flora and fauna, including canopy trees and understorey vegetation, and on remnant native ground cover species' (City of Parramatta, 2011, p1), and preference is to be given to landscaping elements that provide and promote fauna habitat (City of Parramatta, 2011, p2). For land abutting either the environmental conservation zone or the natural waterways zone, the DCP requires that development take into account the provisions of the Bushland in Urban Areas SEPP and adds a required buffer zone (City of Parramatta, 2011, cl 2.4.7.2, p1).

Finally, as part of its other provisions, the Council states that it 'considers it important to carefully manage ... and to preserve the existing urban forest within Parramatta City Council Local Government Area for the purpose of establishing green corridors and maintaining the natural aesthetic values within the urban environment' (City of Parramatta, 2011, cl 5.4).

#### **Sutherland Shire Council DCP**

The Sutherland Shire DCP has a significant number of provisions related to the promotion and protection of urban ecology and biodiversity. The general requirements for multi-dwellings in Chapter 4 stipulate that developments retain existing canopy trees in the vicinity of setbacks and adjoining land, as well as the planting of canopy trees near boundaries (Sutherland Shire Council, 2015). Privacy fencing must be landscaped with screen planting, and any basement that extends beyond the building footprint must be planted (Sutherland Shire Council, 2015, ch 4, p10). Similar requirements are set out in for zoned areas, particularly B3 commercial core precincts (Sutherland Shire Council, 2015, chs 11, 14, 16, 17, 18, 19, 20, 23, 24, 26, 27, 28, 30), which also set minimum setbacks comprising deep soil landscaping (see e.g. Sutherland Shire Council, 2015, ch 7, p1).

In addition to zone requirements, the DCP sets out a comprehensive biodiversity and urban ecology strategy called Greenweb. Under Greenweb, 'core areas' are of high significance to sustainability because they contain key habitats or linkages, 'support areas' provide ancillary habitat areas or lands that form a buffer between developments and core areas, and 'restoration areas' provide opportunities for the establishment and vegetation of corridors between core areas.

The objectives for all Greenweb areas are:

- Prevent the direct loss of habitat in core and support areas by requiring the retention or restoration of areas of habitat in a size and configuration that will enhance long-term sustainability.
- Prevent the fragmentation of bushland by requiring the landscaped component of a site to function as a wildlife corridor, linking proximate areas of habitat.
- Improve the function of riparian zones and foreshores as natural areas so they provide linkages and corridors between areas of habitat.
- Minimise weed invasion and spread by requiring appropriate landscape treatment in Greenweb areas.
- Require revegetation of habitats or corridors so as to compensate for detrimental impacts accruing from the development of land.
- Use landscaped areas to re-establish corridors in urban areas through the establishment of canopy and groundcover links across properties.

Development controls apply to each Greenweb area. Developments in Greenweb core areas must maintain habitats in a size and configuration that ensures their ongoing viability and sustainability and must ensure connectivity between bushland remnants (Sutherland Shire Council, 2015). Development in Greenweb support areas must maximise habitat values and connectivity through continuous canopy and understorey planting and the retention and revegetation of remnant bushland areas. Developments in Greenweb restoration areas must contribute to the long-term strategy of establishing connectivity between bushland remnants through the planting of species indigenous to the locality and the retention of native canopy trees.

The DCP limits the types and sizes of trees and bushland vegetation that can be removed, with the overall objective of ensuring the retention and protection of trees and bushland vegetation important to the conservation of biodiversity in Sutherland Shire.

#### **Newcastle City Council DCP**

The Newcastle City DCP has a number of objectives and controls related to the promotion and protection of

urban ecology and biodiversity. The DCP controls related to landscape, open space and visual amenity contain several components with the general aim of providing habitat for native plants and animals and improving the microclimate (The City of Newcastle, 2012). These controls are in three categories:

- 1) Small-scale development with relatively little impact on the surrounding development. No landscape plan is required for category 1 developments.
- 2) Medium-scale development with potential visual significance and impact on the amenity of the host neighbourhood.
- 3) Large-scale development or development on prominent or ecologically sensitive sites with a high degree of visual significance and environmental impact.

For developments in categories 2 and 3, landscape plans must be submitted detailing the landscape strategy to be used to achieve the general aims.

The general controls also advise that existing trees and vegetation should be preserved, particularly street trees and those within front setbacks, and the existing tree canopy should be retained wherever possible. Finally, the landscaping provisions provide a set of controls on green roofs and wall spaces that apply to landscaping not on natural ground (as required for mixed-use residential development and non-residential development). These controls set out minimum soil depths as well as the requirement for green walls to be used on blank facades, the screening of lift overruns, plant rooms and air conditioning units with green cover (The City of Newcastle, 2012, 7.02.07).

## Development assessment

The purpose of the development assessment process is to ensure that proposed activities meet the requirements set out in the relevant EPIs and follow the process set out in the EP&A Act. A development application can be refused, approved, or approved with conditions. The consent authority varies depending on the type of development and can include:

- Minister for Planning – delegates determination to the Planning Assessment Commission.
- Planning Assessment Commission, which determines major developments as delegated by the Minister of Planning, such as state-significant development (SSD) and state-significant infrastructure (SSI).
- Planning panels – the existing joint regional planning panels, which previously determined development with a capital investment value of \$20 million or more and were among the bodies that made LEPs, will be reconstituted as six ‘planning panels’ in the Greater Sydney Region. These panels will retain the tasks of the joint regional planning panels, and their boundaries of authority will align with the new ‘districts’ that apply across greater Sydney. The planning panels, two of which are in place, are part of the GSC.
- Local councils – the majority of developments are assessed under Part 4 of the EP&A Act and are determined by local councils if under a capital investment value of \$20 million. The councils are created with jurisdictional boundaries set by the *Local Government Act 1993*.

Environmental assessment of development proposals occurs under part 4, part 5 or part 5.1 of the EP&A Act, depending on the type of development. Part 4 of the EP&A Act defines the categories of assessment and approval for private development in NSW, which are of three broad types:

- 1) Development permitted without consent (exempt development) (s76)
- 2) Development permitted with consent (‘local’) (s76A)
- 3) Prohibited development (s76B).

The category of exempt development is generally for minor building works or other development considered to have a low environmental impact. Types of exempt and complying development are set in the *SEPP (Exempt and Complying Development Codes) 2008* and the *Environmental Planning and Assessment Regulations 2000*, and additional types can be found in standardised LEPs. Exempt and complying development provisions prevent development from occurring on or within a certain proximity to land with recognised important natural values. For example, development is not to be undertaken within 100m of environmentally sensitive land.

Development permitted with consent is the most common form of development approval. One subcategory is 'integrated development', defined as development (not SSD or complying development) that requires one or more approvals under associated Acts, as provided by s91 of the EP&A Act. These include works requiring environment protection licences (*Protection of the Environment Operations Act 1997*, ss 43, 47-48, 55, 122), dredging and reclamation work (*Fisheries Management Act 1994*, s 201) and mining and production leases (*Mining Act 1992*, s 63-64, and *Petroleum (Onshore) Act 1991*, s 16).

Prohibited development is development prohibited under an EPI. For example, prohibited uses are listed or identified by the mechanism of absence in part 2 of standardised LEPs.

Depending on the category of development, an assessment of a proposal may be required. Part 4 developments requiring assessment and approval by a consent authority, and developments deemed to be exempt and complying, are subject to compliance with the relevant EPI or DCP.

Under the EP&A Act, any development or class of development can be declared by a SEPP to be an SSD (s 89C). The Minister of Planning may define specific development on specific land as an SSD. The consent authority for development defined as SSD is either the Minister or the Planning Assessment Commission (s 89D).

Under the EP&A Act, SSI is development that has been classified by a SEPP or by an order of the Minister amending a SEPP. The definition of infrastructure includes developments such as stormwater management systems, soil conservation works, public parks, and waterways (s 115T).

Part 5 of the EP&A Act includes the environmental assessment requirements for the Minister or the public authority that will be carrying out the development or will have it carried out on their behalf. The type of environmental assessment will vary according to the location and potential impact of the activity. It may require the Minister or public authority to prepare an environmental impact statement and to have regard for the critical habitats and vulnerable species listed in the *Threatened Species Conservation Act 1995* (TSCA; note, however, that this Act will be repealed by the *Biodiversity Conservation Act 2016*).

Most public agencies have their own internal guidelines for undertaking environmental assessments for proposed activities, either under Part 5 of the EP&A Act or for other more significant activities. Such guidelines might be supported by standard controls or operating procedures linked to an operating licence condition, as issued by the Independent Pricing and Regulatory Tribunal (IPART), a pollution reduction program issued by the NSW Environmental Protection Agency (EPA) or as a voluntary process developed within an agency.<sup>30</sup> Although some formal review processes exist for certain activities and programs, such as an operating licence (IPART) or pollution licence (EPA) review, compliance with guidelines and other controls is generally far from transparent or regular.

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<sup>30</sup> e.g. RMS Environmental Impact Assessment Guidelines (NSW Roads and Maritime Services, 2014b).

## Other NSW statutes relevant to the management and protection of urban ecology

### Local Government Act 1993

The *Local Government Act 1993* (LG Act) is the operational and administrative framework for local councils (NSW Government, 1993). The LG Act sets out provisions for public participation, reporting, and the exhibition of plans and policies, including development applications, and it aims to 'provide the legal framework for an effective, efficient, environmentally responsible and open system of local government in New South Wales' (NSW Government, 1993, s 7(a)). The LG Act sets out the requirements for the classification of public land as either community or operational, and it governs the use and management of community land (NSW Government, 1993, div 1).

The LG Act requires councils to develop and implement strategic planning in the form of community strategic plans (CSPs) (NSW Government, 1993, ss 402-407). CSPs sit above other council policies in the operational hierarchy of a council's functions, and they are intended to set out the main priorities and aspirations of councils, state agencies, community groups and individuals (NSW Premier and Cabinet, 2013). CSPs do not include controls or regulations, but they are written as the apex strategic documents for all operations of a council. No statutory context currently exists tying a CSP to the objectives of an LEP, although councils are required to ensure that their CSPs are consistent with state plans and policies, including regional or metropolitan and district-level plans. In theory, there should be a formal, statutory link between strategic land-use planning and community planning because this is where the management, coordination and regulation of public and private land intersect across and between levels of government.

CSPs inform the operations and reporting frameworks of councils, including four-year operational and asset plans and annual budgeting. Urban ecology initiatives in local council CSPs are common, demonstrating (in theory) that both communities and councils prioritise the natural environment. For example, Sydney City Council's CSP, *Sustainable Sydney 2030*, specifies 'green' as one of its targets, stating that the city intends to be 'internationally recognised as an environmental leader' with 'a network of green infrastructure to reduce energy, water and waste water demands' (City of Sydney, 2014a, p. 16). The City of Sydney Council has developed the Urban Ecology Strategy Action Plan in response to the CSP, which works to horizontally integrate all the council's relevant plans and policies (**Box 4.4**). Waverley Council has incorporated urban ecology management and conservation targets and strategies in its CSP. Waverley is an inner urban council and one of the most densely populated LGAs, and it has adopted a target of no further loss of remnant vegetation and to increase the quantity and quality of habitat cover on private and public properties (Waverley Council Strategic Plan 2013-2025 – Target E6). Although there is an obligation for councils to report on their outcomes at the end of their elected terms, effectively creating an accountability loop to the community on the actions agreed in CSPs and four-year operational plans, this relies on the existence of a robust monitoring and evaluation framework. Biodiversity and broader urban ecological outcomes remain poorly considered and executed elements of CSPs and their reporting.

**Box 4.4.** The City of Sydney Community Strategic Plan in action

Various policies and plans of the Sydney City Council are focused on achieving longer-term sustainability goals. Sydney's goal is to be a 'green, global and connected city'. **Figure 4.6** illustrates the relationship of current urban ecology policy initiatives. The Greening Sydney Plan (City of Sydney, 2012c) coordinates various projects and programs designed to increase tree canopy and landscape amenity and create new habitats. The Urban Ecology Strategic Action Plan (City of Sydney, 2014c) is framed around biodiversity restoration and conservation to create a liveable city. The Urban Forest Strategy set targets and outlines the means by which canopy cover will increase from 15.5% in 2013 to 27% by 2050. The Green Roof and Wall Policy (City of Sydney, 2014b) is designed to support – through leadership and education – the growth of green roofs and walls across the city. The Decentralised Water Plan (City of Sydney, 2012a) focuses on reducing the use of potable water, increasing the use of recycled water, and reducing the discharge of suspended sediments from stormwater by 50% and nutrients by 15% by 2030, with direct benefits for water quality in Sydney Harbour.

The Urban Ecology Strategic Action Plan is a ten-year initiative to address the significant reduction in vegetation and other natural features across the city (**Table 4.3**). The plan outlines two broad areas of intervention, and actions relate to priority sites and fauna, non-priority species, and general actions designed to be implemented across the City of Sydney organisation and the whole LGA. General actions are further categorised as:

- Park and streetscape maintenance
- Planning controls
- Staff and contractor engagement
- Community engagement
- Partnerships.

Each action has a timeframe and target for implementation. Progress is reported in quarterly environmental sustainability progress reports, annual state of the environment reports, and annual corporate plans. The strength of the Sydney City Council's approach in realising its vision for a green, global and connected city arguably comes from its multidisciplinary approach, which aims to engage the whole organisation, the development sector and the community. Under current state government planning laws and policies, which prevent councils from imposing mandatory controls through DCPs and other means, the council has approached the delivery of these initiatives using two approaches. For its own land and buildings, it is leading by example to deliver against its determined targets through internal processes and budgeting. For private land, it is engaging with the community and industry to address barriers to green roofs and walls, including by providing targeted education and research; for general landscaping, it is using established DCP controls to achieve desired urban ecological outcomes.



**Figure 4.6** Sydney City Green Global and Connected strategy and supporting plans and policies.

Table 4.5. Urban Ecology Strategic Action Plan objectives, targets and monitoring requirements. Source: The City of Sydney (2014).

Category	Objectives	Targets	Monitoring	Monitoring frequency
<b>Locally indigenous vegetation</b>	Protect, expand and improve condition of naturally occurring locally indigenous vegetation, including possible remnants	Area of naturally occurring vegetation maintained or increased from 2012 baseline of 2.7 hectares by 2023	Systematic flora surveys and vegetation mapping	Five-yearly
	Increase the extent of bush restoration sites across the LGA, and maintain sites in good condition	<ul style="list-style-type: none"> <li>• Area of bush restoration sites increased by 100 per cent from 2012 baseline of 4.2 hectares by 2023</li> <li>• Bush restoration sites characterised by well-established, structurally complex vegetation, free of weeds by 2023</li> </ul>	<ul style="list-style-type: none"> <li>• Mapping of bush restoration sites</li> <li>• Condition assessment</li> </ul>	<ul style="list-style-type: none"> <li>• As sites are established, with annual review</li> <li>• Monthly reporting, with annual review</li> </ul>
	Re-establish representative patches of the likely original vegetation communities	Representative patches of at least three of the likely original vegetation communities established by 2023	Systematic flora surveys and vegetation mapping	Five-yearly
<b>Fauna</b>	Protect and enhance sites that provide habitat for priority fauna species	Indigenous fauna species diversity maintained or increased by 2023 based on 2012 baseline of 87 confirmed species, comprising: <ul style="list-style-type: none"> <li>– 5 frogs</li> <li>– 11 reptiles</li> <li>– 63 birds</li> <li>– 8 mammals</li> </ul>	Systematic spring bird surveys, with opportunistic reporting of all fauna groups at other times	Annual
	Increase the distribution and abundance of priority fauna species across the LGA	Priority fauna species recorded from greater number of locations and in higher numbers compared to 2012 baseline by 2023	LGA-wide systematic fauna surveys	Five-yearly
<b>Habitat connectivity</b>	Improve habitat connectivity across the LGA, particularly between priority sites, and between identified habitat areas in adjoining LGAs	Progressive increase in number of habitat features for priority fauna species established along potential habitat linkages by 2023	Mapping of habitat features	Annual

### Major reform of NSW biodiversity legislation

Following a review of biodiversity legislation in NSW, the *Biodiversity Conservation Act 2016* (BioCon Act) (NSW Government, 2016a) was enacted in October 2016, the *Local Land Service Act 2013* (LLSA) was significantly amended, and the TSCA (NSW Government, 1995) and the *Native Vegetation Act 2003* (NVA) (NSW Government, 2003) were rescinded. Some mechanisms of the rescinded Acts relevant to urban ecosystem management were brought across to the BioCon Act and the LLSA, the operation of which, as they relate to ecological values in the urban context, are set out below.

### Biodiversity Conservation Act 2016

Assented to on 23 November 2016, the BioCon Act replaces the TSCA. Its purpose is to ‘maintain a healthy, productive and resilient environment for the greatest well-being of the community’ (S1.3). The regulations for this new Act are not yet written.

Similarly to the TSCA, the BioCon Act makes provision for the listing of critically endangered, endangered and vulnerable species and/or communities. It provides for areas of ‘outstanding biodiversity values’ to be identified and for actions such as the establishment of conservation agreements to be put into place to protect such land (s 3.4). There are mechanisms whereby

landholders and lessees can enter into conservation agreements or stewardship agreements with the NSW Government with the objective of conserving biodiversity values (see below). Conservation agreements are also provided for under the *National Parks and Wildlife Act 1974* (see below).

The BioCon Act provides for the establishment of the Biodiversity Conservation Program and the Biodiversity Conservation Investment Strategy, which aim to minimise the impact of key threatening processes. These processes are listed in Schedule 4 and include threats such as development-linked anthropogenic climate change; the clearing of native vegetation; escaped garden plants; and the loss of hollow trees. No detail is provided in the Act to indicate how these threats will be minimised.

The Biodiversity Offsets Scheme is incorporated in the BioCon Act at part 6 (see below), and new processes for the assessment of biodiversity are outlined in part 7. The objectives of the Act do not include an intent for the re-establishment or restoration of degraded ecosystems; the focus of biodiversity assessment is on the protection or mitigation of impacts on threatened and endangered species and communities.

#### Biodiversity offset scheme

The BioCon Act provides for biodiversity offsets. The regulations are yet to be written, but the BioCon Act indicates that the proposed offset scheme is similar to the BioBanking and offset scheme implemented in 2008 under the TSCA and the *Threatened Species Conservation (Biodiversity Banking) Regulation 2008*, which was designed to conserve biodiversity values. The new scheme identifies and provide for land to be set aside by way of stewardship agreements, and tradable biodiversity credits equal to the biodiversity of the land are identified. The scheme does not provide protection for sites in perpetuity, because credits can be 'retired' (part 6).

The offset scheme applies to development consents granted under part 4 of the EP&A Act (not including complying development, state-significant projects in part 5, and public works in part 5.1). Biodiversity assessment reports are required in the assessment of development; the forthcoming regulations will establish a biodiversity assessment method to outline the rules and methods for the creation of these reports.

There are important concerns about the use of biodiversity credits and offsets schemes. The existing approach lacks the evidence base needed to determine its effectiveness in delivering biodiversity outcomes (Hanford *et al.*, 2016; Maron *et al.*, 2016). A number of the assumptions underpinning the benefits of offset schemes lack evidence and rigorous testing (see Chapter 3). When biodiversity offset schemes have lacked an underpinning by sound ecological principles, the result has often been a loss of habitat. It is recommended that significant consultations with ecological experts are undertaken to maximise the potential for positive biodiversity outcomes and to minimise potential harmful outcomes. The review and monitoring of scheme efficacy is essential for minimising damage and maximising benefits in the long term.

#### Biocertification

Biocertification is a mechanism that 'switches off' the requirement for environmental assessment for individual development applications. Before enactment of the BioCon Act, this switching off also applied to the creation of strategic land-use plans, but this is no longer the case and biocertification will apply only to certain developments.

Part 8 of the BioCon Act seeks to implement biocertification for land so that environmental assessment requirements for SSI under part 5.1 of the EP&A Act, part 4 development requiring assessment, and activities under part 5 of the EP&A Act will not be required to undertake biodiversity assessment reports. Biocertification could apply at the lot and multi-lot level, bringing

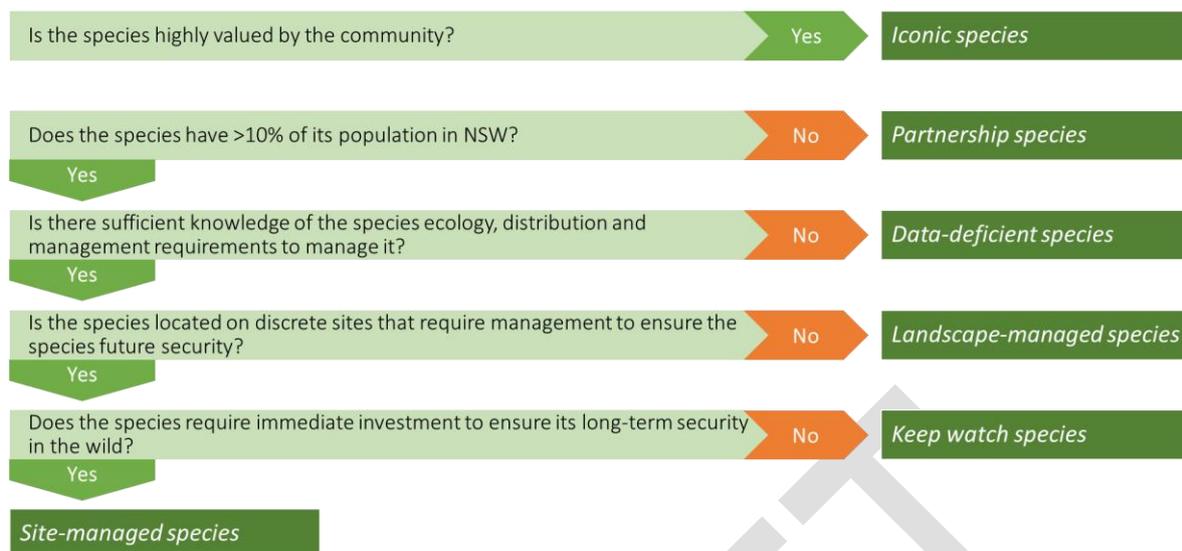
environmental assessment to the fore before development proposals are submitted to relevant consent authorities for consideration.

Any planning authority or landholder can make an application for biocertification (s 8.5). Certificates can be indefinite or for a given period, as stipulated by the Minister (s 8.10), who can review biocertificates. Biocertificates are registered on property titles.

### Saving Our Species program

In 2013, the NSW Government launched the Saving Our Species program as a means of prioritising expenditure linked to the protection of species and populations listed under the TSCA (NSW Government, 1995). There is no indication in either the BioCon Act or the relevant government website that this program will be amended or deleted. Its objective is to 'maximise the number of threatened species that are secure in the wild in NSW for 100 years, recognizing that species can only survive if managed for the long term'. In essence, this program responds to limited funding and other resources in environmental and land management agencies to manage listed endangered species or threatened ecological communities effectively.

The scheme has six 'management streams', through which it determines the actions needed to manage species identified under the TSCA as presumed extinct, critically endangered, endangered or vulnerable. The process for allocating species to one of the six management streams (presented in **Figure 4.7**) informs funding priorities. Tier 1 – the highest priority – is allocated to site management species, iconic species, and landscape-managed species. Tier 2 is allocated to data-deficient species, and tier 3 is allocated to partnership species and 'keep watch' species. Less clear under the program is how the prioritisation affects other agencies and levels of government in undertaking specific activities. In particular, a significant burden of responsibility rests with local governments as major public landowners and managers and regulators of private land through development control. The local government sector is already under significant financial pressure, and, through its own financial prioritisation processes, it is targeting its expenditure according to its own criteria, which may or may not relate to the Saving Our Species decision-making process. The process is further compromised by one-off or short-term external grants targeting regeneration and restoration, or the use of special rate variations through the LG Act to address outcomes that must be framed within a finite (1–7 years) period and therefore has limited capacity to address the cumulative and ongoing causes and pressures of urbanisation on natural systems.



**Figure 4.7.** The Saving Our Species management stream decision process. Source: NSW Office of Environment and Heritage (2013).

### Voluntary conservation agreements

Various types of voluntary agreements are used in NSW to enable landholders to voluntarily protect and conserve private land. These agreements can apply to urban areas and thus have been included here as options for the protection of urban ecology. An independent report (Byron *et al.*, 2014) identified the overlapping nature of these agreements on biodiversity legislation in NSW and recommended a consolidation of approaches (recommendation 21).

The BioCon Act provides for conservation agreements between the Biodiversity Conservation Trust (a new body) and landowners. These are voluntary agreements in perpetuity; they contain terms that bind landowners to ensure the conservation of ecological values. Private and public landholders can also have their land determined as wildlife refuges. Wildlife refuge declarations – legal agreements made under the *National Parks and Wildlife Act 1974* – are more flexible than conservation agreements. An even more flexible approach is the Land for Wildlife scheme, a non-binding agreement designed to support wildlife management but not bound to the title of the land. The impact of the BioCon Act on existing conservation agreements needs to be explored to ensure consistency and clarity between the old and new regimes.

### National Parks and Wildlife Act 1974

The *National Parks and Wildlife Act 1974* (NSW Government, 1974) is concerned with the care, control and management of national parks, historic sites, nature reserves, Aboriginal areas, state conservation areas, karst conservation reserves and regional parks. Each of these types of reserved land must be governed according to a set of management principles covered by the Act. Under the Act, the Chief Executive, who reports to the Minister for the Environment, is the authority for taking action to protect native flora and fauna, Aboriginal artefacts and places across NSW. As of July 2014, the NSW park system comprised 867 parks protecting 8.85% of the state (7,097,735 ha).

### Local Land Services Act 2013

The LLSA established the Local Land Services Corporation, which is tasked with ‘management and delivery of local land services in the social, economic and environmental interests of the State’ (NSW Government, 2013, s 3(a)). An amendment to the LLSA in November 2016 enables the repeal of the

NVA, which includes provisions to ensure development consent for the clearing of native vegetation. The LLSA amendment enables the clearance of native vegetation as complying development, with a provision for self-assessment codes and an increase in the discretion for clearing land.

'Local land services' are defined to include agricultural production, biosecurity, animal welfare, stock, and related services and programs. The amendment to the LLSA transfers oversight of native vegetation to the Local Land Services Corporation. The repeal of the NVA would place significant control of biodiversity conservation in the hands of the LLSA, which could be hamstrung if operational funding – not addressed in the amendment – is not secured.

The amendments to the LLSA make no specific reference to the need to take into account key threatening processes, as listed in the BioCon Act, suggesting a disconnect between these key pieces of legislation.

#### Fisheries Management Act 1994

The *Fisheries Management Act 1994* (FMA) (NSW Government, 1994) oversees the conservation of fish and marine vegetation and ecological communities. In particular, the Act aims to promote ecologically sustainable development and biodiversity while balancing viable commercial fishing and aquaculture industries. The functions of the FMA include licensing, closure periods, offences related to catch size and quantity, and the listing of threatened species and populations. In the context of this study, the FMA applies to all waters within the limits of the state and therefore applies to all bodies of water in cities.

The FMA and its supporting policy and guidelines for fish habitat conservation and management (NSW Department of Primary Industries, 2013) enable the Department of Primary Industry to regulate activities that affect the sustainability of fish habitats and populations and which have implications for human health through fish consumption. In urban areas, this can include banning or limiting certain fishing activities in polluted waters, such as around Homebush Bay (NSW Department of Primary Industries, 2017); regulating activities through licensing or approval conditions (such as prohibiting the disturbance of contaminated soils); and requiring riparian buffer zones to manage diffuse pollution. The FMA and supporting policies and guidelines recognise the impact of urban development on diffuse pollution in waterways, including roads and other infrastructure, and the important contribution of riparian buffers to ameliorate these pressures. Nevertheless, there is tension between the objectives of the Act and those of the *Water Management Act*, which sets the framework for a NSW riparian policy that substantially reduces riparian buffers in urban areas to support more land for urban growth (Ives *et al.*, 2010).

#### Nature Conservation Trust Act 2001

The *Nature Conservation Trust Act 2001* (NCTA) (NSW Government, 2001) establishes the Nature Conservation Trust of New South Wales (NCT), a non-government body corporate, the primary function of which is to facilitate the conservation of natural heritage on private land through the negotiation and administration of trust agreements (made under part 3 of the NCTA and between the NCT and landholders to manage land subject to the agreement and to protect natural heritage). Once an agreement is registered it binds the landowner's successors. The NCTA also informs how the NCT is to operate a 'revolving fund scheme' (s 7), which can also be used to buy or acquire land that is 'significant for the conservation of natural heritage' (s 7(1)(a)).

The NCT environmental land management stewardship program aims to reward landowners dedicated to private land conservation by giving support, guidance and environmental management advice. Trust agreements offer an altruistic alternative to landowners based more on a 'protect and

conserve' ideology than the 'trade and economic return' position offered by the BioBanking scheme. An evaluation and comparison of the merits and outcomes of the two approaches could offer insight to the long-term effectiveness of both, particularly when framed around long-term changes involving subsequent owners of affected properties.

### **Other decision-makers: state and semi-state authorities**

#### **Roads and Maritime Services NSW**

Roads and Maritime Services (RMS) has a crucial role in determining how roads and maritime networks are constructed and managed and their consequent impact on the local environment and particularly waterways. The EP&A Act prescribes environmental approvals for activities undertaken by the RMS and within the Transport for NSW cluster. Depending on their nature, proposed activities will be assessed under the EP&A Act and may be supported by relevant environmental planning instruments, such as SEPP (infrastructure) 2007 and SEPP (major projects) 2005. The NSW Government introduced these SEPPs to support and enable projects of state significance.

The RMS has prepared its own policies to inform the design, construction and maintenance of major projects, and these contain specific provisions for the protection and management of the natural environment. For example, *Beyond the Pavement* (NSW Roads and Maritime Services, 2014a) contains several provisions relating to urban ecology and biodiversity. Principle 5 ('Responding to natural pattern') is concerned with incorporating 'natural forms, materials and processes in the environment' into development (NSW Roads and Maritime Services, 2014a, p. 65). The principle recommends that road designs 'support local biodiversity and reinforce self-reliance and natural resilience' (NSW Roads and Maritime Services, 2014a). The selection and design of landscape planting and vegetation to reconnect natural systems and habitat, and the use of local landscape materials and treatments, is advised as a way to 'restore [and] replace natural system linkages' (NSW Roads and Maritime Services, 2014a, p. 67). The guide advises the use of seeding and the planting of native species, water-sensitive design (NSW Roads and Maritime Services, 2016) and the use of local natural materials to help recover biodiversity and create habitat. At a higher level, the document positions itself as setting design outcomes and principles intended to be 'equally applicable to all infrastructure and not simply roads and maritime projects'. The extent to which the principles have been applied in practice, and the extent of evaluations on their impacts on the environment, are less transparent.

#### **Transport for NSW**

Transport for NSW is the lead agency for transport agencies in NSW, with responsibility for strategy, planning, policy, regulation, funding allocation and other non-service delivery functions for all modes of transport in NSW, including road, rail, ferry, light rail, point-to-point, regional air, cycling and walking. Transport for NSW is responsible for the State Transport Master Plan, which is intended to 'guide the NSW Government's transport funding priorities over the next 20 years', serving as an 'overarching framework that guides subsequent and more detailed transport plans, policy decisions, reforms and funding decisions' (Transport for NSW, 2012). The State Transport Master Plan contains several provisions related to the promotion and protection of urban ecology and biodiversity, and it links to regional land-use plans developed by the Department of Planning. Relevant actions in the State Transport Master Plan include:

- Action 8.3 – 'Promoting sustainability and protecting the environment' – is aimed primarily at protecting natural assets and surroundings as the transport network is upgraded. As part of this action, the Master Plan suggests that 'in some places, we have to accept restrictions on our travel options' to preserve important habitats, species or biodiversity.

- Action 8.8 – ‘Protecting the environment’ – sets out four goals related to urban ecology and biodiversity principles. Goal 1 aims to develop a ‘coordinated Transport Environmental and Sustainability Policy Framework’ intended to comprise governance arrangements such as targets, measures and action plans to deliver positive environmental outcomes. Goal 2 aims to develop an environment and sustainability plan for transport, comprising governance policies for monitoring and reporting on environmental sustainability across the portfolio. Goal 3 relates to the intent to develop and promote design guidance for sustainable transport infrastructure, as well as to trial industry examples such as the Australian Green Infrastructure Council’s Infrastructure Sustainability Tool to test their suitability as benchmarks. Goal 4 sets out an intent to incorporate sustainability principles into Transport for NSW’s procurement policy, including setting minimum design standards for sustainable design and infrastructure.

There seems to be no specific monitoring and evaluation criteria for assessing the environmental performance of agencies in this transport cluster. Performance reporting is focused narrowly on transport reliability, and the most recent annual report (Transport for NSW 2016 Annual report 2015-2016) does not list any metrics or outcomes related to environmental achievement as part of infrastructure works or maintenance programs.

#### Rural Fire Service and bushfire protection

The EP&A Act and the *Rural Fires Act 1997* were reviewed to address the protection of property from bushfires in NSW, which is managed through the planning and development process at both the strategic planning and consent stages of development. Land may be deemed to be in a ‘bushfire prone area’ if identified on a ‘Bush Fire Prone Map’ for the relevant LGA. Depending on the category of vegetation, a landowner may or may not be able to develop their land, including by making changes to existing property. The NSW Rural Fire Service’s Planning for Bush Fire Protection 2006 must be taken into account when a LEP or DCP is made and by a consent authority if the proposed development requiring consent is located in bushfire-prone lands. ‘Principles of protection’ are included as a performance guide for development in bushfire-prone areas, including the use of trees as a measure to protect property and the incorporation of ‘asset protection zones’ whereby the fuel load created by trees and vegetation is to be reduced to enable separation between buildings and bushfire hazards.

Bushfire assessments for urban release areas have been streamlined so that they are undertaken at the subdivision stage. This eliminates site-by-site or individual lot-based assessments, which previously would have been triggered by single development proposals. Bushfire assessments for urban release areas are based on the Bush Fire Prone Maps, which can be updated by the Commissioner of the Rural Fire Service.

In response to bushfires in NSW in 2013, the NSW Rural Fire Service, the Department of Planning and Environment and the Office of Environment and Heritage developed and subsequently amended the *10/50 Vegetation Clearing Code of Practice for New South Wales* (NSW Rural Fire Service, 2015). This code of practice enables the clearing of natural vegetation on properties located in designated areas. The 10/50 code of practice has statutory force under Section 100Q of the *Rural Fires Act 1997*.

In essence, the 10/50 code of practice (or ‘10/50 rule’) permits landowners, without consent, to remove trees within 10m and to thin other vegetation such as shrubs and underlying vegetation, but not trees) within 50m of an external wall of a building such as a home or other type of residential accommodation or high-risk facility. Restrictions apply to the 10/50 code of practice; for example,

types of vegetation that cannot be cleared include listed wetlands, specified koala habitat, critically endangered plants, and specified endangered ecological communities, national park lands, and specific biocertified lands.<sup>31</sup> The 10/50 code of practice does not apply to complying development, and nor can it be undertaken contrary to any conditions of development consent, any instrument under Section 88B of the *Conveyancing Act 1919*, Land and Environment Court orders, or other orders, stop work orders, interim protection orders or remediation directions.

The 10/50 code of practice is an example of the unintended consequences of urban development in and adjacent to significant bushland or other natural reserves. Its primary focus is to protect property, not enhance biodiversity outcomes; accordingly, it is inconsistent with ecological outcomes. Many landowners have used it to clear canopy trees and understorey vegetation, regardless of bushfire risk, consequently compromising the ecological connection between large core natural areas such as national parks to the urban environment. Although Sydney, Wollongong and Newcastle are bushfire-prone, the long-term efficacy of the 10/50 code of practice should be subject to ongoing evaluation to close the policy gap between protecting property and supporting ecology in cities.

#### 4.5 Biodiversity law review

The Independent Biodiversity Legislation Review Panel, referred to as the 'review panel' in this section, released a review of biodiversity legislation in NSW in 2014 (Byron *et al.*, 2014). The review looked at the past 40-50 years of biodiversity legislation in NSW and made general observations on legislations in other Australian states and internationally.

In the review, Byron *et al.* (2014) pointed to an article by Farrier *et al.* (2007) comparing regulations for clearing native vegetation in urban versus rural areas, which suggested a discrepancy between the two: 'decision making in urban areas takes into consideration social and economic factors, whereas rural landholders are subject to stricter rules that require environmental outcomes to be improved or maintained at a site scale' (Farrier *et al.*, 2007; Byron *et al.*, 2014, p4, p18). The review panel suggested amending the NVA to relax regulations for rural landholders.

The preservation of larger ecosystems, especially near urban areas, is essential for maintaining healthy populations of native species requiring relatively large areas of habitat. The relaxation of rural regulations to align them with urban regulations may be counterproductive. Rather, urban regulations should be amended to provide stricter requirements relevant to their urban context. The review panel recommended biodiversity certification to be applied to 'all forms of development in both urban and rural contexts' (Byron *et al.*, 2014, p. 12).

Existing laws and policies have sought to achieve urban ecological outcomes through mechanisms such as Biobanking or offsets that place a financial value on bushland areas otherwise unrecognised in development decisions. Ecologically, offsetting has significant shortcomings, and many argue there is little to no evidence that, as a policy, it advances ecological outcomes. The utility of offsetting is best considered, however, from a socioeconomic viewpoint. As Farrier *et al.* (2007) pointed out, the socioeconomic factors in planning decision-making are given significant weight, and offsetting policies can offer important opportunities to include the natural environment in planning and development decisions, although they are not necessarily ideal. The review by Byron *et al.*

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<sup>31</sup> Section 7.8 of the *10/50 Vegetation Clearing Code of Practice for New South Wales* (NSW Rural Fire Service, 2015)

(2014) into the application of offsetting under NSW biodiversity laws showed that there is a lack of consistency in securing offset sites; long-term biodiversity management is not guaranteed at offset sites; and the varied methods of obtaining offsets creates uncertainty and inconsistency for landholders and advocates (Byron *et al.*, 2014, pp. 36-37).

Consistency in planning and biodiversity laws and policy is important. If urban ecology principles are to be promoted in urban areas in NSW, the principles underpinning reforms need to be reflected coherently and applied consistently in the strategic and statutory application of land-use planning and biodiversity management. The review panel emphasised the need to incorporate any new biodiversity legislation into the planning system, highlighting 'the need to avoid duplication of effort and provide more upfront certainty' (Byron *et al.*, 2014, p. 6).

Initiatives that incorporate educational and incentive measures can demonstrate more success in achieving biodiversity goals than regulation alone (Byron *et al.*, 2014). Policies and programs that use a combination of regulatory, incentivising and educational measures are more likely to achieve urban ecology and liveability goals, but this would require an updating of existing regulatory frameworks that do not incorporate newer legal developments in biodiversity conservation best practice (Byron *et al.*, 2014, p. 6). An example of a more integrated approach is the City of Sydney's Urban Ecology Strategic Action Plan and Native Vegetation Benchmarking Study. These have applied new technologies such as spatial information mapping and education-based policy to serve as a catalyst for change (and they also reflect the legal limitations of enforcing local government DCPs and other policy approaches). Local governments are leading in many areas of urban ecology reform, albeit restricted to those governments' scope of legal power and influence.

NSW is well placed to preserve remnant patches of vegetation. Data from the National Vegetation Information System<sup>32</sup> demonstrate that more remnant vegetation is available in the study area (i.e. the coastal area of the Sydney Basin) than in other urban centres on Australia's east and southeast coast, which have been extensively cleared. The extent of fragmentation of native vegetation in Australia means that remnants are vulnerable and their preservation is important; equally important is enhancing connectivity (e.g. by creating wildlife corridors) between patches of remnant vegetation to sustain species requiring larger territories than can be found in most urban areas.

The Nature Conservation Trust's environmental land management stewardship program aims to reward landowners dedicated to private land conservation by providing support, guidance and environmental management advice. Although the focus is on rural land, the Nature Conservation Trust has made materials available on environmental management and ecological assessments that could also be relevant to conservation efforts in urban areas.

### ***Growing green guide 2014 – the Victorian experience***

The *Growing green guide 2014* (Francis *et al.*, 2013) was written for Victorian local councils, stakeholders in the building industry, the Victorian Government's Department of Transport, Planning and Local Infrastructure, and any potentially interested parties supporting a significant increase in the number of green roofs, green walls and green facades. The guide is based around four principles (Figure 4.8):

- 1) **Exemplify** by demonstrating shared responsibility and leading by example.

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<sup>32</sup> The National Vegetation Information System is the OEH's data system for information on Australia's distribution and extent of vegetation.

- 2) **Enable** specifically by investigating whether barriers can be removed and/or the process can be simplified so as to facilitate community ownership and grassroots initiatives.
- 3) **Encourage** through the use of incentives or influential regulations.
- 4) **Engage** the community and individual stakeholders by getting them involved in and aware of green infrastructure and its benefits.

The aim of this approach is to demonstrate the role of government in leading by example, committing to the development of green infrastructure on public buildings and supporting demonstration roofs on private buildings with public access (e.g. shopping centres and university campuses). The guide advises government agencies to show consistency in their policies and strategies, including at different levels of government (e.g. all relevant council policies should support or at least not discourage green infrastructure). The enabling elements emphasise the importance of policy consistency (vertically and horizontally across neighbouring councils) to

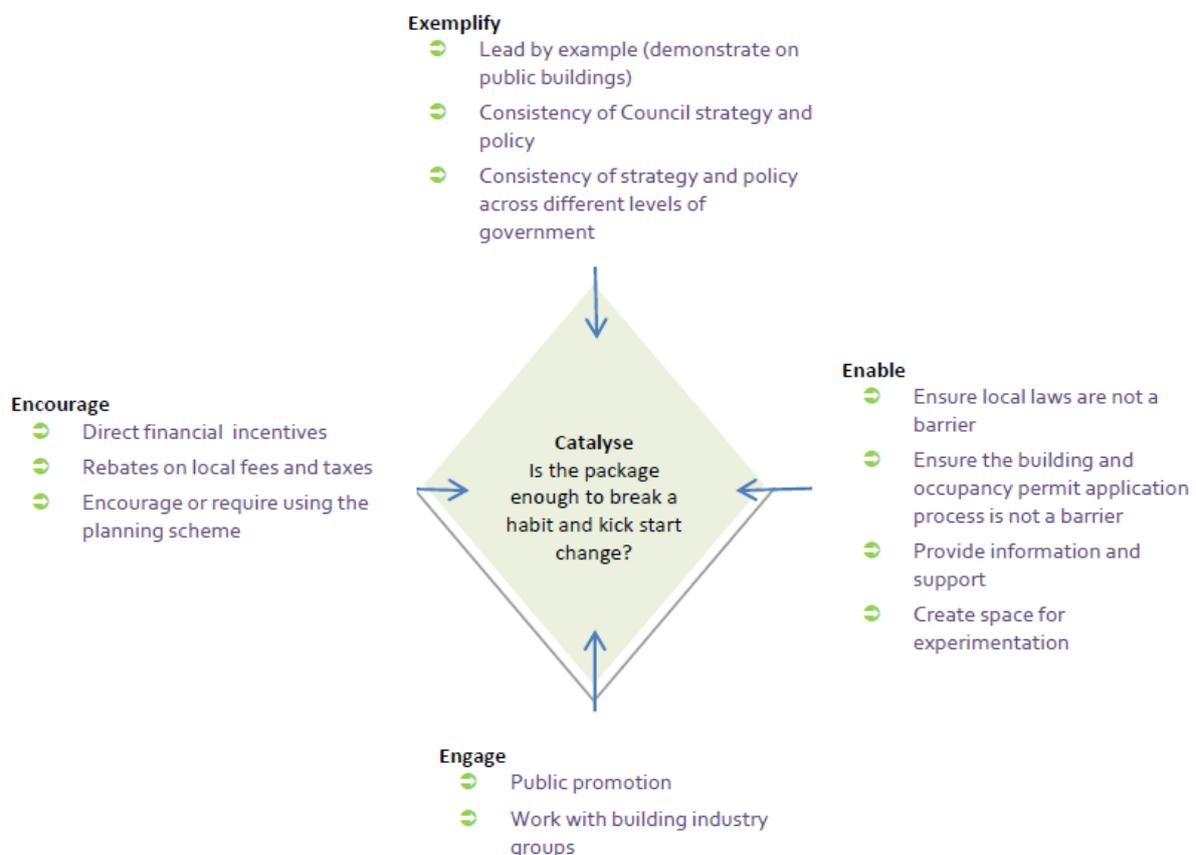


Figure 4.8. The four categories of policy options, with 12 options mapped out. Source: Francis *et al.* (2013).

encourage green infrastructure across a region. Enabling policies are essential for removing potential barriers (e.g. lack of information or capacity to mobilise) and may include providing free information, creating space for and supporting experimentation and innovation around green infrastructure, and providing support services for residents, grassroots initiatives and businesses with special interests in green infrastructure development or urban biodiversity and ecology.

Direct financial incentives can provide a catalyst to encourage individuals to retrofit existing buildings with green infrastructure or include it in new developments. Subsidies, grants and loan programs can include rebates of part or all of service fees (e.g. fees for the offsite treatment of

stormwater runoff). Other agencies, such as water authorities, may also have opportunities to provide incentives (e.g. rebates to property owners charged with annual drainage fees). Reference to specific types of green infrastructure in planning schemes may encourage developers to adopt them and provide guidance in assessing planning applications. There are hurdles to the use of financial incentives, however, which must pass regulatory review processes such as those of IPART.

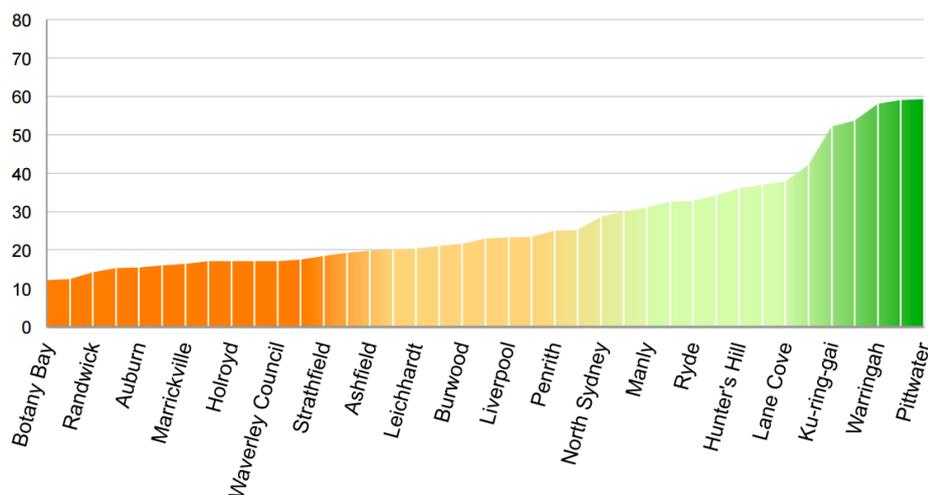
Councils can raise awareness through public promotion and by encouraging public discussion, for example through the media and sensitisation campaigns, e-tools, special events, competitions and demonstration projects. The goal is to give visibility to and promote green infrastructure and its environmental and human benefits. Working with groups in the building and planning industry and multiple councils to develop joint positions on green infrastructure can nurture conversations among relevant stakeholders and help in incorporating green infrastructure in appropriate building ratings and assessment products (e.g. Building Code of Australia, Green Star, STORM, National Australian Built Environment Rating System).

### **Vegetation cover benchmarking Study**

In 2014, the Institute for Sustainable Futures released a report benchmarking Australia's urban tree canopy (Jacobs *et al.*, 2014). For NSW the study included 39 LGAs representing 58% of the population in the Greater Sydney Region and the urban LGA in Newcastle. The i-Tree assessment used four categories of land cover – tree cover; shrub cover; grass and/or bare ground; and hard surfaces – based primarily on height as a surrogate for ecological functions and opportunities. For example, trees, shrubs and the grass layer can be defined as green space, but each serves different ecological functions. Bare surfaces can provide insight into the potential to increase vegetation cover.

In the study area, the range of canopy cover went from a high of 59% in Pittwater to a low of 12.1% in Botany. In Sydney's urban LGAs, canopy cover was assessed at 36% tree, 34% grass/bare ground, 20% hard surface and 10% shrub cover. **Figures 4.1 and 4.9** show the percentage canopy cover across LGAs in the greater metropolitan Sydney area.

The highest proportions of tree cover (>50%) were in LGAs north of greater Sydney, including Ku-ring-gai, The Hills, Warringah and Pittwater. These all have large areas of remnant bushland, including national parks (Berowra Valley National Park; Ku-ring-gai Chase National Park; and Garigal National Park), meaning high absolute levels of tree cover (e.g. Hornsby Shire's tree canopy cover exceeded 273km<sup>2</sup>).



**Figure 4.9.** Canopy cover (%) for selected NSW LGAs. Source: Jacobs *et al.* (2014).

Fifteen urban and peri-urban LGAs had less than 20% tree cover. These included a ‘corridor’ stretching from the coast to Fairfield and Blacktown in the western parts. The inner city and the densely populated City of Sydney, Marrickville and Rockdale LGAs had both low tree cover and relatively high percentages of hard surfaces (up to 69%). Although these LGAs have comparatively small land areas, they share important boundaries to the north and south of the city, with large contiguous vegetation cover linking across the centre of the Sydney Basin.

The value of the Vegetation Benchmark Canopy Study and future vegetation assessments is that they can identify where vegetation is needed (either to augment core areas or for linking corridors) or being lost (thus requiring policy reform) and to quantify gains (and enable the identification of the actions or policies that are working and expanding these). Such assessments also help in quantifying the outcomes of urban forest strategies (such as Sydney City Council), assessing the impacts of clearing (such as for new development areas or lands within the 10/50 clearing zone) and quantifying cumulative changes in vegetation structure (such as in infill development and the adequacy of tree preservation orders). There is an opportunity using existing spatial mapping techniques to expand vegetation mapping to include ground-storey and mid-storey vegetation and thereby better inform urban ecology policy and practice. At a strategic planning level, vegetation mapping datasets should inform metropolitan-to-local planning to enable the preservation of significant vegetation and plan for future biocorridors; such data can also be used with demographic data to assess the impacts of urban greening on socioeconomic factors.

## 4.6 Environmental regulation through environmental planning instruments

IPART provides advice to the NSW Government on pricing and regulation, including on the impact of development charges arising from environmental policies. Good-practice regulatory principles, as applied by IPART, can be used to examine the implications of planning and policy reforms that may affect industry, consumers and the community by (IPART, 2006):

- Identifying the problem and the desired objective(s) or outcome(s), and establishing a clear case for action.
- Considering the options (regulatory and non-regulatory) for achieving the desired outcome(s).

- Assessing the impacts (costs and benefits) of each option for consumers, industry, government and the community.
- Consulting with those potentially affected and developing the regulatory action with the participation of the community.
- Deciding among the alternatives, on the basis of transparent criteria, and adopting the option of greatest net benefit to the community.
- Developing a strategy to implement, enforce and review the preferred regulatory action to ensure regulation is relevant and effective over time.

The purpose of this review is not to provide a regulatory impact assessment of possible reforms. Chapters 3 and 5 can be used, however, as a first step in demonstrating a ‘case for action’. This chapter, and the Byron *et al.* (2014) review, clearly point to the shortcomings of existing frameworks, which have been unable to arrest declines in urban ecosystems.

In the NSW planning system, SEPPs are statutory planning instruments that can modify local planning controls. SEPP 19 (‘Bushland in urban areas’) is the major EPI of direct relevance to urban ecology because it is framed around protection and preservation. Like many older SEPPs, it does not require or mandate prescriptive controls, and nor does it codify planning rules to achieve its objectives. Further, SEPP 19 has no quantifiable targets through which to measure its success.

SEPP 19 is scheduled to be reviewed by the NSW Department of Planning in 2017. This review provides an opportunity to:

- Broaden its focus from bushland in urban areas to advancing urban ecological outcomes across various public open-space zones (as established under the EP&A Act) and land classification (LG Act), incorporating parklands, streetscapes and replanted areas and integrating with landscaping requirements for private lands.
- Expand the geographic scope of the SEPP to include major cities and centres, within which areas of bushland and other important ecological systems are threatened or otherwise affected by urban development.
- Expand the spatial extent from ‘land adjoining’ to ‘land affected or influenced by’ in identified urban ecology areas (for example, this may incorporate buffer-style areas of influence, as applied to land affected by bushfire risk).
- Integrate terrestrial, riparian and aquatic systems into decision-making processes focused on addressing threatening processes.
- Linking the SEPP to planning decisions at a strategic level (such as proactive initiatives like the Sydney Green Grid) and statutory-level controls (for example as achieved via BioBanking).
- Reconcile conflicting outcomes associated with the clearing or thinning of vegetation permitted under the *Planning for Bushfire Protection Guide* (NSW Rural Fire Service, 2006) and the 10/50 code of practice on vegetation clearing under section 100Q of the *Rural Fires Amendment (Vegetation Clearing) Act 2014*.
- Set measurable targets to assess the short-term and long-term efficacy of the SEPP.
- Enable a hierarchy of considerations that place greater importance on the conservation and management of significant sites and locations (**Table 4.6**).
- Codify controls to support a performance-based approach (for example drawing on BASIX) rather than the current merit-based method.

- Increase the importance of the SEPP for its use and impact on and by public authorities, from the current 'have regard', which does not necessarily translate into positive bushland or urban ecological outcomes.

**Table 4.6.** Scale and temporal evaluation matrix for an urban ecology environmental planning instrument.

Scale	Purpose	Measure	How
<b>Regional/ district</b>	Long-term monitoring of biodiversity potential, as expressed by terrestrial vegetation	<p>Four-year (aggregating local datasets) reporting on:</p> <ul style="list-style-type: none"> <li>• % green cover in geographically defined area based on benchmark date</li> <li>• % green cover with identified regional and district corridors</li> </ul> <p>Annual reporting on:</p> <ul style="list-style-type: none"> <li>• % cover of endangered ecological communities</li> </ul>	<p>Spatial information via satellite or aerial photography imagery</p> <p>Should include LiDAR to differentiate vegetation layers</p> <p>Could include hyperspectral analysis to differentiate key species/natives/weeds</p>
<b>LCA</b>	Medium- and long-term monitoring	<p>Four-year reporting (aligning with council reporting cycle)</p> <ul style="list-style-type: none"> <li>• % green cover in geographically defined area based on benchmark date</li> <li>• % green cover with identified regional and district corridors</li> <li>• % cover of endangered ecological communities</li> <li>• Species inventory through ecological surveys</li> </ul>	<p>Spatial information via satellite or aerial photography imagery</p> <p>Should include LiDAR to differentiate vegetation layers</p> <p>Could include hyperspectral analysis to differentiate key species/natives/weeds</p>
<b>Lot</b>	Establish the foundation for urban ecology outcomes on private land	<ul style="list-style-type: none"> <li>• Landscaping requirements (including form of vegetation and species selection)</li> <li>• Setting maximum built-on area (including deep soil zones)</li> <li>• Promoting variable controls reflecting urban density and type of dwelling (high-rise green roof)</li> <li>• Linking to individual dwelling thermal comfort (BASIX) and neighbourhood comfort (e.g. UHI)</li> </ul>	Development assessment process (including capacity for exempt and complying development)

Other legal and policy approaches, such as those presented below, can also be applied to achieve urban ecological outcomes in cities.

- **Use spatially based planning targets and controls to provide specificity for current and future land-use decisions.**

For example, for developments or activities close to key habitats, landscaping and other site controls should seek to complement the ecological attributes of those key habitats and reduce direct impacts. This may require, for example, the increased use of native species (requiring less fertilizer use) and a greater variety of plant types (i.e. ground-storey, mid-storey and canopy) as part of landscaping. Such complementary landscape requirements would seek to enhance the interface and transition between conservation, core bushland areas and areas that form part of a green grid. This form of development control lends itself to a spatial approach to strategic planning and development control that uses maps of important ecological communities and biocorridors at the regional level and overlays to the lot level to inform the assessment of specific development applications. Such an approach could, for example, integrate with the intended urban ecological outcomes of the Green Grid (as identified in the draft district plans for Sydney) and would build on the existing practices of some councils (e.g. Willoughby City Council) that apply varying landscape controls depending on the proximity of a lot to a national park or other bushland site.

- **Minimise key threatening processes.**

The BioCon Act requires the identification of key threatening processes associated with the listing of endangered species or threatened ecology communities (s 4.31, Schedule 4). The recognition of threatening processes is intended to inform how to assess, determine and subsequently manage the direct and indirect impacts of a proposed development or activity (e.g. as would be considered in a species impact statement) under part 7 of the BioCon Act. There is an opportunity to develop a similar process for strategic planning, development assessment and managing public land (ranging from road reserves to bushland sites) to achieve improved urban ecological outcomes in cities. Such a process could be delivered through changes to the statutory provisions detailing what is required for the preparation of management plans for public land (such as those prescribed in part 2 of the LG Act, part 5 of the *National Parks and Wildlife Act 1974*, the assessments provisions in part 5 of the EP&A Act, and the operational procedures of agencies). The process could directly identify processes or activities that complement or conflict with urban ecological outcomes and activities involving the management of land in defined land management units, such as parks or adjacent lands, and it could include catchment-based or bioregional assessments, as appropriate. Stronger statutory arrangements should be in place to ensure that public authorities do more than just consider the impacts of a proposed activity, including maintenance, so they become legally accountable for minimising impacts on, and ideally for improving, urban ecosystems.

- **Have explicit and enforceable controls related to water and catchment management.**

A review by Choi and McIlrath (2016) of WSUD policy in NSW in 2016 revealed a lack of an overarching state-based statutory framework, which is affecting urban stormwater quality and flow objectives and thus the health of riparian systems and waterways. Unlike some other Australian states, NSW lacks clearly defined water-quality and site-discharge targets that apply at the lot level, and nor are there catchment-scale water-quality and stream-condition targets relevant to the modified waterways in cities. More detailed and catchment-specific targets and controls could be used to deliver regionally based environmental outcomes and complement other land-use practices in catchments (such as protecting bushland and deep soil areas to improve water quality and quantity). Initiatives such as the Parramatta River Catchment Group,

which has a goal of a swimmable Parramatta River by 2025, show that collective will exists to improve the environment at a catchment scale; such improvement will only be realised, however, with strong, enforceable controls and coordination and commitment among all agencies with major stakes in catchments. Catchment-based controls and targets are needed to address both point-source and diffuse stormwater pollution and manage the impacts of changes in hydrology associated with urban development. Although some councils prescribe water-quality and site-discharge targets in their DCPs, and some SEPPs incorporate general aims to protect the health of waterways (SEPP Sydney Region Growth Centres, 2006) or have regard to the principle of integrated water-cycle management (Central Westerns Sydney Regional Open Space and Residential – SEPP 59), these are not uniformly adopted across water catchments at the local government level or by state agencies. DCP controls are guidelines only, like statements in other SEPPs that require ‘regard to’ (rather than the achievement of a set, mandatory standard), limiting their effectiveness and compromising the cumulative long-term gains required to address existing land and water controls. An environmental planning instrument that sets minimum requirements for site pollution reductions and ecosystem outcomes (such as stream hydrology) would provide a more consistent and equitable policy framework.

- **Codify landscaping controls.**

Similar unenforceable DCP controls and other local government policies related to landscaping have the potential to be codified within a SEPP or similar environmental planning instrument. Such an approach recognises the importance of scale at the landscape to lot scales and supports a consistent policy framework across major cities, and it can serve to complement public open-space initiatives and planning. A codified approach can set minimum areas or percentages of sites that must be dedicated to landscaping. Additional controls can be included for deep soil zones to support canopy trees and to require a ‘complex’ selection of plant typologies (i.e. ground-storey, mid-storey and canopy) depending on location, ecological potential and land use. Codified controls can also integrate green wall and green roof approaches, as already implemented in a number of cities (see Chapter 7).

- **Assess, monitor and report.**

All environmental planning instruments should include provisions for their review and assessment against their objectives and targets (EP&A Act, s33B). Incorporating a mandatory monitoring, evaluation and public reporting process ensures transparency in the application of EPIs and their utility in achieving stated outcomes. The system of metrics and reporting needs to be integrated into EPIs in the exhibition of ‘explanation of intended effects’ as part of initial public consultations and continued through to gazettal and statutory review.

## **4.7 Policy, regulation and practice for urban ecology**

A Swedish study into the barriers faced by urban planners in maintaining sufficient quality and quantity of green spaces in cities revealed that planners paid little attention to biodiversity, focusing instead on recreation and public health, and were unaware of the new knowledge needed to contribute to biodiversity (Sandström *et al.*, 2006). Only 2 of 18 respondents in the study regularly sought research on biodiversity and green infrastructure planning; when asked what would be

required to take the maintenance of biodiversity into consideration, however, 40% of suggestions pointed to the need for more education. Twenty percent of respondents cited organisational barriers – specifically, the spread of expertise and access to this expertise across multiple departments. Many respondents also questioned whether their organisations had sufficient technical capacity to successfully manage biodiversity. The study concluded that political factors, such as legal and policy settings and historical practices, including organisational traditions (described in the academic literature as ‘path dependencies’; Bai *et al.*, 2010) contributed to the lack of importance and priority placed by the planning profession on urban biodiversity (Sandström, 2002). Spatial information technology, such as biodiversity overlays, were cited as potentially valuable tools for planning (e.g. Scott *et al.*, 2002); another point made was that ecologists needed to learn about planning processes, including to develop ecologically based tools to inform planning decisions. Importantly, the study suggested that ecologists needed to better explain the value of maintaining viable wildlife populations and what it would mean for cities.

Ives and Kelly (2016) explored the nexus between amenity and biodiversity and how this could be considered in urban planning. Their research sought to find opportunities or co-benefits for interactions between communities and environmental concerns. Such interactions are also addressed by terms such as liveability and ‘sense of place’ (Parker & Doak, 2012). The challenge for urban ecology, as argued by Kelly (2014), is that linking amenity to biodiversity conservation is fraught with complexity and relies on three separate but interrelated factors: 1) it must be enjoyed first hand; 2) it is usually restricted to a local context; and 3) what is pleasing may not be ecologically important.

In an Australian context, Ives and Kelly (2016) identified two points at which adverse impacts on biodiversity occur. The first is in the assessment of developments on private land and the reliance on strong plans supported by local politics (including policy formation and the willingness to adhere to policies). Ives and Kelly (2016) suggested (tentatively) that statutory yet flexible processes could be used to promote biodiversity objectives ‘without detracting from the primary purpose of the land’ (p. 505), which is the entitlement pertaining to the land use. The second point is the management of council land (and, more generally, all public land); Ives and Kelly (2016) argued that local governments could use their own internal strategies, policies and practices to prioritise biodiversity. In essence, this relates to their ‘business-as-usual practice’.

Ives and Kelly (2016) also discussed the significance of landscape planning and its connection to amenity at a strategic level. This relates to the importance of interactions between communities and their environment encapsulated by terms such as liveability and ‘sense of place’ (Parker & Doak, 2012). Ives and Kelly (2016) also noted that successful strategies to advance biodiversity outcomes rely on a convergence of three elements: 1) clear objectives; 2) establishing a robust understanding between biodiversity and amenity; and 3) effective public engagement.

In discussions on advancing urban ecological outcomes in cities there is less clarity on potential conflicts over direct and indirect impacts (e.g. public access in areas of high ecological value or sensitivity). Land in cities is highly contested, and the use of any parcel of land will likely involve tradeoffs in social, economic and environmental outcomes. If urban ecology is to be a sustaining principle in city planning and practice, ways must be found to balance such outcomes. For example, fencing to exclude public access to an endangered ecological community may protect parts of the ecological community from compaction, but it might also disconnect the community from the site, thus reducing their first-hand enjoyment and the contribution of the ecological community to urban living.

More research is needed into effective legal and policy approaches to optimise urban ecological outcomes in existing city planning outcomes, such as achieving housing and job targets and a liveable city. New transdisciplinary approaches are required to capture the full complement of benefits and impacts and address individual and organisational behaviours. This is not to lessen the weight of environmental science-based studies that have documented the state and pressures facing the urban environment, or anecdotal evidence that existing regimes and practices are deficient.

Across terrestrial environments, the incremental impacts of urban development (which may range from clearing associated with agriculture and residential subdivisions to bushfire risk, changes to established fire regimes, increases in nutrient levels and invasion by weeds) are analogous to 'death by a thousand cuts', leading to the slow, continual loss of biodiversity (Bradsen, 1992). In terms of policy and regulation, attention to urban ecological outcomes has been limited to a narrow examination of conspicuous species (e.g. koalas and the associated SEPP) and trees (e.g. large and significant trees falling under tree preservation orders), rather than habitats. This is changing, and there is increasing emphasis on endangered ecological communities and the link between their security and protecting both the quality and quantity of habitat. But market-based approaches such as Biobanking (which supports the 'trading' of natural areas) have not been universally successful. As noted by Barry (2007), attempting to maximise ecosystem services through cost-benefit assessments (and arguably similar economics-based approaches) may conceal cultural prejudices and therefore runs the risk of failing to preserve habitats 'evaluated' as having less value relative to other contemporary economic, social or aesthetic considerations. For example, a highly degraded bushland site that does not contain a threatened species or endangered ecological community would most likely not qualify for ecological protection and therefore would be cleared for development, notwithstanding its potential future ecosystem service value as a park or reserve. The inability of mechanisms in the now defunct *Threatened Species Conservation Act 1997* (largely replicated in the newly enacted *BioCon Act*) to arrest the decline of critically endangered ecological communities, such as those on western Sydney's Cumberland Plain, illustrates the inherent tension around land and values-based socioeconomic and environmental approaches in determining which land is protected, managed and developed. It is unclear in the long term whether the existing legal and policy systems can adequately protect key ecological communities in cities; the Cumberland Plain woodland, for example, is still subject to significant clearing and fragmentation, even though it was listed as an endangered ecological community in June 1997 (NSW Office of Environment and Heritage, 2016a).

For riparian systems, the cumulative impacts of traditional stormwater engineering and catchment management can be viewed as 'death by a thousand pipes' (Davies *et al.*, 2011). The need to incorporate WSUD outcomes in land-use policies and the practices of government and industry was a priority of the NSW Government in the late 1990s as part of its Stormwater Trust program (David & Wright, 2014). That program addressed diffuse pollution, in particular with the aim of getting local governments to change the way in which they managed stormwater design, maintenance and land use. The momentum of the NSW Stormwater Trust program was lost, however, despite the geographical importance of waterways and coastal areas in Sydney, Wollongong and Newcastle. This failure was largely attributed to a lack of political will to change planning laws and policies and to apply sufficient funding to enact change (see, for example, the review by Choi and McIlrath, 2016). On the other hand, examples of consistent WSUD outcomes can be found in Victoria and southeastern Queensland, among other places.

Development and housing outcomes, often framed around the cost of construction, have taken precedence over urban ecological outcomes. This can be seen in changes to the NSW riparian policy

in 2012, which explicitly prioritised housing supply over environmental protection (Ives *et al.*, 2010), essentially reducing the width of riparian buffers (which are known to provide essential biodiversity corridors in cities). Positively, the riparian reforms were accompanied by a government guideline supporting a liveability outcome to 'preserve the integrity of riparian corridors' (p. 3), while also permitting multiple uses in riparian zones, such as cycle ways and paths, detention basins, stormwater outlets, stream realignments and road crossings (NSW Department of Primary Industries, 2012a). In essence, the guideline has kept residential development outside riparian corridors, although it has enabled other infrastructure to occur within it that previously would have occurred on 'developable' land outside the riparian zone.

A number of reviews and stakeholder workshops have identified a lack of ecological literacy as a barrier to advancing urban ecology outcomes and therefore a need to educate politicians, communities, practitioners and policymakers. Powers (2000) concluded that community-based education was crucial for overcoming the perception in Australia that native plants are 'messy' and therefore not prioritised in landscaping efforts. This perception drives the provision of plants by nurseries, thereby creating an impasse if native gardens are to be prioritised and promoted by urban ecology policy settings. Policy settings and operational practices around green infrastructure as it relates to urban ecological outcomes give more weight to economic and social benefits than the natural environment (Lennon, 2015), possibly reflecting an inability of ecologists and other environmental professionals to articulate the importance of urban ecosystems, as found by Sandström (2002). Prosecuting the argument for urban ecology is an important challenge for urban environmental scientists and managers. It requires the profession and researchers to improve their communication skills at a policy level to institute political and legal reforms, at the operational level to change institutional practices and standards, and at the community level to shift social norms and expectations.

The nexus between a liveable city and an ecological city means that activities and policy directions will sometimes complement and sometimes conflict. For example, the provision of streetlighting for safety may have adverse impacts on nocturnal fauna species (although reducing lighting at times when most people are asleep might have an ecological benefit and minimal impact on safety). Urban planners should have a clear understanding of the goals of a city and how these are framed by the wider sustainability agenda (Weinstein, 2010; Wu, 2013). Sustainability is the basis of planning law in NSW, and it is the focal point for the development of strategic plans at the regional to local scales. Sustainability incorporates many considerations and perspectives, including those of communities, governments, elected officials, industry, non-governmental organisations and the development sector, and economic, social and environmental outcomes must be balanced. The views of the various sectors and participants on sustainability – and, within this, the merits of urban ecology – and what constitutes a liveable city will inform how cities develop and are managed in the future.

Advancing urban ecological outcomes in cities requires drawing on and learning from existing laws and policies, but new, transformative approaches are also needed. From the perspective of land-use planning, there are significant opportunities to use and build on the two major legislative levers in the planning legislation. At the strategic level, settings are needed for zonings, relevant state and regional policies and the ways in which regional, district and local plans articulate and value urban ecology to provide an overarching framework, vision and targets. These must be supported by statutory provisions to enable development assessments through codified and merit-based decisions. Both strategic settings and statutory provisions must be developed in concert; as reported by others (e.g. Sandström *et al.*, 2006; Lennon, 2015), opportunities exist to reform both by improving communication and literacy, linked to shifting social and technical norms, and quantifying

the benefits of urban ecology and its importance in liveable cities. The reforms of both strategic settings and statutory provisions will require that many disciplines work towards a collective, agreed agenda (Tzoulas *et al.*, 2007) and the decoupling of the perceived nexus and tension between housing affordability and environmental regulation.

DRAFT

## 4.7 International reports and city examples

This section looks at regulations and policies internationally aimed at enhancing urban greening and ecology, with the aim of illustrating international trends and best practices. As per the definition of urban ecology used in this report, the initiatives examined below are considered to be beneficial for the overall health of the urban environment and its biodiversity and the general liveability for citizens.

European examples are based on the 'GREEN SURGE' report, which demonstrates the broad scope of policy practices there and reveals a strong emphasis on innovative governance. Europe also has specific regional laws, such as the European biodiversity protection legislation, that frame national policies. In the US, the Environmental Protection Agency (US EPA) focuses on WSUD as the most common type of green infrastructure installation for improving stormwater management and capacity and providing secondary benefits of enhancing urban ecosystems and liveability.

City-level examples are from Paris, Berlin, Portland and Philadelphia, chosen to demonstrate overall planning policies, programs and initiatives of international cities known for their efforts in green infrastructure and promoting urban renewal with environmental considerations.

### Europe: The GREEN SURGE report

The EU's *Green infrastructure and urban biodiversity for sustainable urban development and the green economy* (GREEN SURGE) report makes it possible to gauge trends in planning and policies across the EU. GREEN SURGE is a transnational research project funded under the EU's Seventh Framework Programme (FP7), which was the EU's research and innovation funding program in 2007-2013. FP7 has since been replaced by Horizon 2020 (2014-2020), but many projects (such as GREEN SURGE) funded under FP7 are still running (Hansen *et al.*, 2015). The GREEN SURGE project has investigated ways in which policies for creating and managing green spaces have or can be adopted in 20 European cities. The project is divided into 'working packages' (WPs). Of particular interest to the current review are the report outputs of WP5 on green infrastructure planning and implementation (Davies *et al.*, 2016; Hansen *et al.*, 2016), and WP6 on the innovative governance of green spaces and biocultural diversity (Buizer *et al.*, 2015; Buijs *et al.*, 2016).

### Trends in green space governance

The *Governance of urban green spaces in selected EU-cities* GREEN SURGE output (Buizer *et al.* (2015) analysed the discourses of city officials on the social and environmental objectives in 60 local green-space initiatives. Most of the initiatives had more than one objective and often combined both environmental and social objectives.

Of the 60 green-space initiatives, 40% included goals to increase the area of (peri-)urban green space, and 40% aimed to provide or promote contact with nature/green spaces. Some objectives were relatively common, such as experiencing green/nature as a social objective and increasing green-space area as an environmental objective. Interestingly, aspects of health, connectivity and ecosystem services were among the least commonly cited objectives. The 60 initiatives were aggregated into seven categories<sup>33</sup>: 29 (48%) were focused on parks and gardens; 11 (18%) were

<sup>33</sup> The categories were: 1) **parks and gardens** – green-space initiatives focused on the creation or enhancement of parks and gardens in cities; 2) **urban farming** – green-space initiatives concerning local food production, such as urban farms and allotment gardens; 3) **conservation** – green-space initiatives focused on conservation actions in natural or semi-natural areas; 4) **advisory** – initiatives focused on giving advice or active participation in planning and decision-making processes; 5) **trails** – green-space initiatives focused on the

concerned with urban farming; six (10%) focused on conservation; and six (10%) were of an advisory nature. Only two (3%) were events, and there were three nature pathways or trails and three web applications (5% each).

The GREEN SURGE report on innovative governance arrangements in planning for and implementing urban green spaces in Europe explored principles, plans and policies on green infrastructure (Hansen *et al.*, 2016). The term ‘urban ecology’ was not used explicitly in the report and therefore its links to the concept are not clear. Many of the initiatives described in the report incorporate both environmental and social objectives in an urban setting, and they are likely to produce co-benefits (e.g. air filtering, citizen engagement and increased biodiversity).

The GREEN SURGE output *Advanced urban green infrastructure planning and implementation* examined innovative approaches and strategies in European cities and draws on the concepts of urban ecology (Hansen *et al.*, 2016). It notes that urban biodiversity is the ‘variation within and between species (natives and non-natives), variety of different biotopes (original and man-made) such as herb-rich forests or dry meadows, and in larger scale variety of different ecosystems like forests, wetlands or lakes’ (Hansen *et al.*, 2016, p. 75). The output further states that urban areas are increasingly recognised as greater opportunities for supporting biodiversity than rural areas.

**Table 4.7.** The main types of innovative governance arrangement, as determined by the GREEN SURGE study. Source: Hansen *et al.* (2016).

Governance arrangements	
Municipalities mobilising social capital	Strategic planning instruments mobilise grassroots movements and individuals to participate in activities that contribute to the creation or maintenance of green and open spaces
Green hubs	Experimental, creative collaborations connecting various networks and information streams to develop community-based solutions
Grassroots initiatives	Relatively small-scale enterprises developed and maintained by local residents, typically on public or shared land
Co-governance	Power shared across partnerships between government authorities and citizens or grassroots initiatives
Organisation-initiated grassroots	Social groups and non-governmental organisations organise community action or activities with power distribution ranging from co-governance to grassroots initiatives
Green barter	Development and/or maintenance requirements for private sector in exchange for formal concessions on right to use the values of space for business profits

In identifying advanced strategies, the GREEN SURGE report examines concepts of integration, connectivity, multifunctionality, social inclusion, planning that promotes biodiversity, climate-change adaptation, and a green economy in the context of urban green infrastructure. Eighteen European city examples are provided, and the analysis identifies six main innovative governance arrangements

creation of pathways or trails; 6) **web applications** – green-space initiatives aimed at the provision of online resources; and 7) **Events** – green-space initiatives such as festivals, markets and fairs (Buizer *et al.*, 2015).

**(Table 4.7).** Noteworthy is the absence of public–private partnerships, whereby power is shared by governments or public entities and private organisations through partnerships that can enable public entities to supplement projects with private funds and cooperation.

GREEN SURGE highlights important trends in innovative governance arrangements in the EU, including a shift in the role of government actors (particularly municipalities and local governments) in providing their citizens with green services. Governance is also seen as a shared responsibility in which such sharing maximises the effectiveness of green infrastructure policies and plans. In particular, the more successful governance models incorporate community-based grassroots initiatives in government planning strategies (e.g. the neighbourhood planning systems of Bristol, United Kingdom, and Utrecht, the Netherlands).

The key lessons identified in the GREEN SURGE report for consideration in the implementation of policies and programs include the following:

- The enthusiasm of residents is needed for enhancing biodiversity and social cohesion. This element was referred to as ‘cultural capital’, and many case studies highlighted the high degree of knowledge and skills held in communities and non-governmental organisations.
- Municipalities (and other state agencies) identified the costs of ‘place making’ and ‘place keeping’ as barriers. To overcome these economic obstacles, the report highlighted the important role of community in maintenance, although this had to overcome the tension of municipalities wanting ‘formal’ maintenance plans (as they would for a standard works contract) and the informal culture of grassroots participation.
- Mutual trust was an important factor, with municipalities needing to trust their communities and communities needing to trust their municipalities. Trust is also reflected in power-sharing arrangements captured in a shift toward more participatory democracy.
- Personal commitment and ownership appeared to be the principal drivers in creating and maintaining high-quality green spaces (Hansen *et al.*, 2016). Green barbers exemplified this well but also demonstrated the strength of flexible regulatory instruments that can stimulate the involvement of economic actors. Generally, citizens were motivated by normative notions to enhance biodiversity; social cohesion; and general accessibility of green areas for diverse people.
- For grassroots initiatives, social impact appeared to be as least as important as environmental impacts. This reinforces the notion that social values are important motivators for involving citizens in the protection of green spaces. Thus, governance arrangements and policies that facilitate social mobilisation around socio-environmental issues stand to benefit from larger community support. Although grassroots initiatives made management decisions, the majority of the decision-making power remained with typical authorities such as owners and legislative bodies or through subsidy regulation.
- In terms of encouraging participation and education, e-tools and social media show potential in helping local communities organise themselves on green topics and importantly for sharing knowledge and expertise.

The GREEN SURGE report highlighted disparities among citizens and neighbourhoods in social capital, raising concern about the effects of decentralised and networked governance arrangements on environmental justice. In most of its case studies, the report found that connecting innovative governance to urban green infrastructure planning was challenging. The report recommended that municipalities develop localised *mosaic governance* that can be sensitive to local social and environmental diversity, the availability of cultural capital and already-present grassroots initiatives. A major take-away from the report is that municipalities that adopt flexible governance arrangements in their policies and planning stand to make savings on 'place making' and especially on the maintenance costs of 'place keeping'. These savings should be emphasised because they can be important drivers for municipalities to reach out to local communities (Dempsey & Burton, 2012).

The most important factor in the success of a green-space initiative appeared to be the availability of resources (such as economic resources and the time available to invest in a project or initiative). Cultural resources were also key because people and communities need the capacity to organise themselves, as well as access to relevant networks and environmental knowledge and expertise.

In case studies where co-management and grassroots initiatives were prominent, the GREEN SURGE report found that communities were able to manage green spaces for long periods (even decades). Success in long-term community management was identified as due to a combination of flexibility in governance arrangements and the ability to adapt to the dynamics of local planning and politics and broader urban demographic and societal trends. Strong leadership and well-established organisational structures were also key to long-term successful outcomes. The internal institutionalisation of rules and resource management is likely to be just as important as external structures and resources.

These lessons are particularly relevant to NSW, where there have been recent shifts in planning strategies, council amalgamations, political instability, increasing land values and the recent enactment of the BioCon Act. Such a changing setting offers opportunities for improving systems and laws and for maximising social capital through innovative governance arrangements that can withstand and adapt to changes.

#### Example: Berlin, Germany

Throughout the 1980s and 1990s, Berlin promoted green urban development through financial aid programs (Senate Department for Urban Development and the Environment, 2016). The Courtyard Greening Programme (1983–1996), for example, aimed to provide green spaces such as green roofs, facades and backyards in the most densely populated areas of the city. The overall goal of the program was to improve the urban climate and urban amenity as well as the overall quality of life of residents. An equivalent of EUR 19.10 per m<sup>2</sup> of green space was provided as financial support, including separate amounts for the construction and design. Under the program, 54 ha of roofs and backyards were greened and 32.5 ha of facades were greened, at a total cost of EUR 16.5 million in support.

Berlin uses a biotope area factor (BAF) and indirect tax/duty regulations and tools to promote green or ecologically effective spaces (see BAF equation below). The BAF is used to secure green spaces and features in Berlin's city centre, and it is established in the city's landscape plans (Becker, 1990). Although the BAF is part of Berlin's legally binding landscape and environmental planning arrangements ('Handbuch der Berliner Landschaftspläne'), it can also be used to establish site-related standards and as a general guideline for environmental assessment (Becker, 1990).

BAF = ecologically effective area

total land area

The BAF supports Berlin's Landscape Programme (LaPro), which is an important strategic instrument for the city-wide promotion of connectivity in Berlin (Cloos, 2004). LaPro outlines targets for ecological urban redevelopment and, since 1990, it has had the general goal of reducing environmental impacts in the inner city area. One means for achieving this goal is improving ecosystem function and the development of biotope areas (Becker, 1990, p. 2). The legal basis for LaPro is Berlin's nature conservation law, which is the main city-wide instrument for landscape planning in the Berlin area. The nature conservation law specifies the themes covered in LaPro (e.g. habitat protection or identifying compensation areas). Under this law, the state of Berlin has to provide a habitat network equating to at least 15% of the land.

LaPro is based on five city plans:

- 1) the Habitat Network Plan, based on target species.
- 2) the Natural Environment Plan, which includes urban climate protection through the city's green infrastructure network.
- 3) the Recreation and Use of Green Spaces Plan, which is concerned with the system of green corridors for humans and priority areas for the improvement of recreation.
- 4) the Scenery Plan, which aims to conserve and improve linear structures such as shore paths and tree avenues.
- 5) the General Urban Mitigation Plan ('Gesamtstädtische Ausgleichskonzeption' – GAK), which is an important instrument for implementing mitigation measures in the city. The GAK is based on the legally binding impact mitigation and compensation regulations in the *Federal Nature Conservation Law*.

In Berlin, the combination of the legally binding impact mitigation and compensation regulation and strategic and proactive planning approaches (such as the GAK) has proved successful in developing the urban green infrastructure network. Where environmental impact mitigation is not possible for a new urban development area, investors have to pay compensation in other areas.

The continuous development of interconnected green infrastructure is supported by Berlin's GAK and impact mitigation and regulations. The approach has been a successful combination of a legal instrument and strategic planning; by holding investors responsible, it links urban development, economic prosperity and positive environmental outcomes.

The issue of the typology of governance arrangements is identified in the GREEN SURGE report as a specific hurdle. Berlin's array of programs and regulations to enhance its urban ecosystems reflects the city's struggle to adapt to a more flexible, community-led governance process.

The objectives and planning approaches in the new LaPro have been revised based on new scientific knowledge and changed priorities (e.g. in socioeconomic or developmental trends) in the LGA. The update represents a change of paradigm, from a reactive approach focused on protecting sensitive and high-value green areas towards a more proactive and integrative approach that does not oppose urban development, instead aiming for coordinated planning.

The Habitat Network Plan is based on new scientific knowledge. Rather than a habitat-based approach, it now addresses 34 target species that are both umbrella species<sup>34</sup> and flagship species.<sup>35</sup> Local experts mapped the existing and potential habitats of these species for inclusion in the designed habitat network, which comprises protected areas such as nature reserves and ‘suitable sites’ such as parks, allotment gardens, cemeteries and other green spaces under legal long-term protection from development.

Additional areas that lack specific protected status (e.g. rivers and their shores, and areas designated for future urban development) are included to complement the green-space network. Their inclusion helps preserve important corridors, resulting in an increase in habitat quality for target species (e.g. lizards, amphibians and butterflies) capable of inhabiting developed areas.

In terms of urban climate, new insights have shown the limitations of corridors for urban cooling in lowlands compared with the impacts of small green spaces in densely built-up areas. Berlin, therefore, has taken an approach that identifies priority areas for greening in densely built-up areas, in addition to the conservation of important green corridors.

For NSW, the identification of priority areas using the vegetation benchmark study (Jacobs *et al.*, 2014) could be an important method of planning urban green spaces across LGAs. The benefits of smaller green spaces in densely urbanised areas will yield better results in mitigating the UHI effect. The incorporation of smaller patches of green space in future urban development plans could start a shift from a reactive to a more proactive approach in planning and development in NSW.

A particular challenge in Berlin has been the limited budget. City planners have had to facilitate external funding through networking and intensive collaboration with non-governmental stakeholders (e.g. the 20 green walks), and it has been necessary to use resources as efficiently as possible.

Citizen-led initiatives and non-governmental organisations in Berlin have successfully altered or blocked plans and projects that have taken top-down approaches. In response, Berlin’s planning authorities are exploring more collaborative approaches in planning and development. To address potential challenges, research is being undertaken into *if* and *how* consensus can be achieved among conflicting parties and/or objectives. Also being researched is whether trust can be developed with a strong and constructive culture of debate.

#### Example: Paris, France

At the Paris climate conference in December 2015, 195 countries adopted the first universal, legally binding global climate deal. France led the negotiations as host of the conference, and the country has adopted strong policy measures to avoid dangerous climate change via reductions in greenhouse gas emissions and a transition to green development.

In March 2015, the French National Assembly (L’Assemblée Nationale) adopted an amendment to a bill that would have obliged all new commercial buildings in commercial zones to have a ‘fifth facade’, meaning that at least part of their roofs would need to be either green roof or fitted with

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<sup>34</sup> Umbrella species are species selected for making conservation decisions because protecting those species will typically lead to the protection of other species and/or the protection of the overall ecological community in the targeted habitat (e.g. the capercaillie, *Tetrao urogallus*, found in Europe and Asia).

<sup>35</sup> Flagship species are species with an intrinsic/iconic value to people (e.g. China’s giant panda, *Ailuropoda melanoleuca*), making them popular as species rather than for their ecological benefit or impact on ecosystems.

solar panels (République Française, 2015). This was part of a biodiversity bill designed 'for the re-conquest of biodiversity, nature and landscapes' (Le Sénat, 2015). After going back and forth between the National Assembly and the Senate, however, the amendment was scrapped, the Senate declaring that it would have had a negative impact on economic vitality and employment in French territories, further arguing that there was a lack of studies to support it. Despite this setback on what would have been a landmark federal law, France has taken large strides in promoting an ecological transition towards green growth and the integration of green infrastructure. Paris has been leading in urban greening and the enhancement of biodiversity and is set to adopt a new biodiversity plan for 2016 onwards, replacing the city's first biodiversity plan, Le Plan Biodiversité 2011-2015.

Generally, Paris's biodiversity plan aims to: reinforce the city's green and blue networks to encourage ecological corridors; integrate biodiversity into the municipality's structure and planning actions; and raise awareness among citizens to better mobilise stakeholders around urban ecology (e.g. through the Parisian Biodiversity Observatory).

Since adopting its first biodiversity plan in 2011, Paris has drastically altered its approach to planning and development and the maintenance of the various parks and public green spaces across the city. Biodiversity features have been installed throughout the city, such as bird and bat nest-boxes and nests for solitary bees using wood logs. The municipality no longer uses pesticides or fungicides to treat its green spaces.

The highly urbanised city has similar development pressures to Sydney, but it has found ways to enhance its urban ecosystems by reducing pollution and through a variety of greening initiatives and installations. The project Reinvent Paris (Réinventer Paris) prioritises housing development but places significant emphasis on environmental innovation. The city proposed 23 'prestigious' sites across Paris and called for innovators in architecture. The tender process focused on adapting architecture to new trends in working and living in the city. Twenty-two projects were retained for the tender that place vegetation and the environment at the forefront; the deputy mayor of Paris in charge of urbanism said that bids needed to consider energy consumption and recovery, the integration of ecological materials, experimentation in greening, and the embodiment of the objective of 'zero waste, zero carbon'. The project also encouraged the use of abandoned sites that could have significant benefits for the environment (e.g. underground spaces, roofs and brownfields) and could add value as 'unexpected' spaces. E-tools are being used to promote Reinvent Paris. A free mobile application has been developed to encourage people to take 'ecological strolls' to discover urban ecology in various districts of the city. The app allows users to visit specific biodiversity hotspots and green infrastructure such as eco-districts, green roofs and facades, urban beehives, ponds, various green streets and buildings with high environmental quality and ratings.

The French Government has promoted a number of changes to encourage cities and localities to innovate towards more sustainable cities and increased biodiversity. Policies aimed specifically at promoting a circular and green economy have enabled innovation in planning and development. Ultimately, the French Government's policies encourage cities to be more efficient, waste-free and clean and hence to have better overall health and biodiversity when combined with the preservation of remnant vegetation (McNeely, 1992).

### **The United States Environmental Protection Agency**

The US EPA has supported the implementation of green infrastructure across the United States of America by providing tools and guidelines for building green infrastructure, as well as information on aspects such as performance and benefits and guides on policies and regulations.

Of particular interest to the US EPA is green infrastructure for the management of stormwater, which tends to yield multiple co-benefits as well as ease pressure on stormwater infrastructure. Thus, there are many US examples of green infrastructure related to urban water management. The US EPA has identified a number of real and perceived barriers to the adoption of green infrastructure in municipalities and among developers and in terms of design challenges.

As also noted in the GREEN SURGE reports, local governments are often well placed to promote sustainable infrastructure on a larger scale but are also faced by complex challenges. The US EPA emphasises four key factors:

- 1) Resource limitation.
- 2) Fragmented responsibilities in governance arrangements.
- 3) A generally low tolerance of risk.
- 4) Policy and planning conflicts in codes and ordinances that complicate the implementation of green infrastructure.

The policy and planning conflicts are confounded by differing state and local requirements across the country (US EPA, 2012). Existing comprehensive plans, zoning codes and building standards can limit the possibilities for implementing green infrastructure where there is a lack of clarity or direct conflict with green infrastructure principles or installation. In the US, zoning density standards, stormwater–sewer connection requirements, and minimum parking and road widths can serve as additional restrictions, emphasising the need for multidisciplinary approaches.

To overcome such barriers, the US EPA prepared a municipal handbook to provide local governments with a step-by-step guide to growing green infrastructure in their municipalities. The handbook has five volumes: on funding options (US EPA, 2008a), green infrastructure retrofit policies (US EPA, 2008b), green streets (US EPA, 2008c), rainwater harvesting policies (US EPA, 2008d) and incentive mechanisms (US EPA, 2009). The US EPA handbook provides an overview of funding strategies and instruments that municipalities can use to better integrate water-sensitive designs and green infrastructure into urban planning and policies. General lessons to consider for the successful promotion of green infrastructure in policies can broadly be placed in two main categories: the removal of obstacles; and the creation of incentives. The handbook concludes that green infrastructure approaches should be key components of all new developments and redevelopments (US EPA, 2008b). Any community planning to address urban stormwater challenges should focus its policies on retrofitting the built environment with green infrastructure. The co-benefits associated with green infrastructure offer creative solutions to issues such as climate change, air quality, water quality and quantity, the UHI effect and energy conservation, enable cross-disciplinary partnerships, and can help in leveraging funding and other resources for accomplishing multiple goals.

The two most common funding options for green stormwater infrastructure are stormwater fees and loan programs (US EPA, 2008a); a third source is grant programs, which provide a limited amount of support that may be adequate for small, local projects but insufficient to sustain large multi-year wet-weather programs. The US EPA's exploration of funding options could be useful for the Sydney Water Corporation and the Hunter Water Corporation, which are looking at how to regulate wholesale services (IPART, 2015). The instruments that regulate such transactions are the *Water Industry Competition (WIC) Act 2006* access regime and the IPART price determination. There is a criticism that a retail-minus-pricing methodology could make water-recycling schemes unviable, potentially stifling innovation.

Stormwater fees are applied in the US to generate funds for responding to and controlling both combined sewer overflow and stormwater runoff. Fees have the added benefit of being easier to adopt and implement for municipalities; in many communities, a new tax would require a vote of approval by the public, whereas municipalities have authority to leverage fees for the services they provide. Although stormwater fees can be an efficient and fair policy instrument for recovering the cost of maintenance and for the general improvement of stormwater infrastructure, they must be planned carefully and implemented with thoroughness. The US EPA outlines the following basic principles in the planning and implementation of stormwater fees (US EPA, 2008a):

- The bulk of stormwater fees should be structured so that properties and sites with the largest amounts of impervious area (and therefore runoff) – typically non-residential buildings and facilities – pay higher fees than residential and other ‘small-meter’ sites with less impervious cover.
- Traction and support for stormwater fees tend to decline dramatically when the cost burden is placed too heavily on residents. The City of Portland has addressed this by offering bill discounts, crisis vouchers (of up to USD 150) and zero-interest loans to low-income customers.
- To be worth implementing, stormwater fees need to provide enough revenue to maintain and enhance existing stormwater infrastructure.

Table 4.8. The US EPA’s framework for stormwater fee discount programs, outlining common stormwater management goals and identifying the discount mechanisms and processes that can be used to implement and achieve these goals. Source: US EPA (2008a).

Purpose of discount	Possible mechanisms for fee reduction	Implementation process
Imperviousness reduction	<ul style="list-style-type: none"> <li>• % fee reduction</li> <li>• Credit per m<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>• % reduction in imperviousness</li> <li>• m<sup>2</sup> of pervious surfaces</li> </ul>
Onsite management	<ul style="list-style-type: none"> <li>• % fee reduction</li> <li>• Performance-based credits (quantity/quality)</li> </ul>	<ul style="list-style-type: none"> <li>• List of practices with various credits</li> <li>• Total area (m<sup>2</sup>) managed</li> </ul>
Volume reduction	<ul style="list-style-type: none"> <li>• % fee reduction</li> <li>• Performance-based quantity reduction</li> </ul>	<ul style="list-style-type: none"> <li>• % reduction in imperviousness</li> <li>• Performance-based</li> <li>• Total area (m<sup>2</sup>) managed</li> <li>• Practices based on pre-assigned performance values</li> </ul>
Encouraging specific practice	<ul style="list-style-type: none"> <li>• % fee reduction</li> <li>• On-time credit</li> </ul>	<ul style="list-style-type: none"> <li>• List of practices with various credits</li> </ul>

Philadelphia has implemented a new imperviousness-based fee with the aim of encouraging retrofits of large impervious sites. Philadelphia’s Water Department convened a citizens’ advisory council, which found that impervious cover was the primary factor determining property runoff; it was thus decided that 80% of the stormwater fee would be based on the impervious area of a property and the remaining 20% would be based on the property’s gross area. The city opted to treat all 450,000 residential properties as a single land parcel, with the total cost of its 80/20 impervious/gross area formula to be divided equally among all households. In so doing, the city avoided an administratively complex detailed analysis of each residential property and spread out and shared the stormwater costs over a larger customer base.

In general, the US EPA recommends the use of both incentives and regulatory measures to drive the wide adoption of retrofitting policies. The city of Basel in Switzerland is a good example of such a combination: an incentive program raised public awareness of the benefits of green roofs for energy savings and biodiversity protection, arguably obtaining wide acceptance of the city's implementation of a green roof requirement. When fees are associated with incentives, such as discounts and credits, they encourage the retrofitting of existing properties and the implementation of green infrastructure in new developments.

On the use of financial measures to promote urban ecological outcomes, the US EPA remarked that an equilibrium must be reached such that the fee is high enough to discourage developers from avoiding the implementation of urban ecology outcomes, and the credit or standards must be perceived as attainable (and beneficial) to ensure that developers implement the initiatives (Portland, Oregon, is an example of a city that gives credits for sites with eco-roofs or trees over 4.5m in height).

The US EPA noted that incorporating green retrofits into municipal infrastructure has presented both institutional and regulatory challenges (US EPA, 2008b) and proposed retrofit policy solutions by technology type (e.g. downspout and impervious cover disconnection). The US EPA acknowledged that what is valid for one green infrastructure practice is often also applicable to others, which can lead to overlapping goals and outcomes.

Typical incentives include:

- Grants
- Subsidies (e.g. the Eco-Roof Incentive Program of Toronto, Canada)
- Consultations (e.g. Stuttgart, Germany, provides free consultations and documentation for green infrastructure retrofits)
- Reimbursements
- Fee reductions.

Approaches to regulations include, for example, making green roof requirements according to building size or roof pitch (e.g. Toronto's Green Roof Bylaw is based on gross floor area and Copenhagen's green roof requirement is based on roof pitch). Onsite stormwater management/downspout disconnection requirements are common measures in the US (e.g. Portland's regulation requires the disconnection of downspouts within a year of notification).

Other policy and planning measures that facilitate urban green infrastructure retrofitting include the following:

- Fast-tracking the review process – implementing policies that expedite project reviews for applicants proposing to install green infrastructure is a good incentive (e.g. Philadelphia's Post-Construction Stormwater Management Plan Reviews).
- Free disconnections – offering to install green infrastructure can be a good motivator for owners who otherwise may not have the finance or the time to undertake a retrofit (e.g. in Portland, property owners have a choice between undertaking the work themselves and receiving reimbursements on completion and applying to the city municipality to get their downspout disconnection done for free by the municipality).

- Assistance with compliance – providing property owners with assistance in complying with regulations or other instruments helps in achieving the correct standards (e.g. Portland implemented such a program to encourage retrofit disconnection).

The US EPA report makes an important note on the difference between promoting public versus private green infrastructure retrofits. Publicly owned paved surfaces present an opportunity for retrofitting because they typically account for a large proportion of impermeable cover in urban areas. Typically, it is easier to make the argument for wider benefits to the community in publicly owned assets than for private properties. The combination of raising awareness in the community and providing incentives and regulations is the best way to ensure the wide adoption of retrofitting on private properties. The US EPA also noted that, once test-beds or the first districts have been fitted with green infrastructure and experienced environmental improvements, private uptake rises as the benefits of green infrastructure become apparent at the local and neighbourhood scales (Chicago's Green Alley Program and Green Alley Handbook are good examples of this effect).

There is evidence that installing green infrastructure in the planned development of vacant lots and brownfields, and retrofitting existing buildings, increases the value of the lot or property under development as well as of the surrounding buildings and streets. The US EPA offers Philadelphia as an example: that city started transforming vacant lots in 1995 (some 1,100 parcels of abandoned land in its New Kensington neighbourhood), adopting a strategy of stabilising vacant lots with grass, trees and wood fencing as well as creating community gardens and renovation parks. A study conducted by the University of Pennsylvania (Wachter, 2005) found that green lots had increased adjacent property values by as much as 30%; and tree plantings had increased the collective value of neighbouring property by some USD 4 million and of the lots themselves by some USD 12 million. Interestingly, Philadelphia also transferred vacant lot rights to neighbouring homeowners for private use and management. To address concerns about the maintenance of the lots, the city established a maintenance program that hired and trained community residents, providing not only local jobs but also informal community education as employees discussed their work. This proved to be an effective method of both raising awareness in the community and promoting a sense of ownership among local residents.

The Green Streets US EPA report outlined specific opportunities as well as common (and perceived) implementation barriers for the greening of streets (US EPA, 2008c). It noted that, in order to incorporate green streets into urban stormwater management, policies must match road function with environmental performance. Adapting streets into fully functional green streets requires an evaluation of how to maximise the benefits of environmental systems that typically do not require major design modifications. The US EPA identified the following five crucial elements for the successful implementation of green streets programs (see **Appendix B** for a full description of each point):

- 1) Use of pilot projects
- 2) Leadership in sustainability from the top
- 3) Buy-in from all municipal infrastructure departments
- 4) Documentation of design, construction and city-wide tracking
- 5) Public outreach.

Enabling legislation and the provision of technical guidance are also essential for a successful green streets program. An institutional evaluation is needed on how rights-of-way can be managed most effectively, typically involving: an assessment of the required functions of roads; selection of the

minimum required street width to reduce impervious cover; enhancing streetscaping elements to manage stormwater and identifying opportunities to integrate stormwater management into roadway design; and transportation and environmental planning integration to capitalise on economic benefits.

In the US, streets need to meet code requirements for emergency service vehicles and allow a free flow of traffic. Urban and suburban streets, therefore, are oversized for their typical everyday functions (which is also true in NSW urban areas to provide access for rubbish-removal trucks). Wide streets have a number of detrimental implications for liveability, traffic conditions and pedestrian safety. In 1997, the State of Oregon granted local governments (on consultation with fire departments) the authority to establish alternative street design standards (to the state's *Uniform Fire Code*), increasing flexibility for the installation of green infrastructure across the state; a similar policy could be applied in urban centres in NSW.

#### Example: Portland, Oregon

The City of Portland has been a pioneer in greenhouse gas emission reductions, with measures predating widespread concern about climate change (the city adopted a carbon dioxide (CO<sub>2</sub>) reduction strategy in the early 1990s). In the early 1970s, Oregon adopted a state-wide land-use policy to restrict urban sprawl via the establishment of urban growth boundaries. In so doing, the city opened the way to enhancing its air quality and the overall health of inhabitants and its urban ecology.

The policy restricting urban sprawl guided and encouraged the city to develop denser urban neighbourhoods while preserving farmland and wilderness areas. The policy has been a success, and it arguably set the stage for a series of effective urban greening policies and initiatives. Portland has adopted a number of policies and strategies to promote urban greening and buildings of high environmental standards. Between 1993 and 2011, Portland's Downspout Disconnection Program disconnected over 56,000 downspouts from the city's combined sewer system, removing around 5 billion litres (over 1.3 billion gallons) of stormwater per year from the city's combined sewer system.

In 2007, Portland approved its 'green-street' resolution, report and policy (Portland City Council, 2007) to promote and implement the greening of streets for the management of stormwater runoff at both the source and the surface. Between 2005 and 2007, the city's 'green streets team' investigated barriers to the public initiation of green street projects. They found that city codes and standards discouraged communities from adopting green street strategies, but also that uncertainty about long-term performance and maintenance responsibilities were hindering the program.

Portland now has 180 certified green buildings, and 2012 data indicated more Leadership in Energy and Environmental Design<sup>36</sup> platinum-certified buildings than any other city in the US.<sup>37</sup> In February 2010, the City of Portland published a report quantifying the ecosystem benefits of green infrastructure, with a focus on social and economic benefits, which has been used in the Portland Bureau of Environmental Services' Systems Planning and Alternative Analysis for Prioritisation. Coupled with flow management analyses, the report became part of infrastructure decision-making.

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<sup>36</sup> Leadership in Energy and Environmental Design (LEED) certification is a popular international green building certification program developed by the non-profit US Green Building Council. It includes rating systems for the design, construction, operation and maintenance of green buildings, housing and neighbourhoods.

<sup>37</sup> Leadership in Energy and Environmental Design buildings remain ad-hoc. From 1993 to 2013, they made up only 0.17% of the total built space in the US (van der Heijden, 2015, p. 7).

Before the green-street policy, the majority (around 90%) of implemented green street projects were issued through private permits rather than city-initiated projects. The city emphasised public education and uses signage, art installations, workshops, meetings, newsletters, factsheets and other outreach tools and events to increase awareness and encourage private participation in developing and implementing green street solutions.

#### Example: Philadelphia, Pennsylvania

The US EPA promotes green infrastructure as a useful and efficient policy option for enabling local decision-makers to achieve multiple municipal goals and meet the requirements of the *Federal Clean Water Act* (US EPA, 2010). Philadelphia has adopted a number of green infrastructure policies with a view to better managing infrastructure assets and avoiding future operational and maintenance costs.

The Philadelphia Water Department estimates that the new stormwater standard to reduce combined sewer overflow inputs by just under 1 billion litres will save the city an estimated USD 170 million.<sup>38</sup> The vision of the Philadelphia Water Department ('Philadelphia Water') is 'to protect and enhance our watersheds by managing stormwater runoff with innovative green stormwater infrastructure throughout our City, maximizing economic, social, and environmental benefits for Philadelphia' (Figure 4.15).

Philadelphia Water's green stormwater infrastructure programs aim to implement practices in the context of:

- **Green streets**, with stormwater tree trenches, planters, bump-outs and pervious pavements.
- **Green schools**, in which green stormwater infrastructure practices such as raingardens, green roofs, rain barrels, pervious pavement and tree trenches are implemented on school properties.
- **Green public facilities** that can be retrofitted to allow public facilities to lead by example in installing green stormwater infrastructure.
- **Green parking**, which can also be retrofitted and redesigned, presenting an opportunity to reduce stormwater runoff and improve urban aesthetics with installations such as vegetated strips and swales and infiltration beds.
- **Green parks**, which can help drain neighbouring impervious areas, provide a range of co-benefits and serve as highly visible demonstration projects.
- **Green industry, business, commerce and institutions**, in which industries across the board are incentivised and can pioneer and lead innovation.
- **Green alleys, driveways and walkways** are clear opportunities for retrofitting or redesigning and maximising the infiltration of underused areas.

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<sup>38</sup>"These savings are derived from the fact that one square mile (about 2.5 km) of impervious cover has been redeveloped under Philadelphia's updated stormwater regulations, and the cost of storing that same volume of stormwater in a CSO tank or tunnel comes to \$170 million in capital, not including operations and maintenance costs. After two years of effectively enforced stormwater regulations, the City now estimates that two square miles are using green infrastructure, saving about \$340 million in capital." (US EPA, 2010).

- **Green homes**, by encouraging homeowners to undertake green infrastructure retrofits (e.g. green roofs and the general reduction of impervious pavements), install rain barrels, and connect downspouts to raingardens or flow-through planters.



Figure 4.15. Artistic rendition of Philadelphia Water's vision for green stormwater infrastructure. Source: Philadelphia Water (2016).

In Philadelphia, vacant properties can be used for green infrastructure projects as permanent functional landscapes or as interim land uses to promote economic development. The local transportation department can also use green infrastructure for street and transportation right-of-way improvements; typical practices include the establishment of street trees to improve pedestrian areas, the use of sidewalk planters, narrowing street widths, and extending curbs.

Philadelphia residents can obtain fee discounts and credits by decreasing impervious surfaces and using green infrastructure techniques to reduce stormwater runoff. This reduces the burden on public infrastructure because property owners are encouraged to manage their own stormwater runoff on site. Discounts also support the fee-for-service system, with property owners able to reduce their fees by reducing the service needed.

'Rain check' offers property owners a free rain barrel and cost-sharing arrangements for the installation of downspout planters, raingardens and porous paving.

The Stormwater Management Incentives Program (SMIP), established in 2012, provides direct stormwater grants to non-residential property owners who want to construct stormwater retrofit projects. The Greened Acre Retrofit Program (GARP), created in 2014, provides stormwater grants to contractors, companies and project aggregators to build large-scale stormwater retrofit projects across multiple properties. Together, SMIP and GARP have created 298 greened acres (around 1.2 km<sup>2</sup>).

The City of Philadelphia's Greenworks Program has been particularly successful in driving urban greening in the city (The City of Philadelphia, 2015). This program, which was launched in 2009, was the city's first comprehensive sustainability plan. It aims to enhance the city's overall sustainability, and it includes targets such as improving the urban green-space network and connectivity, increasing tree coverage towards 30% citywide by 2025, and promoting resilient and green infrastructure. The City of Philadelphia has pledged to take a new look at how to set ambitious yet achievable goals, recognising the need for strong baseline data, improved tracking systems, and experience and noting that improvements can be made to make data more meaningful. The current framework does not fully recognize the interconnectedness of outcomes; the recommendation for a future plan is to consider a systems approach in conjunction with an understanding that efforts towards sustainability often meet multiple goals simultaneously. Another important lesson is that

not all initiatives roll up into a number: work that supports sustainability goals but doesn't produce impressive quantitative outcomes might nevertheless be important.

DRAFT

## 4.8 Discussion

The incorporation of urban ecology into laws and policies provides a number of opportunities. Presently, biodiversity conservation is framed in the context of ‘protect, conserve, preserve’<sup>39</sup>; additional legal importance is given to species and communities deemed by the NSW Scientific Committee as threatened or endangered via listings under the TSCA and now the BioCon Act 2016. As indicated by local and regional vegetation mapping, however, and in the face of the emergence of market-based tools (e.g. BioBanking) for arresting biodiversity loss and the identification of strategic urban growth areas in or affecting listed endangered ecological communities (notably in Sydney’s northwest and southwest), the extent and distribution of remnant vegetation across cities in NSW is both under pressure and in decline.

There is a lack of research on NSW laws and policies as they apply to urban biodiversity protection and management, and it is unclear therefore whether existing legal and policy frameworks are inherently flawed and contributing to the loss, the failings are due to poor implementation and regulation, or other social, political and economic factors are at play that fail to capture the value of biodiversity in land-use planning and operational decisions. The governance processes affecting urban biodiversity are complex. Accountabilities and responsibilities overlap, and they are caught between jurisdictional and functional needs, differing perceptions of the value of urban biodiversity, inconsistencies in the practices of local governments and state agencies, and a general hesitancy to embrace community-based planning and its role in urban biodiversity and broader liveability outcomes. These are all areas for future research that, in turn, can inform better practice.

There are notable examples of a lack of vertical and horizontal integration aimed at protecting and coordinating the management of key reserves at the local, regional and catchment levels. On the other hand, strategic planning is emergent in draft district plans that places emphasis and plans for urban ecology outcomes and identifies opportunities in the Sydney Green Grid although an added biodiversity layer would be required. The delivery and coordination of the grid are yet to be fully tested and it is unclear how existing EPIs will facilitate this outcome, given the lack of uniform landscape controls for private development directed towards promoting a green and blue city at the local to regional scales. Caution is advisable on optimism over planning given the lack of success of WSUD policies and targets such as an overarching SEPP, despite the significance of waterways in Sydney, Wollongong and Newcastle and the success of WSUD approaches in Melbourne and southeast Queensland, among other locations.

A shift in expression may be needed, along with greater socio-political engagement on urban ecology. We suggest that it is necessary to change the debate from ‘environmental protection’ to ‘environmental management’ (Taylor, 2005). From a management perspective, nature can be both conserved and created (Hajer, 2003), and these can be complementary activities in urban landscapes.

From a legal and policy perspective, implementing reforms to protect and manage urban ecosystems opens the door to a multidisciplinary approach requiring collaboration and consistency in the drivers affecting the terrestrial and aquatic resources of our cities (Lennon, 2015). Although urban ecology may be a driver of reform, policies and planning must deliver on multifunctional outcomes. Increasingly, such outcomes are being framed around ‘liveability’, which captures the health, community and economic benefits delivered by ecosystem services (chapters 3 and 5). If liveability is

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<sup>39</sup>For example, SEPP 19 clause 2(2) and *Environmental Planning and Assessment Act 1979* (NSW) s 5.

to become a driver of urban planning reform, the traditional silo approach to biodiversity management (and other approaches such as housing affordability) need to be replaced with a more integrated approach that has been shown to have greater adaptive capacity (Pahl-Wostl, 2009). Such a change will no doubt require considerable negotiation across disciplines, not least in how urban ecology is valued in decision-making processes and how green infrastructure is defined (Matthews *et al.*, 2015).<sup>40</sup>

Many examples exist of policies, projects and initiatives that contribute positively and enhance urban ecology (also refer to Chapter 6). In both national and NSW legal and policy areas, however, there is a lack of consistency and priority, and many actors have not yet realised the urgent need for a coherent program of integrated reforms.

Across Australia (including in NSW), the major hurdles to implementing and encouraging urban ecology are as follows (e.g. Lawlor *et al.*, 2006; Josh Byrne & Associates, 2016):

- Lack of federal and state government policy and support (providing a strong vertical policy framework).
- Lack of drivers to encourage implementation across all levels of government (including both regulatory and non-regulatory measures).
- Lack of consistency between laws, policies and management practices across all levels of government.
- Lack of coordination in relation to the development (currently ad hoc) and application of policies affecting on-the-ground decisions by and between all levels of government.
- Lack of a prioritised compliance and regulatory culture (resulting in ongoing and excessive clearing of vegetation and habitat).
- Absence of, or incomplete, development design and construction rating tools to promote urban greening at the design and development assessment stages.
- Poor green asset management and maintenance practices.
- Pressure on land for development in urbanised areas, particularly in greenfields.
- Lack of, or incomplete, knowledge base on the benefits of green spaces in urban settings (ranging from carbon sequestration to mental wellbeing).
- Lack of adequate funding mechanisms to manage existing and future biodiversity assets.

The following immediate recommendations can be made to advance urban ecology outcomes in NSW.

- **Strategic planning must incorporate urban ecological outcomes.** The GSC has released its draft district plans, which ultimately will inform local plans and a future review of the metropolitan plan for Sydney. The GSC can also provide leadership on ongoing reform to city planning in Newcastle and Wollongong. As noted by Stockwell (1993), policymaking does not follow a rational process, and science-informed evidence is one of many considerations in determining the directions of government (Ryder, 1996; Hickey *et al.*, 2013). For this reason, the transformation of policy and practice led by the GSC needs the support of other government departments, and a multidimensional approach must be adopted in which

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<sup>40</sup> Noting that this must be more than trees and bushland to unshackle biodiversity from the perception that it is a purely environmental concern. Also, special consideration will be needed of urban ecology's role in climate-change adaptation and mitigation.

sustainability-driven reform is based on the notion of a liveable city (Cilliers *et al.*, 2015). For biodiversity, this requires coordination at geographic scales, including grassroots community-led strategic planning for neighbourhoods and reforms to planning (such as the use of an urban ecology SEPP) and governance systems (to resolve, among other things, gaps and duplications in decision-making and accountability) (Andersson *et al.*, 2014).

- **A performance-based design and construction ratings tool, with statutory effect, should be developed to support and advance urban ecological outcomes.** The Department of Planning is reviewing a number of state environmental planning policies, including SEPP 19 ('Bushland in urban areas'), providing an ideal opportunity to implement such a tool or tools. Currently, the mandatory building rating schemes, the Nationwide House Energy Rating Scheme (NatHERS), and the National Australian Built Environment Rating System (NABERS), do not incorporate the contribution of urban green spaces to building performance beyond considerations pertaining to green walls and roofs (NatHERS) and a limited consideration of land-use ecology for public buildings (NABERS). Of the voluntary industry-led rating tools, the Green Building Council of Australia and its Green Star ratings system, and the Infrastructure Sustainability Council of Australia and its Infrastructure Sustainability rating scheme, offer specific categories to reward ecological protection and enhancement, but they have relatively low impact as voluntary tools. The goal should be to have codified development standards that protect and manage urban ecological outcomes, and the standards should be mandatory and set the minimum expectations.
- **Regulatory reform must be combined with incentives and awareness programs.** Reforms for improving urban ecological outcomes need to be funded, and they must offer sufficient incentives to maximise outcomes rather than simply support minimal compliance. Associated with the reforms, tailored awareness programs and technical information are needed to support government, industry (the building and design sector) and households.
- **Systems should be established to coordinate and provide consistent policies, guidelines and operational protocols between and within state and local governments.** Such systems would extend to utilities and land development organisations (e.g. Urban Growth NSW) to ensure that their activities are framed within a sustainability agenda (and not one that prioritises economic outcomes). Coordination, consistency and spatial alignment between and within government agencies is required to achieve long-term beneficial urban ecological outcomes. For land-use planning, this must also overcome the inherent governance tensions between the roles of state and local governments and the sectoral (silo) policies and practices within and between levels of government (territorial integration; see Vigar & Healey, 1999).
- **A review of urban biodiversity governance in NSW cities should be undertaken** to reveal, for example: the major players; the actual and perceived roles and responsibilities; the locations of institutional barriers and opportunities (inter- and intra-organisational review); the role of community-based participatory processes; collaborative approaches that work – and why they do (inter- and intra-agency and community-based); and the coalitions that exist or could be formed that align with a values-based urban ecology agenda.
- **Government and industry must apply innovative and multidisciplinary approaches to promote urban ecology in their operational planning and maintenance practices.** Such practices should be founded on scientific evidence (Ives *et al.*, 2010), have social relevance (liveability), and be communicated clearly and consistently (Hickey *et al.*, 2013). Examples of

good-practice planning and management exist and are contributing to successful urban ecological outcomes (such as the Roads and Maritime Services' guidelines for roadside management plans: NSW Roadside Environment Committee, n.d.). What is lacking is the 'mainstreaming' of such practices across and between institutions; in effect, they have been insufficient to change organisational (and social) norms and expectations. Identifying and promoting urban ecology approaches may be a role for an independent (e.g. Environmental Trust) or central (e.g. Premier and Cabinet) government agency, with clear and accountable measures and targets.

- **Local government should review their community strategic plans linking neighbourhood planning based on participatory process to planning outcomes.** This reform has been foreshadowed by the Minister for Planning (9 January 2017) as part of broader planning reforms. It provides an opportunity for grassroots involvement in defining the character of neighbourhoods, which is envisaged to be codified in explicit planning outcomes. Although details on such a codification are lacking, it is likely to involve a change to LEPs and the formation of new local policies, both of which provide opportunities to bring urban ecology and liveability to the fore.
- **Mechanisms should be identified to incorporate ecosystem services into decision-making processes.** Ecosystem services are inadequately valued in planning and development decisions. In the context of climate change, urban greening can provide a number of services over and above carbon sequestration and pollution filtration. The Australian Government's National Carbon Offset Standard and Emissions Reduction Fund<sup>41</sup> fail to recognise these functions. Ultimately, this is contrary to realising the true value of urban green assets and their potential to mitigate climate change and improve urban ecological outcomes. The mitigation of climate change will be pivotal in providing a healthy and resilient urban environment.
- **Mechanisms should be established to monitor and evaluate urban ecological outcomes.** Such mechanisms should be designed to assess the efficacy of land-use policies and practices using scientific and citizen science approaches. Monitoring and evaluation must be undertaken at timely intervals to maintain scientific relevance and community engagement, and data must be publicly accessible.

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<sup>41</sup>includes the former Carbon Farming Initiative.

## 4.9 Chapter references

- ABS (Australian Bureau of Statistics) (2010). *Year Book Australia, 2009-10*. Available at <http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/916F96F929978825CA25773700169C65>
- Andersson, E., Barthel, S., Borgstrom, S., Colding, J., Elmqvist, T., Folke, C., & Gren, A. (2014). Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services. *Ambio*, 43(4), 445-453. doi:10.1007/s13280-014-0506-y
- Bai, X., McAllister, R. R. J., Beaty, R. M., & Taylor, B. (2010). Policy and governance in a global environment: complex systems, scale mismatches and public participation. *Current Opinion in Environmental Sustainability*, 2(3), 129-135.
- Barry, J. (2007). *Environment and Social Theory*. Routledge.
- Beatley, T. (2011). *Biophilic Cities, Integrating Nature into Urban Design and Planning*. Washington, DC: Island Press.
- Becker, C. (1990). *The Biotope Area Factor as an Ecological Parameter: principles for its determination and identification of the target*. Berlin Senate Department for Urban Development and the Environment, Berlin.
- Blacktown City Council (2015). *Development Control Plan*. Available at [http://www.blacktown.nsw.gov.au/Planning\\_and\\_Development/Plans\\_and\\_Guidelines/Blacktown\\_Development\\_Control\\_Plan\\_2015](http://www.blacktown.nsw.gov.au/Planning_and_Development/Plans_and_Guidelines/Blacktown_Development_Control_Plan_2015)
- Bradsen, J. (1992). Biodiversity legislation: species, vegetation, habitats. *Environmental and Planning Law Journal*, 9, 175.
- Buijs, A., Elands, B., Havik, G., Ambrose-Oji, B., Geróházi, E., Jagt, A. v. d., Mattijssen, T., Møller, M. S., & Vierikko, K. (2016). *Innovative Governance of Urban Green Spaces: learning from 18 innovative examples across Europe*. Available at [http://greensurge.eu/working-packages/wp6/files/Innovative\\_Governance\\_of\\_Urban\\_Green\\_Spaces\\_-\\_Deliverable\\_6.2.pdf](http://greensurge.eu/working-packages/wp6/files/Innovative_Governance_of_Urban_Green_Spaces_-_Deliverable_6.2.pdf)
- Buizer, M., Elands, B., Mattijssen, T., van der Jagt, A., Ambrose, B., Geróházi, É., Santos, A., & Steen Møller, M. (2015). *The Governance of Urban Green Spaces in Selected EU-Cities: policies, practices, actors, topics*. Available at [http://greensurge.eu/working-packages/wp6/files/Buizer\\_et\\_al\\_2015\\_D6.1\\_GREEN\\_SURGE\\_The\\_governance\\_of\\_urban\\_green\\_spaces\\_in\\_selected\\_EU\\_cities.pdf](http://greensurge.eu/working-packages/wp6/files/Buizer_et_al_2015_D6.1_GREEN_SURGE_The_governance_of_urban_green_spaces_in_selected_EU_cities.pdf)
- Byron, N., Craik, W., Keniry, J., & Possingham, H. (2014). *A Review of Biodiversity Legislation in New South Wales: final report*. Independent Biodiversity Legislation Review Panel, NSW Office of Environment and Heritage. Available at <http://www.environment.nsw.gov.au/resources/biodiversity/BiodivLawReview.pdf>
- Choi, L., & McIlrath, B. (2016). *New South Wales' Planning Framework for Water Sensitive Urban Design*. Cooperative Research Centre for Water Sensitive Cities. Available at <https://watersensitivecities.org.au/content/new-south-wales-planning-framework-water-sensitive-urban-design/>
- Cilliers, E. J., Timmermans, W., van den Goorbergh, F., & Slijkhuis, J. S. A. (2015). Designing public spaces through the lively planning integrative perspective. *Environment, Development and Sustainability*, 17, 1367-1380.

- City of Parramatta (2011). *Development Control Plan*. Available at [http://www.parracity.nsw.gov.au/build/forms\\_and\\_planning\\_controls/planning\\_controls/development\\_control\\_plans/dcp](http://www.parracity.nsw.gov.au/build/forms_and_planning_controls/planning_controls/development_control_plans/dcp)
- City of Sydney (2012a). *Decentralised Water Master Plan*. Available at [http://www.cityofsydney.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0005/122873/Final-Decentralised-Water-Master-Plan.pdf](http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0005/122873/Final-Decentralised-Water-Master-Plan.pdf)
- City of Sydney (2012b). *Development Control Plan*. Available at <http://www.cityofsydney.nsw.gov.au/development/planning-controls/development-control-plans>
- City of Sydney (2012c). *Greening Sydney Plan*. Available at [http://www.cityofsydney.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0009/135882/GreeningSydneyPlan.pdf](http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0009/135882/GreeningSydneyPlan.pdf)
- City of Sydney (2014a). *Community Strategic Plan*. Available at [http://www.cityofsydney.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0005/209876/Community-strategic-plan-2014.pdf](http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0005/209876/Community-strategic-plan-2014.pdf)
- City of Sydney (2014b). *Green Roofs and Walls Policy Implementation Plan*. Available at [http://www.cityofsydney.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0010/200242/Green-Roofs-and-Walls-Policy-Implementation-Plan-Adopted.pdf](http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0010/200242/Green-Roofs-and-Walls-Policy-Implementation-Plan-Adopted.pdf)
- City of Sydney (2014c). *Urban Ecology Strategic Action Plan*. Available at [http://www.cityofsydney.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0011/198821/2014-109885-Plan-Urban-Ecology-Strategic-Action-Plan\\_FINAL-\\_adopted.pdf](http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0011/198821/2014-109885-Plan-Urban-Ecology-Strategic-Action-Plan_FINAL-_adopted.pdf)
- Cloos, I. (2004). A project celebrates its 25th birthday – the landscape programme including nature conservation for the city of Berlin. *STADT+GRÜN*. Available at [http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/lapro/download/lapro-25jahre\\_englisch.pdf](http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/lapro/download/lapro-25jahre_englisch.pdf)
- Commonwealth of Australia and NSW Government (2015). New South Wales Bilateral Agreement Information. Available at <https://www.environment.gov.au/protection/environment-assessments/bilateral-agreements/nsw>.
- CRCWSC (Cooperative Research Centre for Water Sensitive Cities) (2016). *Opportunities for a Water Sensitive Greater Sydney*. Available at <https://watersensitivecities.org.au/content/opportunities-water-sensitive-greater-sydney/>
- David, P. J., & Wright, I. A. (2014). A review of policy, legal, land use and social change in the management of urban water resources in Sydney, Australia: a brief reflection of challenges and lessons from the last 200 years. *Land Use Policy*, 36, 450-460.
- Davies, C., Hansen, R., Rall, E., Pauleit, S., Laforteza, R., Bellis, Y. D., Santos, A., & Tosics, I. (2016). *Green Infrastructure Planning and Implementation: the status of European green space planning and implementation based on an analysis of selected European city-regions*. Available at [http://greensurge.eu/working-packages/wp5/files/D\\_5.1\\_Davies\\_et\\_al\\_2015\\_Green\\_Infrastructure\\_Planning\\_and\\_Implementation\\_v2.pdf](http://greensurge.eu/working-packages/wp5/files/D_5.1_Davies_et_al_2015_Green_Infrastructure_Planning_and_Implementation_v2.pdf)
- Davies, P. J., Ives, C. D., Findlay, S. J., & Taylor, M. P. (2011). Urban rivers and riparian systems: directions and recommendations for legislators, policy makers, developers and community users. *Environmental and Planning Law Journal*, 28(5), 313-331.
- Dempsey, N., & Burton, M. (2012). Defining place-keeping: the long-term management of public spaces. *Urban Forestry and Urban Greening*, 11(1), 11-20.

- Department of Environment and Energy (1992). Intergovernmental Agreement on the Environment. Available at <https://www.environment.gov.au/about-us/esd/publications/intergovernmental-agreement>
- Department of Infrastructure and Regional Development (2015). *State of Australian Cities 2014-2015*. Commonwealth of Australia. Available at [https://infrastructure.gov.au/infrastructure/pab/soac/files/2015\\_SoAC\\_full\\_report.pdf](https://infrastructure.gov.au/infrastructure/pab/soac/files/2015_SoAC_full_report.pdf)
- Department of Infrastructure and Regional Development (2016). *Western Sydney Airport*. Commonwealth of Australia. Available at [http://westernsydneyairport.gov.au/resources/factsheets/files/Fact\\_sheet-Biodiversity.pdf](http://westernsydneyairport.gov.au/resources/factsheets/files/Fact_sheet-Biodiversity.pdf)
- Department of the Prime Minister and Cabinet (2016). *Smart Cities Plan*. Commonwealth of Australia. Available at <https://cities.dpmc.gov.au/smart-cities-plan/documents/48080/download>
- Farrier, M. D., Kelly, A. H., & Langdon, A. (2007). Biodiversity offsets and native vegetation clearance in New South Wales: the rural/urban divide in the pursuit of ecologically sustainable development. *Environmental and Planning Law Journal*, 24(6), 427.
- Francis, J., Murphy, S., Hall, G., Jones, M., McElroy, E., Ayrey, K., Ramachandran, L., Alsop, N., & Rayner, J. (2013). Growing Green Guide: Green Roofs, Walls & Facades Policy Options Background Paper. *Growing Green Guide for Melbourne*, VIC Department of Environment and Primary Industries.
- Frantzeskaki, N., & Tilie, N. (2014). The dynamics of urban ecosystem governance in Rotterdam, the Netherlands. *Ambio*, 43(4), 542-555.
- GSC (Greater Sydney Commission) (2016a). *A Draft Amendment to Update A Plan for Growing Sydney*.
- GSC (Greater Sydney Commission) (2016b). *Draft District Plans*. Available at <http://www.greatersydneycommission.nsw.gov.au/district-plans>
- GSC (Greater Sydney Commission) (2016c). Governance: the Greater Sydney Commission Act 2015 sets out our objectives and functions. Available at <http://www.greatersydneycommission.nsw.gov.au/en/About-Us/Governance>.
- GSC (Greater Sydney Commission) (2016d). A Plan for Growing Sydney: the directions. Available at <http://www.greatersydneycommission.nsw.gov.au/What-We-Do/A-Plan-for-Growing-Sydney/The-Directions>.
- Haddow, A. (2007). Shall we dense? The Winston Churchill Memorial Trust of Australia.
- Hajer, M. (2003). A frame in the fields: policymaking and the reinvention of politics. In M. Hajer & H. Wagenaar (Eds.), *Deliverative Policy Analysis: understanding governance in the network society* (pp. 88-110). Cambridge: Cambridge University Press.
- Hall, T. (2010). Goodbye to the backyard? The minimisation of private open space in the Australian outer-suburban estate. *Urban Policy and Research*, 28(4), 411-433. doi:10.1080/08111146.2010.496715
- Hanford, J. K., Crowther, M. S., & Dieter, F. H. (2016). Effectiveness of vegetation-based biodiversity offset metrics as surrogates for ants. *Conservation Biology*, Early view, doi: 10.1111/cobi.12794.
- Hansen, R., Buizer, M., Rall, E., DeBellis, Y., Davies, C., Elands, B., Wiersum, F., & Pauleit, S. (2015). *Report of Case Study City Portraits. Appendix – GREEN SURGE study on urban green infrastructure planning and governance in 20 European case studies*. Available at [http://greensurge.eu/filer/GREEN\\_SURGE\\_Report\\_of\\_City\\_Portraits.pdf](http://greensurge.eu/filer/GREEN_SURGE_Report_of_City_Portraits.pdf)

- Hansen, R., Rolf, W., Santos, A., Ana, C. L., Száraz, L., Tosics, I., Vierikko, K., Rall, E., Davies, C., & Pauleit, S. (2016). *Advanced Urban Green Infrastructure Planning and Implementation: innovative approaches and strategies from European cities*. Available at [http://greensurge.eu/working-packages/wp5/files/D5\\_2\\_Hansen\\_et\\_al\\_2016\\_Advanced\\_UGI\\_Planning\\_and\\_Implementation\\_v3.pdf](http://greensurge.eu/working-packages/wp5/files/D5_2_Hansen_et_al_2016_Advanced_UGI_Planning_and_Implementation_v3.pdf)
- Hickey, G. M., Forest, P., Sandall, J. L., Lalor, B. M., & Keenan, R. J. (2013). Managing the environmental science-policy nexus in government: perspectives from public servants in Canada and Australia. *Science and Public Policy*, 40, 529-543.
- IPART (Independent Pricing and Regulatory Tribunal) (2006) *Investigation into the Burden of Regulation in NSW and Improving Regulatory Efficiency*. Other Industries – Final Report, October 2006.
- IPART (Independent Pricing and Regulatory Tribunal) (2015). Review of wholesale pricing for Sydney Water and Hunter Water. Available at [http://www.ipart.nsw.gov.au/Home/Industries/Water/Reviews/Metro\\_Pricing/Review\\_of\\_wholesale\\_pricing\\_for\\_Sydney\\_Water\\_and\\_Hunter\\_Water](http://www.ipart.nsw.gov.au/Home/Industries/Water/Reviews/Metro_Pricing/Review_of_wholesale_pricing_for_Sydney_Water_and_Hunter_Water).
- Ives, C. D., & Kelly, A. H. (2016). The coexistence of amenity and biodiversity in urban landscapes. *Landscape Research*, 41(5), 495-509. doi:10.1080/01426397.2015.1081161
- Ives, C. D., Taylor, M. P., & Davies, P. J. (2013). A setback for river and riparian ecosystem: a response to the New South Wales office of water 2012 policy on riparian controls. *Environmental and Planning Law Journal*, 30, 122-131.
- Ives, C. D., Taylor, M. P., Nipperess, D., & Davies, P. (2010). New directions in urban biodiversity conservation: the role of science and its interaction with local environmental policy. *Environmental and Planning Law Journal*, 27, 249.
- Jacobs, B., Mikhailovich, N., & Delaney, C. (2014). *Benchmarking Australia's Urban Tree Canopy: An i-Tree assessment. Final report*. Institute for Sustainable Futures.
- Josh Byrne & Associates (2016). *The 2020 Vision Policy Guide: top ten opportunities*. Available at [http://2020vision.com.au/media/72585/jba\\_book3\\_fa-spreads.pdf](http://2020vision.com.au/media/72585/jba_book3_fa-spreads.pdf)
- Kelly, A. H. (2014). Amenity enhancement and biodiversity conservation in Australian suburbia: moving towards maintaining indigenous plants on private residential land. *International Journal of Law in the Built Environment*, 6, 91-105.
- Ku-ring-gai Council (2016). *Development Control Plan*. Available at [http://www.kmc.nsw.gov.au/Plans\\_regulations/Building\\_and\\_development/Town\\_Planning\\_Documents/Ku-ring-gai\\_Development\\_Control\\_Plan](http://www.kmc.nsw.gov.au/Plans_regulations/Building_and_development/Town_Planning_Documents/Ku-ring-gai_Development_Control_Plan)
- Lawlor, G., Currie, B., Doshi, H., & Wieditz, I. (2006). *Green Roofs: a resource manual for municipal policy makers*. Canada Mortgage and Housing Corporation.
- Le Sénat (2015). *Projet de loi pour la reconquête de la biodiversité, de la nature et des paysages [Bill of law for the re-conquest of biodiversity, nature and landscapes]*. Available at <http://www.senat.fr/dossier-legislatif/pjl14-359.html>
- Lennon, M. (2015). Green infrastructure and planning policy: a critical assessment. *Local Environment: The International Journal of Justice and Sustainability*, 20(8), 957-980.
- Maron, M., Ives, C. D., Kujala, H., Bull, J. W., Maseyk, F. J., Bekessy, S., Gordon, A., Watson, J. E., Lentini, P. E., Gibbons, P., & Possingham, H. P. (2016). Taming a wicked problem: resolving controversies in biodiversity offsetting. *BioScience*, 66(6), 489-498.

- Matthews, T., Lo, A. Y., & Byrne, J. A. (2015). Reconceptualizing green infrastructure for climate change adaptation: barriers to adoption and drivers for uptake by spatial planners. *Landscape and Urban Planning*, 138, 155-163.
- McNeely, J. A. (1992). The sinking ark: pollution and the worldwide loss of biodiversity. *Biodiversity and Conservation*, 1, 2-18.
- Meadowcroft, J. (2009). What about the politics? Sustainable development, transition management and long term energy. *Policy Sciences*, 42(4), 323.
- Newton, P. W. (2010). Beyond greenfield and brownfield: the challenge of regenerating Australia's greyfield suburbs. *Built Environment*, 36(1), 81-104.
- North Sydney Council (2013). *Development Control Plan*. Available at [http://www.northsydney.nsw.gov.au/Building\\_Development/LEP\\_DCP/Development\\_Control\\_Plan#1](http://www.northsydney.nsw.gov.au/Building_Development/LEP_DCP/Development_Control_Plan#1)
- NSW Department of Planning & Environment (2015). *Draft Hunter Regional Plan*. Available at <http://www.planning.nsw.gov.au/~media/Files/DPE/Plans-and-policies/draft-hunter-regional-plan-2015-11.ashx>
- NSW Department of Planning and Environment (2014). *A Plan for Growing Sydney*. Available at <http://www.planning.nsw.gov.au/~media/Files/DPE/Plans-and-policies/a-plan-for-growing-sydney-2014-12.ashx>
- NSW Department of Planning and Environment (2015). *Illawarra-Shoalhaven Regional Plan*. Available at <http://www.planning.nsw.gov.au/~media/Files/DPE/Plans-and-policies/illawarra-shoalhaven-regional-plan-2015-11.ashx>
- NSW Department of Planning and Environment (2016). List of state environmental planning policies (SEPPs). Available at <https://www.planningportal.nsw.gov.au/understanding-planning/legislation/state-environmental-planning-policies/list-state-environmental>.
- NSW Department of Primary Industries (2012a). *Controlled Activities on Waterfront Land: guidelines for riparian corridors on waterfront land*. Available at [http://www.water.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0004/547222/licensing\\_approvals\\_controlled\\_activities\\_riparian\\_corridors.pdf](http://www.water.nsw.gov.au/__data/assets/pdf_file/0004/547222/licensing_approvals_controlled_activities_riparian_corridors.pdf)
- NSW Department of Primary Industries (2012b). *Guidelines for Riparian Corridors on Waterfront Land*. Office of Water. Available at [http://www.water.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0004/547222/licensing\\_approvals\\_controlled\\_activities\\_riparian\\_corridors.pdf](http://www.water.nsw.gov.au/__data/assets/pdf_file/0004/547222/licensing_approvals_controlled_activities_riparian_corridors.pdf)
- NSW Department of Primary Industries (2013). *Fisheries NSW Policy and Guidelines for Fish Habitat Conservation and Management (2013 update)*. Available at [http://www.dpi.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0009/468927/Policy-and-guidelines-for-fish-habitat.pdf](http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/468927/Policy-and-guidelines-for-fish-habitat.pdf)
- NSW Department of Primary Industries (2017). Fishing in Sydney Harbour. Available at <http://www.dpi.nsw.gov.au/fishing/recreational/fishing-skills/fishing-in-sydney-harbour>
- NSW Government. *National Parks and Wildlife Act 1974*. Available at <http://www.legislation.nsw.gov.au/#/view/act/1974/80>
- NSW Government. *Environmental Planning and Assessment Act 1979*. Available at <http://www.legislation.nsw.gov.au/#/view/act/1979/203/title>
- NSW Government. *Local Government Act 1993*. Available at <http://www.legislation.nsw.gov.au/inforce/ca7de0d2-0087-6c91-bdba-892f060e8ed8/1993-30.pdf>

NSW Government. *Fisheries Management Act 1994*. Available at <http://www.legislation.nsw.gov.au/#/view/act/1994/38>

NSW Government. *Threatened Species Conservation Act 1995*. Available at <http://www.legislation.nsw.gov.au/#/view/act/1995/101>

NSW Government. *Environmental Planning and Assessment Regulation 2000*. Available at <http://www.legislation.nsw.gov.au/inforce/9d376d33-da45-c796-d869-86fe6d73c9c1/2000-557.pdf>

NSW Government. *Nature Conservation Trust Act 2001*. Available at <http://www.legislation.nsw.gov.au/#/view/act/2001/10>

NSW Government. *Native Vegetation Act 2003*. Available at <http://www.legislation.nsw.gov.au/#/view/act/2003/103/title>

NSW Government. *Local Land Services Act 2013*. Available at <http://www.legislation.nsw.gov.au/#/view/act/2013/51/full>

NSW Government. *Environmental Planning and Assessment Amendment (Savings and Transitional) Regulation 2015*. Available at <http://www.legislation.nsw.gov.au/regulations/2016-2.pdf>

NSW Government. *Biodiversity Conservation Bill 2016a*, 63/2016 C.F.R. Available at <https://www.parliament.nsw.gov.au/bills/Pages/bill-details.aspx?pk=3357>

NSW Government (2016b). Premier's priorities in action. Available at <https://www.nsw.gov.au/premiers-priorities>.

NSW Office of Environment and Heritage (2013). *Introducing Saving our Species*. Available at <http://www.environment.nsw.gov.au/resources/threatenedspecies/SavingOurSpecies/130344intsos.pdf>

NSW Office of Environment and Heritage (2016a). Cumberland Plain Woodland in the Sydney Basin Bioregion: proposed critically endangered ecological community listing. Available at <http://www.environment.nsw.gov.au/determinations/cumberlandplainpd.htm>.

NSW Office of Environment and Heritage (2016b). *NSW Climate Change Policy Framework*. Available at <http://www.environment.nsw.gov.au/research-and-publications/publications-search/nsw-climate-change-policy-framework>

NSW Premier and Cabinet (2013). *Integrated Planning and Reporting Manual for local government in NSW: Planning a sustainable future*. Division of Local Government. Available at <https://www.olg.nsw.gov.au/sites/default/files/Intergrated-Planning-and-Reporting-Manual-March-2013.pdf#page=17>

NSW Roads and Maritime Services (2014a). *Beyond the pavement: Urban design policy procedures and design principles* Available at <http://www.rms.nsw.gov.au/documents/projects/planning-principles/beyond-pavement.pdf>

NSW Roads and Maritime Services (2014b). *EIA Guidelines: environmental assessment procedure. Project review of environmental factors: roads*. Available at <http://www.rms.nsw.gov.au/documents/about/environment/planning-and-assessment/eia-guidelines-project-review-environmental-factors.pdf>

NSW Roads and Maritime Services (2016). *Water Sensitive Urban Design Guideline: applying water sensitive urban design principals to NSW transport projects*. Available at <http://www.rms.nsw.gov.au/documents/projects/planning-principles/urban-design/water-sensitive-urban-design-guideline.pdf>

- NSW Roadside Environment Committee (n.d.). *Guidelines for the development of Roadside Management Plans*. Roads and Traffic Authority. Available at <http://www.rms.nsw.gov.au/documents/about/environment/rec-rmp-guidelines.pdf>
- NSW Rural Fire Service (2015). *10/50 Vegetation Clearing Code of Practice for New South Wales*. Available at [http://www.rfs.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0003/18453/1050-Vegetation-Clearing-Code-of-Practice.pdf](http://www.rfs.nsw.gov.au/__data/assets/pdf_file/0003/18453/1050-Vegetation-Clearing-Code-of-Practice.pdf)
- NSW Spatial Services (2016). Spatial services portal: spatial information exchange maps. Available at <https://six.nsw.gov.au/>.
- Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change*, 19(3), 354-365.
- Parker, G., & Doak, J. (2012). *Key Concepts in Planning*. Sage.
- Philadelphia Water (2016). Green Stormwater Infrastructure. Available at [http://www.phillywatersheds.org/what\\_were\\_doing/green\\_infrastructure](http://www.phillywatersheds.org/what_were_doing/green_infrastructure)
- Portland City Council (2007). *Green Streets Policy*. Available at <https://www.portlandoregon.gov/bes/45386>
- Powers, J. (2000). How effective are local government planning schemes in protecting ecosystems? *Local Government Law Journal*, 5, 172-184.
- République Française, *National Strategy for Ecological Transition towards Sustainable Development 2015*. Available at <http://www.developpementdurable.gouv.fr>
- Ruming, K. J., & Davies, P. J. (2014). To what extent 'an entirely new approach to how planning is done'? Tracing planning system reform in New South Wales. *Australian Planner*, 51(2), 122-131.
- Ryder, D. (1996). The analysis of policy: understanding the process of policy development. *Addiction*, 91(9), 1265-1270.
- Sandström, U. G. (2002). Green infrastructure planning in urban Sweden. *Planning Practice and Research*, 17(4), 373-385.
- Sandström, U. G., Angelstam, P., & Khakee, A. (2006). Urban comprehensive planning: identifying barriers for the maintenance of functional habitat networks. *Landscape and Urban Planning*, 75, 43-57.
- Scott, J. M., Heglund, P. J., Morrison, M., Haufler, J. B., Raphael, M. G., & Samson, F. B. (2002). *Predicting Species Occurrences: issues of scale and accuracy*. Covello, CA, USA: Island Press.
- Senate Department for Urban Development and the Environment (2016). The history of open space development in Berlin. Available at [http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/chronik/index\\_en.shtml](http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/chronik/index_en.shtml)
- Stockwell, T. (1993). Influencing the labelling of alcoholic beverage containers: informing the public. *Addiction*, 88, 53S-60S.
- Sutherland Shire Council (2015). *Draft Development Control Plan*. Available at <http://www.sutherlandshire.nsw.gov.au/Development/Development-Control-Plans-DCP/Draft-Development-Control-Plan-2015>
- Taylor, G. (2005). *Negotiated Governance and Public Policy in Ireland*. Manchester: Manchester University Press.

- The City of Newcastle (2012). *Development Control Plan*. Available at <http://www.newcastle.nsw.gov.au/Development/Land-Use-Planning/Development-control-plans>
- The City of Philadelphia. (2015). *Greenworks Philadelphia 2015 Progress Report* [Press release]. Available at <https://alpha.phila.gov/media/20160419140539/2015-greenworks-progress-report.pdf>
- Transport for NSW (2012). *NSW Long Term Transport Master Plan*. Available at <http://www.transport.nsw.gov.au/sites/default/files/b2b/publications/nsw-transport-masterplan-final.pdf>
- Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. *Landscape and Urban Planning, 81*(3), 167-178. doi:<http://dx.doi.org/10.1016/j.landurbplan.2007.02.001>
- US EPA (United States Environmental Protection Agency) (2008a). *Funding Options*. Available at [https://www.epa.gov/sites/production/files/2015-10/documents/gi\\_munichandbook\\_funding.pdf](https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_funding.pdf)
- US EPA (United States Environmental Protection Agency) (2008b). J. Bitting, C. Kloss, & Low Impact Development Center. *Green Infrastructure Retrofit Policies*. Available at [https://www.epa.gov/sites/production/files/2015-10/documents/gi\\_munichandbook\\_retrofits.pdf](https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_retrofits.pdf)
- US EPA (United States Environmental Protection Agency) (2008c). R. Lukes, C. Kloss, & Low Impact Development Center. *Green Streets*. Available at [https://www.epa.gov/sites/production/files/2015-10/documents/gi\\_munichandbook\\_green\\_streets\\_0.pdf](https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_green_streets_0.pdf)
- US EPA (United States Environmental Protection Agency) (2008d). C. Kloss & Low Impact Development Center. *Rainwater Harvesting Policies*. Available at [https://www.epa.gov/sites/production/files/2015-10/documents/gi\\_munichandbook\\_harvesting.pdf](https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_harvesting.pdf)
- US EPA (United States Environmental Protection Agency) (2009). *Incentive Mechanisms*. Available at [https://www.epa.gov/sites/production/files/2015-10/documents/gi\\_munichandbook\\_incentives.pdf](https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_incentives.pdf)
- US EPA (United States Environmental Protection Agency) (2010). *Green Infrastructure Case Studies: municipal policies for managing stormwater with green infrastructure*. (EPA-841-F-10-004). Washington, DC. Available at [http://greatlakesresilience.org/sites/default/files/library\\_resources\\_2010\\_EPA\\_GreenInfrastructureCaseStudies.pdf](http://greatlakesresilience.org/sites/default/files/library_resources_2010_EPA_GreenInfrastructureCaseStudies.pdf)
- US EPA (United States Environmental Protection Agency) (2012). *Urban Runoff: low impact development*. Barrier Buster Factsheets.
- van der Heijden, J. (2015). On the potential of voluntary environmental programmes for the built environment: a critical analysis of LEED. *Journal of Housing and the Built Environment, 30*(4).
- Vigar, G., & Healey, P. (1999). Territorial integration and 'plan-led' planning. *Planning Practice & Research, 14*(2), 153-169.
- Wachter, S. (2005). *The Determinants of Neighborhood Transformations in Philadelphia Identification and Analysis: the new Kensington pilot study*. The Wharton School, University of Pennsylvania.

Weinstein, M. (2010). Sustainability science: the emerging paradigm and the ecology of cities. *Sustainability: Science, Practice, & Policy*, 6(1), 1-5.

Wu, J. G. (2013). Landscape sustainability science: ecosystem services and human well-being in changing landscapes. *Landscape Ecology*, 28, 999-1023.

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## 5 THE BUILT ENVIRONMENT AND LANDSCAPE DESIGN

### DESKTOP REVIEW OF LITERATURE

Prepared by:

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National Green Infrastructure Network

2017

## 5.1 Key points

- Wide-ranging, measurable benefits can be obtained by protecting and enhancing urban ecosystems in the process of urban development and acknowledging the intrinsic value of urban biodiversity.
- Benefits arising from ecosystem services include: carbon sequestration, air-quality improvement, stormwater management, energy-use reduction, habitat provision, and improvements in local climate.
- Ecosystem services also generate social, health, wellbeing and economic benefits, including enhanced visual and aesthetic values.
- Taking urban ecology into account in urban development increases a city's resilience to change, including changes in climate and the UHI effect.
- Urban ecosystems are enhanced by green infrastructure, which comprises products, technologies and design approaches that mimic natural processes and extend green cover in built-up urban environments.
- The use of green infrastructure approaches can support urban ecological renewal at the site to city scales.

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## 5.2 Introduction

Urbanisation is rapidly changing the shape and composition of Australian cities, putting major pressures on biodiversity, water resources and human health and wellbeing. Based on the current trajectory of urban intensification and expansion, there will be further losses of biodiversity and habitats.

In 2007, for the first time, the proportion of the world population living in urban areas exceeded 50%, and urban populations are predicted to continue increasing (Ahern, 2011). The United Nations estimates that 70% of the world's population will be urban by 2050. The population of NSW is estimated to be 11.5 million people in 2061 (ABS, 2013), an increase of 4.2 million people (or 57%) compared with 2013. In Sydney, the population is expected to increase by 1.65 million people by 2031, with 900,000 of this increase occurring in western Sydney (NSW Government, 2014).

This desktop literature review discusses the relationship between the built environment and urban ecology. Given the large body of literature on this topic, the review focuses on literature published in the last ten years and on two primary research themes:

- 1) The importance of applying urban ecology in urban renewal and development projects.
- 2) Methods and strategies for integrating urban ecology into the built environment.

These two themes address the 'why' and 'how' of urban ecology and its integral relationship with the built environment. A key aim of the review is to provide the NSW Environmental Trust with an evidence base to enable the greatest gains in urban ecology. This chapter provides a succinct review of evidence to support policies and funding models to promote ecological outcomes in urban renewal and development projects.

A wide range of evidence is explored, the nature of which varies depending on disciplinary traditions. We acknowledge differences in the approaches taken to research by social scientists compared with natural scientists. **Appendix C** contains a full list of journals consulted in the review.

The findings apply to the built environment in various ways, and they can be applied at different geographic scales and to different demographic groups, ecological communities and cultural contexts. All these factors influence urban ecological outcomes in unique and different ways.

## 5.3 Aims and objectives

The primary aim of this literature review is to establish an evidence base to assist in the development and implementation of urban ecology principles in urban renewal and development projects in cities of more than 100,000 people in NSW, focusing on the relationship between urban ecology and the built environment. The review aims to guide the NSW Environmental Trust and other NSW government agencies in areas where they can be most influential. Other literature reviews undertaken as part of the project focus on the relationships between urban ecology and urban biodiversity (Chapter 3) and urban ecology and legislation and policy (Chapter 4). Inevitably there are crossovers between these areas.

The review is intended to provide a plain-English discussion of relevant literature accessible to readers from a range of professions. Its objectives are to:

- Provide the evidence base for practical recommendations that will be set out in the blueprint document to improve biodiversity outcomes in Sydney, Wollongong and Newcastle.
- Provide a succinct review of literature from the past ten years.
- Use plain English to engage with a multidisciplinary readership.

## 5.4 Scope and methodology

### Research question formulation

The theme of urban ecology and the built environment encompasses a range of multidimensional, multispatial and multitemporal relationships that cross disciplinary boundaries. Such complexity makes urban ecology difficult to define, map and monitor.

To help in achieving the aims of the literature review, two research questions were formulated to define its scope. The questions were informed by the project brief, discussions with the built-environment project team, and a preliminary review of relevant academic and grey literature using Google searches. The research questions are given below.

#### Question 1

##### **Why is it important to apply urban ecology principles to urban renewal and development projects?**

This leads to the question of ‘What are the benefits of applying urban ecology principles?’ The literature provides evidence of numerous benefits, including the provision of urban ecosystem services, urban resilience, health benefits, economic benefits and visual and aesthetic benefits.

#### Question 2

##### **How can urban ecology be integrated into the built environment?**

The literature demonstrates that urban ecology can be integrated into the built environment through green infrastructure interventions such as:

- Green roofs and green walls
- Parks and gardens
- Street trees
- Parklets
- Urban forests
- Green corridors/greenways, such as riparian corridors
- Residential gardens
- Public institutional green spaces associated with facilities such as schools, universities and hospitals
- Private green spaces such as cemeteries and golf courses, and corporate landscapes such as business parks
- Wetlands and intertidal zones
- WSUD features such as constructed wetlands, bioswales and raingardens
- Infrastructure corridors such as road and rail reserves.

Emerging technologies also provide examples of best-practice design.

## **Search strategy**

The search for relevant literature was conducted using databases, internet search engines and websites, and various combinations of relevant key words, in a three-step process.

In step 1, a general Google search was conducted for relevant terms to identify journal articles and grey literature. This provided an overview of some of the key authors and research organisations working in this space.

In step 2, peer-reviewed papers published in English in the period 2007–2016 were searched using the SCOPUS database and a series of pre-defined search queries (see below). We reviewed the reference lists of key articles, including systematic review journal articles, and documents. Where key documents cited other literature, the original source of information was located and reviewed. Additional papers were identified from the reference lists of papers found in the database search. This is known as the ‘snowball method’ of literature review (Wohlin, 2014).

In step 3, we supplemented the research done in steps 1 and 2 with a search of Google Scholar using the relevant key words.

Throughout the literature review process, we collected articles from team members, the client, PhD candidates and members of the project advisory committee. A Google search was used to locate relevant grey literature.

## **Search terms**

The following terms and combinations of terms were applied in the search strategy:

urban ecology AND ecosystem services AND review

urban ecology AND built environment AND review

urban ecology AND resilience and review

urban ecology AND resilience

urban ecology AND urban resilience

green infrastructure AND urban resilience

urban resilience AND review

urban ecosystem services AND stormwater

urban ecology AND economic benefits

urban ecology AND aesthetic benefits

urban ecology AND visual benefits

urban ecology AND visual

urban ecosystem services

built environment AND ecology

green roofs AND urban heat island

urban ecology AND green wall

## 5.5 Definitions

Chapter 2 provides definitions of the key terms used in this report. Urban ecology is inherently an interdisciplinary field; many of its concepts and terms have various meanings, depending on factors such as the nationality and professional background of the authors. Policymakers, ecologists, architects, planners, landscape architects, arborists, ecological economists and a host of other professions are an integral part of, and help shape, the field, and a common understanding of its key terms is important for ensuring a consistent understanding of it. A potential spin-off benefit of this review could be to provide a basis for an accepted, industry-wide terminology to enhance communication between sectors.

## 5.6 The evidence: the importance of applying urban ecology in urban renewal and development projects

Urban ecosystems have intrinsic value for which they should be protected; however, they also provide a wide range of valuable services and benefits for human populations. These are generally known as **ecosystem services**, and include:

- **Biophysical** benefits such as carbon sequestration, air quality, stormwater management, energy efficiency, habitat provision, noise reduction, microclimate amelioration (including reducing the UHI effect), pollination and seed dispersal, and waste treatment.
- **Social and health** benefits (mental and physical wellbeing).
- **Economic** benefits.
- **Visual and aesthetic** benefits.
- Urban **resilience** (the capacity of a system to maintain its identity in the face of internally or externally driven change).

Understanding of urban ecosystem services has grown rapidly since 2010 (Ziter, 2016). The majority (80%) of studies on the topic have been in North America and Europe, with the remainder conducted in Asia, Oceania and Africa (Ziter, 2016).

There are numerous definitions of ecosystem services in the academic literature. In their review of urban ecosystem service challenges, Luederitz *et al.* (2015) used the definition of Daily (1997) to define ecosystem services as ‘the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life’ (p. 99). Elsewhere, ecosystem services are defined as ‘benefits that humans obtain from ecosystem functions, or as direct and indirect contributions from ecosystems to human well-being’ (Gómez-Baggethun & Barton, 2013, p. 236). This document uses the following succinct definition: ecosystem services are the benefits that the human population receives from natural processes (Figure 5.1).



**Figure 5.1.** Ecosystem services provided by natural assets. Source: Hawkesbury-Nepean Catchment Management Authority (2013).

The intrinsic value of ecosystems and reasons for maintaining them is addressed explicitly in Chapter 3. This chapter focuses on *urban* ecosystem services as distinct from the more general services provided by ecosystems. Urban ecosystem services are ‘the benefits urban residents derive from local and regional urban ecosystem functions’ (McPhearson *et al.*, 2016, p. 200). Although the concept of ecosystem services and its application to urban environments has gained increasing attention in the last decade, more research is needed specifically on ecosystem services in the urban context (Luederitz *et al.*, 2015). The present review has revealed that this is particularly the case in NSW, where little research has been completed; most of the research used in this review, therefore, originates in other parts of Australia and internationally.

Ecosystem services apply at a range of scales, from global to local. The links between ecosystems and human health, prosperity, security and identity are firmly established (Pitman & Ely, 2015), and urban populations are inextricably dependent on the goods and services that ecosystems provide. The TEEB (‘The Economics of Ecosystems and Biodiversity’) Report identified 22 types of ecosystem services in four categories (TEEB, 2010): provisioning; regulating; habitat; and cultural and amenity services (**Table 5.1**). Depending on the context, some ecosystem services might be more important in one city than another.

**Table 5.1.** Summary of services provided by the world’s ecosystems. Source: Adapted from Kumar (2010) and TEEB (2010). Note that an additional cultural service, the biophilic benefit of mental health and wellbeing, which is not fully accounted for in other services, has been added by the authors.

<p><b>Provisioning</b> services are ecosystem services that describe the material outputs of ecosystems – food, water and other resources</p>	Food (e.g. fish, game, fruit)
	Water (e.g. for drinking, irrigation, cooking)
	Raw materials (e.g. fibre, timber, firewood, fodder, fertiliser)
	Genetic resources (e.g. for crop improvement and medicinal purposes)
	Medicinal resources (e.g. biochemical products, models and test organisms)
	Ornamental resources (e.g. artisan work, decorative plants, pet animals, fashion)
<p><b>Regulating</b> services are the services that ecosystems provide by regulating the quality of air, water and soil and by providing climate and disease control</p>	Air-quality regulation (e.g. capturing particulates, chemicals)
	Climate regulation (including carbon sequestration and storage, influence of vegetation on rainfall)
	Moderation of extreme events (e.g. storm protection and flood prevention)
	Regulation of water flows (e.g. natural drainage, irrigation and drought prevention)
	Waste treatment (especially water purification)
	Erosion prevention
	Maintenance of soil fertility (e.g. soil formation and nutrient cycling)
	Pollination
Biological control (e.g. seed dispersal, pest and disease control)	
<p><b>Habitat or supporting</b> services underpin almost all other services. Ecosystems provide living spaces for plants and animals, and also maintain a diversity of breeds</p>	Maintenance of life cycles of migratory species (including nursery services)
	Maintenance of genetic diversity (especially through gene pool protection)
<p><b>Cultural services</b> include the non-material benefits humans obtain from contact with ecosystems. They include benefits to physical and mental health, as well as aesthetic and spiritual benefits</p>	Mental health and wellbeing (biophilic benefits)
	Aesthetic information
	Opportunities for recreation and tourism
	Inspiration for culture, art and design
	Spiritual experience
	Information for cognitive development (educational benefits)

The urban ecosystem services described below relate most directly to aspects of urban development and renewal. Relevant key literature and their findings are summarised and discussed.

## Carbon sequestration and storage

As urban areas expand, they require and consume increasing amounts of energy and emit increasing amounts of CO<sub>2</sub> (Escobedo *et al.*, 2010), one of the main contributors to the greenhouse effect. Cities are linked to approximately 70-80% of global CO<sub>2</sub> emissions (Wiedmann *et al.*, 2015). In developed countries, buildings contribute to approximately half of primary energy consumption and therefore also of CO<sub>2</sub> emissions (Castleton *et al.*, 2010).

Vegetation and soil naturally regulate atmospheric CO<sub>2</sub> (Kuittinen *et al.*, 2016) and are important stores of carbon. Plants sequester atmospheric carbon through photosynthesis and convert it to sugars, which are then stored in biomass. Soils store carbon as soil organic carbon (SOC), a depository of slowly decaying remains of plants, animals and microbes. Because nearly 80% of terrestrial carbon resides in soils, SOC is vital for ensuring a liveable climate on our planet (Kuittinen *et al.*, 2016).

Coastal and marine ecosystems play key roles in storing and regulating carbon, sequestering millions of tonnes annually (Barbier *et al.*, 2011). The contribution to carbon sequestration of vegetated coastal habitats such as mangrove forests, seagrass beds and salt marshes is much greater per unit area than that of terrestrial forests (McLeod *et al.*, 2011), indicating the potential significance of urban marine ecological restoration.

A study in Leicester, United Kingdom, found that soil is the largest repository of organic carbon in urban areas and that urban soil stores significantly more carbon than soil in rural areas at equivalent depths (Edmondson *et al.*, 2012). Measuring soil to a depth of 1m, no difference was found between the storage of soil OC in urban green spaces and under impervious surfaces. The study posits that this is likely due the underlying root systems of nearby lawns, garden trees and shrubs under smaller patches of impervious surface maintaining the soil active and accumulating soil OC. The study also found that above-ground vegetation OC storage greatly increased the overall OC storage of rural areas. This was attributed to increased tree cover and frequency of large trees compared to the smaller tree and shrub cover found in more urban and residential areas (Edmondson *et al.*, 2012). Australian studies have also found that reducing the amount of tree cover leads to decreases in the amount of organic carbon in soil sinks up to a depth of 1m (Chen *et al.*, 2005; Commonwealth of Australia, 2009). It is important to protect these carbon sinks and the vegetation they support to maximise the carbon storage potential of soil.

Urban forests can mitigate CO<sub>2</sub> emissions through carbon sequestration and storage, depending on a variety of factors such as tree density, species composition, tree age and environmental conditions (Escobedo *et al.*, 2010; Liu & Li, 2012). A study of two urban forests in Florida showed that urban tree sequestration offset CO<sub>2</sub> emissions to a minor extent relative to total city-wide emissions, at 3.4% and 1.8% (Escobedo *et al.*, 2010).

Although most studies on urban forests and carbon sequestration and storage have been conducted in the US, a study of 213 urban forests with an average size of 0.25 ha in Shenyang, China, found that they stored 337,000 tonnes of carbon, equivalent to 3.02% of the annual carbon emissions from the city's combustion of fossil fuels (Liu & Li, 2012). Carbon storage and sequestration were estimated using biomass equations, field survey data and data on urban forests derived from high-resolution QuickBird satellite images.

Street trees also have the potential to contribute to carbon sequestration and storage in urban areas. In the north of Sydney, the 30,500 urban trees on 19km of the Pacific Highway store 71,700 tonnes of carbon and sequester 1,220 tonnes of carbon per year (Amati *et al.*, 2013). In western

Sydney, 9,580 trees on 11km of Parramatta Road store 22,600 tonnes of carbon and sequester 573 tonnes of carbon per year (Amati *et al.*, 2013).

Younger, faster-growing trees are generally more efficient in sequestering and storing carbon, although this depends on tree species, climate and site conditions. Trees store more carbon than other types of vegetation such as groundcovers and grasses. Some Australian native eucalypt forests store up to ten times more carbon per ha (both above and below ground) than Australian native and introduced grasslands (Commonwealth of Australia, 2009). Therefore, it is important to preserve remnant forests and urban trees and to plant more urban trees.

On the other hand, the effects of street-tree maintenance and longevity on carbon sequestration and storage require further research. More generally, soil health (e.g. the role of soil microflora) is not well understood and needs more research and advocacy. Further, planners, designers and managers need to acknowledge potential conflicts, for example between street trees and power lines and underground services.

Green walls and green roofs can help reduce a city's carbon footprint, albeit minimally, through the capacity of the vegetation to absorb carbon. A study in Hong Kong found that, on a sunny day, a green roof may reduce the concentration of CO<sub>2</sub> in the immediate surroundings by about 2% (Li *et al.*, 2010). Retrofitting green roofs and walls requires careful consideration of structural and waterproofing issues.

Because buildings contribute greatly to CO<sub>2</sub> emissions, it is important to consider methods to reduce the energy required for heating, ventilation, cooling and lighting. Green infrastructure elements such as green roofs, green walls and street trees can help reduce energy use through passive cooling techniques, such as locating trees on the western side of buildings, using vegetation to channel cooling breezes, and installing green roofs and green walls.

### **Stormwater management**

Efficient water management contributes to the liveability of towns and cities (Pitman & Ely, 2015). Increased water stress is predicted as urbanisation and population growth increase (Floyd *et al.*, 2014). The 'Big Dry' drought that affected Sydney between 2003 and 2007 caused a water crisis, exacerbated by the city's growing population and water-consumptive lifestyle (Floyd *et al.*, 2014). Water conservation and effective stormwater management are both essential for water security, especially in urban areas, where water demand is increasing.

Urban development significantly modifies hydrological systems in urban areas. Changes to the natural environment, such as creek channelisation, an increase in the area of impervious surfaces, and topographic modifications affect the quantity, speed and direction of stormwater (Barbosa *et al.*, 2012). Stormwater quality is reduced by pollutants such as solids, heavy metals, nutrients, pathogenic microorganisms and organic micropollutants (Barbosa *et al.*, 2012). Flash flooding and increased urban stormwater runoff become more likely as the area of impervious surface grows in urban areas (Walsh *et al.*, 2012). Increasing the capacity of urban stormwater drainage systems can be difficult because of the scale required, the cost, and the disturbance it creates (Livesley *et al.*, 2016).

Terrestrial and aquatic vegetation in urban catchments play important roles in providing cities with fresh drinking water and in managing water flows, including stormwater runoff and in urban waterways (Gómez-Baggethun & Barton, 2013). Vegetation can be used in managing urban water flows, especially by adopting new ways of thinking about stormwater in the urban context. WSUD provides a conceptual framework for this.

WSUD is a type of urban design involving the capture of stormwater for local use, thereby reducing the deterioration of creeks, streams and receiving waters that results from the influx of sediment, oil, litter and other pollutants from roads, drains and gutters (Floyd *et al.*, 2014). WSUD elements include bioretention swales, raingardens, permeable paving and constructed wetlands (**figures 5.2 and 5.3**). WSUD can remove pollutants from stormwater such as nitrates, phosphates, suspended solids, organic compounds and faecal coliforms (Scholes *et al.*, 2008). The elements selected in the WSUD influence its effectiveness. Scholes *et al.* (2008) showed that ponds, porous asphalt, grasses and vegetated areas are particularly effective. In Melbourne, Bratieres *et al.* (2008) showed that plant species and soil media have significant impacts on the effectiveness of bioswales, and Ossola *et al.* (2015) showed that complex habitats in parks intercept and hold more stormwater than do simple habitats, with low-complexity urban habitats exhibiting slower rates of soil water infiltration due to the reduced presence of soil macropores. Habitat complexity and biodiversity, therefore, should be considered at project design stage.



**Figures 5.2 and 5.3.** Bioswales designed to improve biodiversity in Jellicoe Street, Auckland (left), and in Queen Elizabeth Park, London (right). Sources: Wraight and Associates Landscape Architecture and Urban Design (2015) (left) and Chaoming (2015) (right).

Street-tree canopies can be a cost-effective complement to WSUD for stormwater reduction benefits. Urban trees play important roles in urban catchment hydrology: the interception of rainfall by their canopies reduces beneath-canopy throughfall and therefore catchment peak flows (Livesley *et al.*, 2014). A Melbourne study demonstrated that eucalypt street-tree planting can result in rainfall and runoff reductions of up to 20% in impervious streetscapes (Livesley *et al.*, 2014). It also found that tree canopy and bark characteristics have a significant impact on water availability, soil water recharge and runoff. Trees with larger and denser canopies and rougher, more deeply fissured bark intercept and store more rainfall. WSUD systems that include trees can increase the return of collected runoff to the atmosphere. Trees planted in bioswales accounted for 46-72% of total water use, significantly reducing water runoff and discharge (Scharenbroch *et al.*, 2016); these results were dependent on the tree species selected.

Green roofs (**figures 5.4 and 5.5**) store water during rainfall events, delaying runoff until after peak rainfall and returning precipitation to the atmosphere through evapotranspiration (Oberndorfer *et al.*, 2007; Wilkinson *et al.*, 2015; Wilkinson & Dixon, 2016), thereby reducing the peak loading of water during storm events and relieving pressure on stormwater systems (Wilkinson *et al.*, 2014). The effectiveness of green roofs in delaying runoff flows is dependent on the depth of substrate, the slope of the roof, the type of plant community, and rainfall patterns (Oberndorfer *et al.*, 2007). In many jurisdictions, stormwater management is the key driver for roof-greening initiatives.



**Figures 5.4 and 5.5.** Green roofs improve urban stormwater management. Sources: Landscaping (2015) (left); Rosie (2015) (right).

Permeable pavements can assist in urban stormwater management by reducing runoff volume. One study showed that stormwater runoff volume can be reduced by 70-90% when the surface is turfed and 'subsoiled' (i.e. deep-tilled) (Wheeler, 2010; Foster *et al.*, 2011). A permeable pavement in a typical alley can infiltrate eight centimetres of rainwater from a 1-hour storm (Kloss & Calarusse, 2006; Foster *et al.*, 2011). Permeable paving is a promising area for further applied research; more generally, ways to reduce the infrastructure and maintenance costs of WSUD need more exploration.

### Energy efficiency

The UHI effect and climate change will continue to affect Australian cities, resulting in increased temperatures and extreme weather events. As temperatures increase, cooling requirements also increase, resulting in additional energy use by cooling devices such as air conditioning and fans (Santamouris, 2016). Urban greening can reduce the UHI effect and the energy requirements of buildings in urban environments (Castleton *et al.*, 2010; Rajagopalan & Fuller, 2010). Elements such as green roofs, green walls, open green spaces, wetlands and street trees can contribute significantly to such reductions by regulating the internal temperatures of buildings and reducing ambient temperatures in urban areas (**figures 5.6 and 5.7**) (Jim, 2015; Pérez-Urrestarazu *et al.*, 2015; Silva *et al.*, 2016).



**Figures 5.6 and 5.7.** Street trees provide shading and cooling in urban environments. Sources: Loucas (2016) (left); NSW Government Architect's Office (n.d.) (right).

Urban trees decrease the cooling demands of buildings through shading and evapotranspiration, thereby reducing the CO<sub>2</sub> emissions associated with fossil fuel use for air conditioning (Escobedo *et al.*, 2010). Gallagher (2015) showed that, over a 40-year period, retrofitting an existing north–south residential street in northwestern Sydney with street-tree plantings could save 150 tonnes of carbon by reducing air conditioning requirements and sequestering 20 tonnes of carbon; households would save 8-11% in energy consumption due to the tree planting. Mature trees can reduce typical household energy bills by more than AUD 500 per annum (Gallagher, 2015). The choice of tree species, including between deciduous and evergreen species, and the location of trees relative to buildings, are important factors in achieving maximum cooling outcomes and reducing the UHI effect. Tree species with denser canopies produce more shade, which, in turn, influences cooling outcomes.

Green roofs are another passive cooling technique. They reduce the amount of solar radiation reaching building structures below and increase the insulation properties of buildings. Green roofs also add thermal mass, which helps stabilise internal temperatures year round. As reviewed by Castleton *et al.* (2010), many studies have shown that green roofs reduce requirements for winter heating and summer cooling, although the extent of the benefits depends on variables such as soil depth, substrate composition, water retention layers, types of plants and soil moisture content (Wilkinson & Feitosa, 2015). The effects of green roofs are most pronounced in the storey directly below the roof and decline exponentially in the lower storeys (Berardi, 2016).

A study of green roofs and energy performance in a Mediterranean climate showed that buildings with extensive green roofs require 20% less energy than traditional black roofs, and those with semi-intensive and intensive green roofs use 60-70% less energy (Silva *et al.*, 2016). A French study of a single-family house found that the extent of temperature change on the roof slab was reduced by 30 °C in summer due to a green roof (Jaffal *et al.*, 2012). The study also found that green roofs decreased summer indoor air temperatures by 2 °C and annual energy demand by 6% (Jaffal *et al.*, 2012). The effects of the additional insulation created by green roofs are most significant in single-storey buildings. In Sydney, green roofs have been shown to reduce the summer temperature of roofs comprising metal sheeting by 15 °C (Wilkinson & Feitosa, 2015).

Testing of green roofs in Adelaide showed that the insulation value of a 125-300mm-thick profile is sufficient to reduce summer heat flow in Adelaide's climate, and that cooling effects extend to a distance of 200m (Hopkins & Goodwin, 2012), although most research suggests that the effects are limited to less than 10m. The deeper the green roof profile, the greater the insulation value: for example, a 300mm depth profile reduces temperature by 41%, a 125mm depth profile with aluminium grating reduces temperature by 20.5%, and a 125mm depth profile reduces temperature by 8% (Hopkins & Goodwin, 2012). When water is introduced into green roofs, however, the insulation value declines as the temperature of the profile layers rises, because water is a good thermal conductor (Hopkins & Goodwin, 2012).

Green walls can also reduce energy consumption (Wong *et al.*, 2010; Perini *et al.*, 2011). Insulation applied to an exterior is much more effective than interior insulation, especially in summer (Wong *et al.*, 2010). Green walls insulate the outsides of buildings and have a two-fold effect: reducing the penetration of incoming solar energy into the interior by shading, and reducing heat flow into the building by evaporative cooling (**figures 5.8 and 5.9**) (Wong *et al.*, 2010).



**Figures 5.8 and 5.9.** The green facade at Sihl City Shopping Centre in Zurich (left) and the living wall at One Central in Sydney (right). Sources: MMA Architectural Systems (2017) (left); P. Osmond (2016) (right).

Living green walls (using felt layers or modular hydroponic systems) can have a greater impact on the thermal resistance of a building than other types of green walls and have greater energy-saving potential because of their extra depth (Perini *et al.*, 2011). A facade fully covered by greenery is protected from intense solar radiation in summer and can reflect or absorb, in its leaf cover, 40-80% of the received radiation, depending on the amount and type of greenery (Wong *et al.*, 2010). Double-skin green facades can also produce energy savings, as demonstrated in a study in Hong Kong, which showed that these structures can generate energy savings of 2,651 kWh x 10<sup>6</sup> per year in overall electricity consumption for air conditioning in high-rise (generally over 20 storeys) residential buildings (Wong & Baldwin, 2016). Double-skin green facades are green walls of climbing plants supported by a framework separated from the wall of the building by an air space, which acts as an additional insulation layer.

Simulation modelling found that the shading effects of a green wall on a three-storey office building in various locations across Canada, including Montreal and Vancouver, reduced the energy used for

cooling (air conditioning) by at least 23% and the energy used by fans by 20%, resulting in an 8% reduction in annual energy consumption (Bass & Baskaran, 2003). Alexandri and Jones (2008) found that projected energy savings ranged from 35% to 90% in various cities (London, United Kingdom; Montreal, Canada; Moscow, Russia; Athens, Greece; Beijing, China; Riyadh, Saudi Arabia; Hong Kong, China; Mumbai, India; and Brasilia, Brazil) when all possible facades are implemented with vertical greenery systems, showing the potential for reductions in cooling-load demand.

Parks can reduce cooling requirements through what is known as the park cool island effect. Numerous studies have shown the climate-mitigating potential of green spaces in urban areas (Chang *et al.*, 2007; Roy *et al.*, 2012; Ren *et al.*, 2013; Zhang *et al.*, 2014) (discussed later in this chapter).

### **Habitat provision and enhancement**

Although urban areas continue to grow and threaten biodiversity (Philpott *et al.*, 2014), they also have the potential to provide good habitat and refuge for many species (Pitman & Ely, 2015). Connected networks of green spaces and water systems reduce habitat fragmentation and contribute to species diversity and health (Pitman & Ely, 2015). Green infrastructure provides a variety of habitats for plants, insects, birds, reptiles, mammals and invertebrates (Roy *et al.*, 2012; Philpott *et al.*, 2014; Beninde *et al.*, 2015; Ives *et al.*, 2016). This section outlines some of the roles that urban greening can play in habitat provision; Chapter 3 provides a more detailed review of urban biodiversity. Different species respond differently to urban environments (Philpott *et al.*, 2014), with many responding favourably to city conditions (Ives & Kelly, 2016). Some adapt more effectively than others, and there is growing evidence of microevolutionary changes in some species associated with adaptive responses to urban environments (McDonnell & Hahs, 2015) (see section 3.5).

Green roofs and walls provide habitat, food and protection for a variety of flora and fauna species (**figures 5.10 and 5.11**), and they may enhance urban biodiversity by allowing vegetation to colonise them (Pérez-Urrestarazu *et al.*, 2015). Green roofs and walls can also mimic natural vertical habitats such as cliffs and vegetated waterfalls (Pérez-Urrestarazu *et al.*, 2015). Greater variety in the design and construction of green roofs contributes to an increase in the diversity of plant and animal species (Oberndorfer *et al.*, 2007; Fernandez-Canero & Gonzalez-Redondo, 2010; Latty, 2016). A study of green roofs found that species-rich systems generally have higher functional diversity and, as a result, provide better ecosystem services (Berthon *et al.*, 2015).

Informal green spaces, street trees, parks, urban coastal ecosystems and WSUD elements such as bioswales provide habitat for flora and fauna species (see Chapter 3). Such sites can disappear quickly, however, in the face of development pressures, and mapping existing informal green spaces, therefore, is crucial for habitat protection and maintenance.

The degree to which frontyards and backyards provide ecosystem services is affected by urban form and sociodemographic factors (Lin *et al.*, 2017). Vegetation in residential gardens provides opportunities for habitat diversity, and a range of socioeconomic characteristics has been shown to influence garden management (Goddard *et al.*, 2010). Influencing the social norms and resources that inform garden management is a key challenge for maximising vegetation complexity and diversity. Community programs such as Birds in Backyards (run by Birdlife Australia) and Hollows as Homes (supported by the Sydney Coastal Councils Group, the Australian Museum, the Royal Botanic Gardens and the University of Sydney) are working to increase community awareness and education on the potential for residential properties to increase urban biodiversity. Gardening TV shows and magazines can also play an important role.



**Figures 5.10 and 5.11.** Green roofs provide habitat at Prince Alfred Park (left) and Beare Park (right) in the Sydney central business district. Sources: Boardman (2014) (left); Fytogreen (n.d.) (right).

Urban forests are important because they provide a diversity of habitats for flora and fauna. Many public urban green spaces lack ground-storey and mid-storey plant species, depending on the aesthetic preferences of park designers and the maintenance practices and safety-risk perceptions of park managers. CPTED practices, which promote the use of design in reducing crime, often mean that mid-storey plantings are designed out or removed from parks because CPTED design principles require clear sightlines, which shrubs can hinder. Although safety is a key planning and design criterion for public spaces, a balanced approach is required to achieve both urban biodiversity and CPTED outcomes. The suitability of areas for ecological complexity should be determined with reference to acceptable levels of security risk. CPTED criteria generally prohibit vegetation 0.6-1.8m in height in urban areas because it impairs sightlines through, for example, urban parklands. This requirement severely limits the opportunity for mid-storey plantings. CPTED also requires lighting for public safety at night, which can disturb nocturnal animals such as bats (see section 3.5).

### Noise reduction

Construction, traffic and human activities create noise pollution in urban areas, with impacts on psychological and physiological health. Green infrastructure can mediate noise pollution through the absorption, deviation, reflection and refraction of sound waves (Gómez-Baggethun & Barton, 2013). Roadside trees with high leaf density, for example, disperse sound and reduce the reverberation effect on facades and other hard areas caused by the noise of wheeled traffic (**Figure 5.12**) (Chaparro & Terradas, 2009).



**Figure 5.12.** Street-tree planting in Wagga Wagga town centre. Source: N. Pelleri (2014).

Green roofs and walls can reduce noise pollution inside the buildings on which they are located. Green roofs reduce sound pollution by absorbing sound waves originating outside buildings and preventing their inward transmission (Oberndorfer *et al.*, 2007). Green walls have more potential for noise reduction because most urban noise enters buildings through walls. Green walls and facades with a thin (20-30cm) layer of vegetation can provide an increase in sound insulation of 1dB for traffic noise (for both green walls and green facades) and of between 2dB (green wall) and 3dB (green facade) for pink noise (similar to white noise, with the power to mask low-frequency background sounds) (Pérez *et al.*, 2016).

### **Local climate regulation**

The local climate of urban areas is changing due to the UHI effect and global warming. Urban ecosystems contribute to microclimate amelioration, including by reducing the UHI effect (Doick & Hutchings, 2013). The UHI effect is caused by the absorption, reflection and re-emission of solar energy by built surfaces and by waste heat from air conditioning and traffic (Gómez-Baggethun & Barton, 2013). As the UHI effect increases, additional energy is required for building space cooling (Livesley *et al.*, 2016), creating a positive feedback loop.

The NARClIM (NSW/ACT Regional Climate Modelling) project provides regional climate projections for NSW and the Australian Capital Territory. The aim of NARClIM's climate modelling is to provide a comprehensive and consistent set of climate projections that can be used by relevant government departments in their considerations of climate change. In a study prepared for the ARC Centre of Excellence for Climate System Science, researchers found that temperatures in Sydney could rise by up to 3.7 °C by 2050 as a result of the UHI effect (Argüeso *et al.*, 2014). Temperatures could increase by 1.1-3.7 °C on Sydney's urban fringes and by 1.1-2.5 °C in existing urban areas closer to the central business district (Argüeso *et al.*, 2014). The UHI effect is influenced by the size and density of a city (Doick & Hutchings, 2013), so it is important that planners and urban designers take these two factors into consideration in, for example, master planning and the review of specific development applications.

The UHI effect can have significant impacts on human health, particularly when combined with the projected effects of climate change. Global warming is driving the frequency, intensity and duration of heatwave events (Sharifi *et al.*, 2016), which, in Australia, kill more people than any other natural hazard (Chen *et al.*, 2014). The combination of heatwaves and the UHI effect poses an increased risk

to public health, which green infrastructure can help alleviate. A study in the Sydney region found that, as urban expansion continues and climate change takes place, the risk of heat-stress conditions will likely increase, with substantially more frequent adverse conditions in urban areas (Argüeso *et al.*, 2015). An earlier study estimated the annual heat-related deaths for people aged over 65 years to be around 1100 people across 12 cities in Australia and New Zealand (McMichael, 2003). Amplified heat stress in summer heatwaves contributes significantly to heat-related morbidity in Australia (Sharifi *et al.*, 2016). Inland suburban regions such as western Sydney are at particular risk. Australian studies have shown that excess heat-related mortality in the population group aged above 65 years could increase rapidly when the mean daily temperature exceeds about 30 °C (Chen *et al.*, 2014), which is especially concerning given the country's aging population. With Australia likely to see temperature increases of 1-5 °C by 2070 (Bureau of Meteorology & CSIRO, 2014), creating urban areas that incorporate built forms and integrate green infrastructure systems will be crucial for increasing resilience to these changing conditions.

Urban microclimates are the complex outcome of spatial and climatic variables (Sharifi *et al.*, 2016), and vegetation plays an important role in temperature regulation in urban areas (Norton *et al.*, 2015). A recent Australian report (Pitman & Ely, 2015) found that nothing ameliorates the UHI effect as well as plants, which moderate and cool the microclimate through two major natural mechanisms: reducing temperature by shading urban surfaces from solar radiation; and evapotranspiration, which has a cooling and humidifying effect on the air (**figures 5.13 and 5.14**).

The informed selection and strategic placement of trees and green infrastructure can reduce the UHI effect and cool the air by 2-8 °C, reducing heat-related stress and premature human deaths in high-temperature events (Doick & Hutchings, 2013). Various tree-planting arrangements can also alter wind profiles, which can influence urban cooling and outdoor thermal comfort.

Using urban climate modelling, Kalkstein *et al.* (2014) investigated the cooling effects of urban vegetation cover and surface reflectivity in the US District of Columbia. Based on the relationship between ambient weather conditions and the heat-related mortality rate, Kalkstein *et al.* (2014) estimated that a 10% increase in vegetation cover can result in an average 7% reduction in mortality during heatwaves.

Research by the Green Infrastructure Research Group at the University of Melbourne (Coutts *et al.*, 2016) showed that the cooling benefit of street-tree canopies increases as the height of adjacent buildings decreases and the width of the street increases. There is insufficient Australian-based work in this domain, however, although it is expected that the outcomes of current studies supported by the Cooperative Research Centre for Low Carbon Living will be released in 2017.



Figures 5.13 and 5.14. Urban green spaces with trees provide cooling. Sources: Huang (2012) (left); Hester (2010) (right).

Parks are cooler than surrounding urban areas (Bowler *et al.*, 2010). The cooling effects of urban green spaces are related to their size and characteristics, such as the area of pavement, and vegetation cover and structure (Chang *et al.*, 2007; Bowler *et al.*, 2010; Jaganmohan *et al.*, 2016). Parks with large areas of pavement absorb more heat, resulting in higher temperatures (Chang *et al.*, 2007). Increased tree and shrub cover result in cooler parks during the day and warmer parks at night when vegetation hinders the exchange of heat with cooler air above (Chang *et al.*, 2007). Turf does not absorb as much heat as paved areas but does not provide daytime shading. An increase in the area of green space increases the cooling effect (Chang *et al.*, 2007; Jaganmohan *et al.*, 2016). In particular, parks more than 3 ha in size have been found to be more consistently cooler (Chang *et al.*, 2007). In general, forests provide larger maximum temperature differences and cooling distances than parks (Jaganmohan *et al.*, 2016) due their greater vegetation density.

Urban green spaces reduce temperature, not only within the spaces themselves but also in the adjacent environment, depending on the type of green space, adjacent land use and urban morphology (Lee *et al.*, 2009; Jaganmohan *et al.*, 2016). In Seoul, South Korea, for example, a park in the central business district (the Seolleung Royal Tomb Park) generated a cooling effect of 2 °C per 100m between it and the Seolleung subway station, over a distance of 370m (Lee *et al.*, 2009). Vaz Monteiro *et al.* (2016) found that cooling distance was most strongly related to tree canopy, whereas the amount of cooling (i.e. decrease in air temperature) was most strongly linked to grass coverage. That study suggested that a comprehensive cooling service on calm warm nights in cities with similar climate and characteristics to London may be produced by green spaces 3-5 ha in size situated 100-150m apart. The lack of relevant data for Sydney suggests an opportunity for investigation.

Green roofs have been shown to reduce urban temperatures (Oberndorfer *et al.*, 2007; Razzaghmanesh *et al.*, 2016; Sharma *et al.*, 2016). In Adelaide, research showed that green roofs have significant cooling effects in summer and could behave as an insulation layer to keep buildings warmer in the winter (Razzaghmanesh *et al.*, 2016). A study of two green roofs in Melbourne found that the air temperature at the vegetation was 5.3-6.2 °C lower than the ambient temperature, and that when surface temperatures of an adjacent concrete roof surface rose to 55 °C, the soil temperature under the plants was 20-24 °C (Rajagopalan & Fuller, 2010). Green walls can also reduce temperatures, but few studies have investigated the influence of plant morphology and physiology on facade performance (Hunter *et al.*, 2014).

Water mediates temperatures, absorbing heat in summer and releasing it in winter. Numerous studies have shown that urban water bodies such as reservoirs, lakes, rivers and wetlands help cool urban environments (Pitman & Ely, 2015). Green infrastructure such as WSUD elements, including bioswales, can reduce urban temperatures through increases in evapotranspiration (Tapper, 2014).

### **Air-quality regulation**

Urban vegetation can improve air quality. Trees intercept atmospheric particles and absorb various gaseous pollutants, including sulphur dioxide, ozone, carbon monoxide and nitrogen dioxide (Gómez-Baggethun & Barton, 2013). Various tree configurations can alter wind profiles and create local inversions to trap pollutants to increase the localised removal of pollutants (Cavanagh *et al.*, 2009). Leaf area and proximity to pollution influence the capacity of trees to remove air pollution (Escobedo *et al.*, 2011). Plant species used for green walls and green roofs have the potential to remove air pollutants; a variety of species have been shown to have this ability (Pérez-Urrestarazu *et al.*, 2015).

### **Pollination and seed dispersal**

Urban ecosystems provide habitats for a host of bird and insect species that help maintain the ecosystem services of seed dispersal and pollination (Oberndorfer *et al.*, 2007; Gómez-Baggethun & Barton, 2013; Pérez-Urrestarazu *et al.*, 2015). Animals, especially bird species, play important roles in seed dispersal; it is important, therefore, to ensure that ecosystems support fauna that maintain pollination and seed dispersal processes. The built environment can facilitate pollination and seed dispersal through landscape designs such as mass planted garden beds, tree planting and the establishment of mid-storey layers. Careful plant selection can attract fauna species that provide seed dispersal and pollination services.

Some plant species can produce ecosystem disservices, which are ecosystem functions with harmful effects on human wellbeing (von Döhren & Haase, 2015), including negative health impacts; for example, pollen can trigger asthma (Beggs, 2010). Landscape architects and other built-environment professionals must be aware of this when designing planting palettes. Designers also need to know which plant species are noxious or environmental weeds so they can avoid specifying such species and inadvertently contributing to weed spread. The NSW Department of Primary Industries, which is responsible for weed management in NSW, has resources such as NSW WeedWise, an online resource and smartphone app describing weed species, control options and legal requirements.

### **Waste treatment**

Urban areas can produce high loads of contaminants in waterways, such as sediments, nutrients, metals, hydrocarbons and organic micropollutants (Greenway, 2016). Urban ecosystems can help treat waste and reduce pollutant loads. Green infrastructure and WSUD elements reduce the pollutant load discharging into downstream waterways and, ultimately, wetlands (Ely & Pitman, 2014).

Constructed wetlands, biofiltration systems and bioswales can play significant roles in the treatment of urban stormwater and even industrial wastewater by helping filter out and decompose organic waste (Ely & Pitman, 2014).

Biofiltration systems are vegetated filtration trenches or basins with an underlying collection pipe designed to remove fine suspended solids and dissolved pollutants. Filtration media remove particulates and their associated pollutants (e.g. metals, phosphorus) by mechanical straining, and nutrients are removed by biological processes. Biofiltration systems have been shown to remove more than 80% of solids and more than 90% of lead, copper and zinc (Hatt *et al.*, 2007).

Constructed wetlands are a WSUD element that can help in managing urban stormwater and treating water pollution. Constructed wetlands manage pollution through phytoremediation, which is a cost-effective and environmentally friendly remediation method in which organic and inorganic pollutants are absorbed through plant roots and translocated into the upper parts of the plants (Rezania *et al.*, 2016). Heavy metals, pesticides and organic pollutants can be removed by submerged, emergent and free-floating plant species growing in wetlands.

Green roofs can also contribute to waste treatment. Testing of green roof systems in Adelaide showed that a 125mm extensive green roof performed better than a 300mm intensive green roof system in terms of stormwater pollutant removal (Hopkins & Goodwin, 2012).

Notably, WSUD and related stormwater interventions can help protect habitat as well as contribute to human wellbeing.

### **Health and wellbeing benefits**

Landscapes have the potential to promote mental, physical and social wellbeing, and empirical evidence of the health benefits of green space is growing. Biophilia – the concept that humans possess an inherent tendency to affiliate with natural systems and processes (Hélène, 2016; Kellert, 2016) – links green spaces and human health. It is a foundation concept on which research into the relationship between the environment and social and health benefits is based. Green spaces are associated with better physical and mental health across different types of urban areas, genders and socioeconomic statuses (Bowen & Parry, 2015; Triguero-Mas *et al.*, 2015).

Green space contributes to mental health and wellbeing through attention restoration, stress reduction, and the evocation of positive emotions, and to physical health and wellbeing by encouraging physical activity. Green space contributes to social wellbeing through social integration, social engagement and participation, and social support and security (Abraham *et al.*, 2010). Species-rich green spaces are of particular benefit (Fuller *et al.*, 2007). The health and wellbeing benefits of green spaces are supported by evidence from international research projects, as discussed below.

### **Mental health**

Mental health refers to a person's state of mind and ability to cope with the everyday things going on around them (ReachOut, 2016). Nature contact is important for general mental health; plants have a role to play in supporting good mental health (Frumkin, 2001).

There is increasing empirical evidence that the presence of natural assets and elements in urban contexts increases quality of life in many ways (Chiesura, 2004). Urban nature provides important social and psychological benefits to human communities, enriching life with meaning and emotions (Chiesura, 2004). Exposure to the natural environment has been shown to support mental health in various ways, including nature's ability to reduce stress, create positive states and improve cognitive functioning (Coutts & Hahn, 2015).

Living closer to urban green spaces such as parks is associated with lower mental distress (White *et al.*, 2013), and interacting with nature improves cognition for individuals with major depressive disorders (Berman *et al.*, 2012). A study in the United Kingdom recorded people and their place of residence over a three-year period in relation to green and less-green areas. It found that individuals who moved to greener areas had significantly better mental health in all three of the post-move years (Alcock *et al.*, 2014). In Australia, a survey of 1,800 Adelaide residents revealed that respondents who perceived their neighbourhoods as 'highly green' were 1.6 times more likely to have better mental health than respondents who perceived the lowest level of neighbourhood greenness (Sugiyama *et al.*, 2008). Participants in the survey rated their own mental and physical

health, and perceived greenness was measured using a scale that recorded the following attributes: access to a park or nature reserve; access to bicycle or walking paths; presence of greenery; presence of tree cover or canopy along footpaths; and presence of pleasant natural features (Sugiyama *et al.*, 2008). Mental health was measured by a combination of respondent's social coherence and social interaction scores.

In relation to size requirements for green spaces, a study of 300 people in Bogota, Colombia, found that respondents in large urban parks (i.e. larger than 100,000m<sup>2</sup>) experienced higher levels of connectedness to nature, feelings of human–nature interdependence, and perceived restorative and positive affective qualities of the environment compared with respondents in smaller (10,000-100,000m<sup>2</sup>) district parks. Park size did not directly affect the emotions and overall wellbeing of respondents, however (Scopelliti *et al.*, 2016).

A study in Sheffield, United Kingdom, showed measurable positive associations between the species richness of urban green spaces and the wellbeing of green-space visitors. The degree of psychological benefit was positively related to plant species richness and, to a lesser extent, bird species richness (Fuller *et al.*, 2007).

Green roofs provide people living in urban areas with psychological benefits. Oberndorfer *et al.* (2007) reported benefits from viewing green roofs, including relaxation and restoration.

### **Stress relief**

Stress contributes to short- and long-term physiological outcomes, such as sleep loss, suppressed immune system function, susceptibility to illness, high blood pressure, cardiovascular disease, stroke, and diabetes (Wolf & Robbins, 2015). The design of the built environment can help reduce stress and related illness, thereby reducing pressure on the health system (Huisman *et al.*, 2012).

Many studies have shown that stress can be reduced by exposure to green views. In a classic paper, Ulrich (1984) studied the differences in patient recovery after gall bladder surgery depending on whether the rooms of patients had views of a natural setting or a brick wall. Results showed that patients with a view of nature had shorter postoperative hospital stays and far fewer negative comments in nurses' notes, and tended to have lower scores for minor postsurgical complications.

Hansmann *et al.* (2007) surveyed the effects of visiting an urban forest or park in Zurich and found stress relief benefits: significantly fewer people reported suffering from headaches and stress and more reported feeling well-balanced, based on a survey of general (i.e. non-clinical) populations. The recovery ratio for stress was 87%, and there was a 52% reduction in headaches. The study also found that the positive effects increased with the length of visit and that individuals participating in sports showed significantly greater improvements than those engaged in less strenuous activities.

A study in Dundee, United Kingdom, found that an increase in green spaces reduced self-reported stress levels (Ward Thompson *et al.*, 2012), although it also found that more 'green' did not always lead to less stress. An experimental study of the effect of street-tree density on stress recovery revealed diminishing returns at high levels of tree density, and that recovery times varied between men and females (Jiang *et al.*, 2014).



**Figures 5.15 and 5.16.** Urban green spaces such as Prince Alfred Park (left) and Darling Quarter, Sydney (right), provide important places of respite. Sources: N. Pelleri (2015) and Aspect Studios (n.d.-a) (left); The Glebe Society (2014) (right).

### **Cognition and attention**

Cognition is the process of receiving information, processing it, and applying it to make decisions (Coutts & Hahn, 2015). The theoretical foundation for explaining the potential influence of landscapes on cognitive attention restoration was established in 1989 in *The experience of nature: a psychological perspective*, a book by Kaplan and Kaplan (Abraham *et al.*, 2010). Since then, many studies have investigated the links between nature and cognition (Berman *et al.*, 2008; Kuo, 2010; Berman *et al.*, 2012; Bratman *et al.*, 2012).

Researchers have used attention restoration theory to analyse the kinds of environments that lead to improvements in directed-attention abilities. A study by Berman *et al.* (2008) found that, unlike natural environments, urban environments are filled with stimulation that captures attention dramatically and requires additional directed attention, making them less restorative, and that walking in nature or viewing pictures of nature can improve directed-attention abilities.

Many studies have examined children's attention, in particular behavioural disorders such as attention deficit hyperactivity disorder (ADHD). Kuo (2010) reported that one study completed in the US found that parents of children with ADHD rated activities in green settings as more helpful than activities conducted indoors or in outdoor settings without vegetation. Access to or views of green space have been positively correlated with cognitive development and self-discipline in children (Wells, 2000; Taylor *et al.*, 2002).

Exposure to green roofs increases the ability to concentrate on tasks: a study of 150 University of Melbourne students showed that a 40-second view of a green roof improved attention and accuracy when completing a task (Lee *et al.*, 2015).

### **Infectious disease**

Fauna species can spread infectious disease in urban areas (Soulsbury & White, 2015). Insect species, including mosquitoes and ticks, can spread diseases such as dengue and Ross River fever. Human-induced environmental changes, such as habitat fragmentation, can increase disease risk by

reducing insect predators and biodiversity, and biodiversity can also protect human health by reducing the probability of human exposure to disease agents transmitted from wildlife (Ostfeld, 2016). Studies have demonstrated the various pathways through which patterns of green infrastructure can limit the spread of infectious disease (Coutts & Hahn, 2015). Urban ecosystems can help reduce human disease by directly changing the abundance of human pathogens, such as cholera, and by altering the abundance of disease vectors such as mosquitoes (Ely & Pitman, 2014). The risk of vector-borne diseases for humans decreases with increasing biodiversity due to the dilution effect (Bradley & Altizer, 2007; Swaddle & Calos, 2008), which describes the mechanisms by which vertebrate diversity protects people against exposure to zoonotic diseases.

### **Physical health and healing**

Research shows links between physical health and proximity to green space (Handy *et al.*, 2002; Gies, 2006; Bell *et al.*, 2008; Maas & Verheij *et al.*, 2009; Abraham *et al.*, 2010; Ely & Pitman, 2014). A survey of the electronic medical records of 345,143 people in the Netherlands and their proximity to green space found that the annual prevalence rate of 15 of the 24 disease clusters (e.g. cardiovascular, musculoskeletal, mental, respiratory, neurological and digestive diseases) was significantly lower for people living in environments with relatively high proportions of green space within a 1km radius. The survey found that this relationship was strongest for anxiety disorder and depression, linking green space to mental health. The correlation was stronger for children and people with lower socioeconomic status, demonstrating the importance of green spaces close to the homes of those groups (Maas & Verheij *et al.*, 2009). A study in England found that populations exposed to the greenest environments have the lowest levels of income-related health inequality (Mitchell & Popham, 2008), suggesting that physical environments that promote good health are important for reducing socioeconomic health inequalities. A study of children aged 3-16 in Indianapolis, US, found that greenness may help prevent child obesity: Bell *et al.* (2008) found that children and youth living in greener neighbourhoods had a lower body mass index, presumably due to increased physical activity or time spent outdoors.

Urban greening has positive and negative impacts on human respiratory health and immune system. The human immune system function may be improved by exposure to microbiota in natural ecosystems (Rook, 2013). Urban shrubs and trees remove significant quantities of air pollutants (see sections 3.4 and 7.1) and consequently improve environmental quality and human health (Nowak *et al.*, 2006). A study of 55 cities across the US found that urban trees remove an estimated 711,000 metric tonnes (with a value of USD 3.8 billion) of pollutants annually, including ozone, particulate matter, nitrogen dioxide, sulphur dioxide and carbon monoxide (Nowak *et al.*, 2006). A study in New York, US, found that street trees were associated with a lower prevalence of early childhood asthma (Lovasi *et al.*, 2008).

### **Physical activity**

In the past two decades there has been a substantial increase in literature examining the ecological influence of the physical environment on physical activity behaviour (Coutts & Hahn, 2015). Research shows that the way in which urban landscapes and the environment are designed and built is crucial for the level of physical activity in daily life, work and leisure (**figures 5.17, 5.18 and 5.19**) (Abraham *et al.*, 2010). Inequalities in the built environment, such as in access to facilities, lead to disparities in levels of physical activity and obesity (Gordon-Larsen *et al.*, 2006).

Research has also demonstrated an association between parks and open spaces and the propensity to engage in physical activity, although some studies show this is not consistent (Wolf & Robbins, 2015). A literature review by Abraham *et al.* (2010) identified that, in terms of physical activity in leisure time, location and green and built infrastructure play essential roles.

Various studies have investigated factors that influence the use of open space, including the role of access to destinations, the mix of land uses, traffic safety and aesthetically pleasing landscapes (Jennings & Gaither, 2015; Ward Thompson *et al.*, 2016).



**Figures 5.17, 5.18 and 5.19.** Urban green spaces provide opportunities for physical activity. Sources: The Glebe Society (2014) (left); The Royal Botanic Gardens (n.d.) (middle); and Group GSA (n.d.-b) (right).

### **Social health, community and social capital**

The built environment can foster a sense of community by facilitating interactions with other people and with nature (**Figures 5.20, 5.21 and 5.22**) (Ely & Pitman, 2014). Urban parks and other public places can enhance social integration by encouraging social contacts, community building, empowerment and mutual trust (Abraham *et al.*, 2010). Research has shown that, in addition to enhancing physical health, the presence of nature can improve the social health of individuals and communities (Maas & van Dillen *et al.*, 2009; Kuo, 2010; Hale *et al.*, 2011; Holtan *et al.*, 2015). Social health (or social wellbeing) refers to the satisfaction that a person receives from social networks, supports and interactions (Larson, 1996). Positive social health in individuals and communities can reduce crime, vandalism, aggression and littering. It also contributes to increased feelings of safety and leads to positive social interactions in urban neighbourhoods (Troy *et al.*, 2012; Wolfe & Mennis, 2012; Ely & Pitman, 2014).



**Figures 5.20, 5.21 and 5.22.** Urban green spaces improve social health and social capital. Sources: Chang (2014) (left); Bila (n.d.) (middle); Boardman (2010) (right).

A study in the Netherlands measured social contacts and health in 10,089 residents and calculated the percentage of green within 1km and 3km radii of the postcode coordinates of each resident's address. After adjusting for socioeconomic and demographic characteristics, less green space in people's living environment was found to coincide with feelings of loneliness and a perceived shortage of social support (Maas & van Dillen *et al.*, 2009).

Social capital refers to the 'shared knowledge, norms, rules and networks that facilitate collective experience within a neighbourhood' (Vemuri *et al.*, 2011 in Holtan *et al.*, 2015, p. 4). In a study in Baltimore, US, Holtan *et al.* (2015) identified a significant positive relationship between tree canopy and social capital associated with an increased use of sidewalks and outdoor spaces with trees and increased neighbourhood satisfaction and mental restoration. Holtan *et al.* (2015) also found that green space close to a person's home significantly increased social support, and the 'green fabric' of a neighbourhood created by tree canopies facilitates social health. Urban green spaces such as community gardens, bush regeneration sites and city farms provide opportunities for community members to gather, interact and work together towards common goals, which builds a sense of community, achievement and unity (Hale *et al.*, 2011).

### **Economic benefits**

This section outlines the two main types of monetary benefits associated with urban ecology: commercial benefits such as increases in property values, economic activity and consumer spending, as well as savings in operational costs; and the monetary benefits of ecosystem services, in which dollar values are calculated for ecosystem services and functions such as pollution mitigation and stormwater management. The total economic value (TEV) framework can be used to assess the economic value of green infrastructure. A brief discussion of TEV here is followed by a summary of key findings on the economic benefits of urban ecology and green infrastructure in the urban context.

Quantifying the economic benefits of green infrastructure can be difficult, especially in relation to aesthetic and cultural values. Nevertheless, assigning a monetary value to the economic benefits of urban ecology can help in influencing communities, stakeholders and policymakers in the adoption of urban ecology approaches (Vandermeulen *et al.*, 2011). Research is increasing on the economic value of urban ecosystems and the ecosystem services they provide, including the economic savings that can be realised from the use of green infrastructure compared with conventional approaches

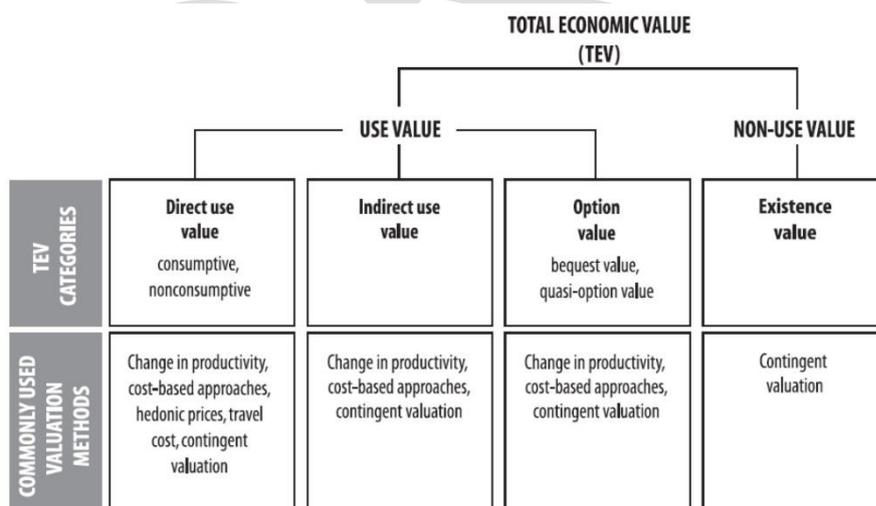
and the commercial benefits that urban ecosystems can generate with respect to retail spending and real estate values.

For example, New York City’s 2010 Green Infrastructure Plan estimates that every fully vegetated acre of green infrastructure would provide total annual benefits of USD 8,522 (AUD 11,189, in 2016) in reduced energy demand, USD 166 (AUD 217) in reduced CO<sub>2</sub> emissions, USD 1,044 (AUD 1,370) in improved air quality, and USD 4,725 (AUD 6201) in increased property value (Foster *et al.*, 2011). Philadelphia City has been using policies and demonstration projects since 2006 to promote green infrastructure in planning and development. Uptake has drastically reduced combined storm and sewer overflows, improved compliance with federal water regulations, and saved approximately USD 170 million (AUD 223 million) (Foster *et al.*, 2011).

Although urban ecology and green infrastructure provide a wide range of economic benefits, their design and construction also involves cost outlays.

TEV is commonly used to assess the economic value of green infrastructure (**Figure 23**). TEV, which provides a framework for examining the utilitarian value of ecosystems (Ely & Pitman, 2014), captures the full value of the various components of natural resources (Vandermeulen *et al.*, 2011). These include:

- Use values:
  - Direct use values: direct benefits from the use of primary services such as the provision of food and water.
  - Indirect use values: benefits from secondary services such as air and climate regulation.
  - Option values: benefits of preserving an option for future use.
- Non-use values:
  - Existence value: value of the existence of a service without its actual use.



**Figure 5.23.** Total economic value framework. Source: Ely & Pitman (2014).

Use values are often relatively easier to quantify because they involve observable behaviours (Netusil *et al.*, 2014), and non-use and option values are often more difficult to quantify. Although it might be possible to calculate the various values of a green space, generally it is not practical to do so and only the most important values are captured, given time and resource constraints (Mekala *et al.*, 2015).

Urban ecology generates a range of commercial benefits, including economic regeneration, commercial viability, increased consumer spending, increased property values, and reduced energy and infrastructure costs.

### Property values

Donovan and Butry (2010) studied the effects of street trees on the sale prices and time on market of houses in Portland, US. They used hedonic pricing, which is based on the concept of a willingness to pay and is used to estimate economic values for ecosystem or environmental services that directly affect market prices. The hedonic pricing method is most commonly applied to variations in housing prices that reflect the value of local environmental attributes (Ely & Pitman, 2014). Donovan and Butry (2010) found that, on average, street trees add USD 8,870 (AUD 11,638) to sales prices and reduce the time on market by 1.7 days. They also found that the benefits of street trees extend to neighbouring houses and that urban trees increase the prices of monthly rent by USD 5.62 (AUD 7.37) (Donovan & Butry, 2011). A study in Florida by Escobedo *et al.* (2015) quantified the effects of the structure of urban forests on property values, revealing that, on average, property value increased by USD 1,586 (AUD 2,080) per tree and by USD 9,348 (AUD 12,263) per one-unit increase in leaf area index; increasing maintained grass from 25% to 75%, on the other hand, decreased home value by USD 271 (AUD 355).

In Australia, a survey by the Real Estate Institute of Queensland in 2004 found that the values of homes in leafy streets were up to 30% higher than those in non-leafy streets of the same suburb (Ely & Pitman, 2014), a good argument for retaining existing vegetation and encouraging new planting. To date, however, most investigations of this sort have been conducted in North America and Europe, and there is a need for more Australian work on this topic.

Wolf (2007) conducted a review of studies evaluating urban forest and landscape conditions affecting the pricing of single-family homes, finding that houses with trees are generally preferred to comparable houses without trees, with a trend across the studies of a price increase of about 7%. Table 5.2 shows the influence of vegetation on the price of single-family homes in urban settings.

**Table 5.2.** The influence of vegetation on the price of single-family homes in urban settings. Source: Wolf (2007).

Price increase	Condition
2%	Mature yard trees (greater than 9-inch diameter at breast height)
3-5%	Trees in frontyard landscaping
6-9%	Good tree cover in a neighbourhood
10-15%	Mature trees in high-income neighbourhoods

Wolf (2007) also reviewed residential development properties and the market price of treed versus un-treed sites, summarised in Table 5.3.

**Table 5.3.** Residential development properties and the market price of treed versus un-treed sites. Source: Wolf (2007).

Price increase	Condition
18%	Building lots with substantial mature tree cover
22%	Tree-covered undeveloped acreage
19-35%	Lots bordering suburban wooded preserves
37%	Open land that is two-thirds wooded

The findings of Wolf (2007) suggest that, although some developers argue that the costs of tree protection are prohibitive, the increased sale price of properties would cover those extra costs.

According to Wolf (2007), more than 30 studies have shown that people are willing to pay more for a property located close to an urban open space than for a house that does not offer this amenity, a finding known as the 'proximate principle'. Table 5.4 shows the increases in relation to parks and open spaces usually containing trees and forests.

**Table 5.4.** Price increases in relation to parks and open spaces usually containing trees and forests. Source: Wolf (2007).

Price increase	Condition
10%	Inner-city home located within quarter of a mile (400m) of a park
10%	House 2-3 blocks from a heavily used, active recreation park
17%	Home near cleaned-up vacant lot
20%	Home adjacent to or fronting a passive park area
32%	Residential development adjacent to greenbelts

Views to parks or forests have been shown to increase property values. The value of an apartment block with a view of forested open space is 4.9% higher compared with one without, and the value of a house with a park view is 8% higher (Wolf, 2007). Trees also increase returns for retail and commercial spaces: rental prices for commercial offices with high-quality landscapes are 7% higher than for those without (Wolf, 2007).

A study in Philadelphia, US, found that proximity to a new tree planting is associated with overall increase in house prices of 9%, and that streetscaping (including initiatives such as tree plantings, container plantings, small pocket parks, parking lot screens, and median plantings) increases surrounding home values by up to 28% relative to similar homes in comparable areas without streetscape improvements (Wachter & Gillen, 2006).

### **Increase in economic activity and consumer spending**

Whitehead *et al.* (2006) studied the influence of urban quality improvements on business location and related activities in Manchester, England, measuring the willingness of a range of users to shop, do business and work in areas before and after 'walkability' improvements. The findings suggest that positive increases associated with environmental improvement programs, such as street-tree plantings, may be highly significant.

Wolf (2009) surveyed residents of three major cities in the US Pacific Northwest, finding that respondents strongly associated green malls (those with trees and shrubs) with a more positive atmosphere and cleanliness, and they thought of them as more favourable places for residents and tourists. The survey also revealed a willingness to pay 9.8% more for goods and services in well-landscaped malls (Wolf, 2009).

### **Energy savings**

Implementing urban ecology principles can result in energy savings in a range of ways (see section 5.7). A 2011 North American review of studies found that green roofs saved 15-45% in annual energy consumption, mainly due to lower cooling costs (Foster *et al.*, 2011). Green roofs provide additional insulation, thereby helping mediate temperatures within buildings.

Trees appropriately located around residences can also contribute to energy savings. A 20% tree canopy over a house results in annual cooling savings of 8-18% and annual heating savings of 2-8% (Foster *et al.*, 2011). A study in Sydney found that a single tree could reduce annual heating, ventilation and air conditioning use by 9.6%, and well-considered street-tree plantings could reduce it by 19.5% (Gallagher, 2015). This result is dependent on the species and size of tree, proximity to buildings and building form. Parks and other green spaces have been shown to provide localised urban cooling, reducing the need for reliance on air conditioners to cool buildings.

### **Infrastructure savings**

Implementing an urban ecology approach to infrastructure can result in cost savings. There is significant potential to integrate green infrastructure and WSUD into urban renewal and development projects, which would have both urban ecological and economic benefits. WSUD involves the replacement of grey infrastructure elements with green infrastructure, including constructed wetlands, bioswales, raingardens and biofiltration beds. Foster *et al.* (2011) demonstrated that building a wastewater treatment system using constructed wetlands would cost about USD 5 (AUD 6.50) per gallon (3.78 litres) of capacity compared with roughly USD 10 (AUD 13.11) per gallon of capacity for a conventional advanced treatment facility.

According to Foster *et al.* (2011), green alleys or green streets (streets with WSUD), water tanks, and tree plantings are estimated to be 3-6 times more effective in managing stormwater per USD 1,000 (AUD 1,310) invested than conventional methods. They cite the example of Portland, US, where an investment of USD 8 million (AUD 10.6 million) in green infrastructure saved USD 250 million (AUD 332 million) in hard, or grey, infrastructure costs.

### **Ecosystem benefits**

#### **Ecosystem services**

A review of cities in the US, Canada and China found that the monetary benefits of ecosystem services provided by urban forests and vegetation ranged from USD 3,212 (AUD 4,211) to USD 17,772 (AUD 23,303) per ha per year (Elmqvist *et al.*, 2015).

Ecosystem services also provide benefits in indoor environments. Wang *et al.* (2014) reviewed the literature on the effect of ecosystem services provided by urban green infrastructure on indoor

thermal comfort and environment. They found that the economic effects of adjacent vegetation and green roofs on climate regulation provided energy savings of up to almost USD 250 (AUD 327) per tree per year. Air-quality regulation was valued at between USD 0.6 (AUD 0.78) and USD 0.12 (AUD 0.15) per m<sup>2</sup> of tree cover per year. Maximum monetary values attributed to noise regulation and aesthetic appreciation of urban greening strategies were USD 20 and USD 25 (AUD 26 and AUD 32) per person per year, respectively.

### **Benefits of urban trees**

The i-Tree STRATUM (Street Tree Resource Analysis Tool for Urban Forest Managers) is a peer-reviewed software suite released by the USDA Forest Service in 2006 for urban and community forestry analysis and benefits assessment. i-Tree STRATUM has been used in many US cities, including Berkeley, California, and Fort Collins, Colorado, to value tree services and compare them with the cost of management. These valuations indicate that, for every dollar invested in management, benefits returned annually ranged from USD 1.37 to USD 3.09 (Soares *et al.*, 2011).

Other countries have also used i-Tree STRATUM, although regional modification is required. In 2011, for example, a study of street trees in Lisbon, Portugal, used the program to quantify the economic benefits of the city's 41,247 trees, finding that for every USD 1 invested in tree management, residents received USD 4.48 in benefits (Soares *et al.*, 2011).

In Australia, i-Tree STRATUM was trialled by the University of Melbourne in a study of two Melbourne city councils: City of Melbourne, and the outer suburban City of Hume. The study was funded by Nursery and Garden Industry Australia and was intended as a proof of concept for adapting i-Tree tools to an Australian setting (Fairman & Livesley, 2011). It showed that annually, for the cumulated benefits estimated (carbon sequestration, water retention, energy saving, aesthetics and air pollution removal), street trees in two suburbs of the City of Melbourne were estimated to provide ecosystem services equivalent to just over AUD 1 million, and about AUD 1.5 million in the City of Hume. Each tree was estimated to provide ecosystem services valued at AUD 163 in the City of Melbourne and AUD 89 in the City of Hume per year (Fairman & Livesley, 2011). An Australia-compatible version of i-Tree ECO, part of the i-Tree software suite, was introduced in 2011, and users in NSW, the Australian Capital Territory and Victoria now have the same access and automated processing as ECO users in the US (Ely & Pitman, 2014). In 2013, a representative sample of Brisbane City Council's street trees was assessed using the Australian i-Tree ECO program. It was estimated that approximately 575,000 street trees provide AUD 1.65 million worth of carbon sequestration, air-quality improvement and rainfall interception per year (Ely & Pitman, 2014). That is an equivalent of over 10% return on yearly planting and maintenance costs.

### **Visual and aesthetic benefits**

The visual appearance and attractiveness of towns and cities is strongly influenced by the provision of green space (Ely & Pitman, 2014). 'Amenity and aesthetics' encapsulates perhaps the most widely perceived benefit of trees, parks and greening. Many in the green industries rely on appeals to clients' emotions and sense of beauty (Wolf & Robbins, 2015).

As the landscape architect Frederick Law Olmsted commented in 1865, 'The enjoyment of scenery employs the mind without fatigue and yet exercises it; tranquilizes it and yet enlivens it; and thus, through the influence of the mind over the body gives the effect of refreshing rest and reinvigoration to the whole system' (Olmsted, 1865).

Trees and other green spaces have a significant role to play in the aesthetic quality of urban areas. They are generally highly valued by communities and can become significant features of urban areas.

Ely & Pitman (2014) referred to a study showing that the single biggest factor in determining the attractiveness of a street scene was the size of the trees and their canopies.

A study of Australians in street-tree-related professions found that the highest rating of the perceived benefits of street trees was for their visual/aesthetic benefit (Ely & Pitman, 2014). Similar results were found when Brisbane City Council surveyed its local residents in 2010, with aesthetic appeal the second highest perceived benefit of trees (49%) after shade (59%) (Ely & Pitman, 2014).

Trees and other vegetation help create a sense of place, or character, in urban areas. They have the potential to reinforce local character and shape an identity for an area. Their distinctive forms, textures and colours create seasonal interest that imparts a unique character to a particular place.

Trees and other vegetation can also help define space by their size and form, contrasting open and enclosed spaces and creating visual corridors (**figures 5.24 and 5.25**). Vegetation can help screen undesirable views and provide privacy, which is especially important in dense urban areas.



**Figures 5.24 and 5.25.** Street-tree planting in Victoria Park town centre (left) and along Bourke Street, Sydney (right). Sources: NSW Government Architect's Office (n.d.) (left); Group GSA (n.d.-a) (right).

### Urban resilience

Urban ecosystems contribute to the resilience of cities and towns, where resilience is defined as 'the ability of an urban system and all its constituent socioecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity' (Meerow *et al.*, 2016, p. 45). The urban resilience of a town or city depends on the capacity of its various systems to simultaneously maintain social and ecological functions. Ecosystem services provide an important framework for linking these functions (McPhearson *et al.*, 2014).

The development of specific resilience plans and targets has generally been overlooked in urban planning policies and frameworks. This is beginning to change, however, especially in sensitive areas where urban environments are experiencing the effects of climate change, urbanisation and development and as policymakers aim to reduce the risk of disaster and vulnerabilities related to

climate change (McPhearson *et al.*, 2014). In December 2014, Sydney was selected as a member of the 100 Resilient Cities program, pioneered by the Rockefeller Foundation. As part of the two-year initiative, the City of Sydney will develop a resilience strategy to help build the strength of the community, infrastructure and economy of Sydney (City of Sydney, 2015).

High population density and dependence on grey infrastructure can make urban populations vulnerable to disturbances such as flooding, heatwaves, disease outbreaks and storms. Ecosystems and the associated services they deliver in and around urban areas can help buffer against many of these (McPhearson *et al.*, 2014).

Building cities that protect and encourage biodiversity can help buffer the impacts of disturbances on the provision of ecosystem services (McPhearson *et al.*, 2014). Mangroves are an example of an ecosystem or ecological community that acts as a natural buffer to protect urban areas from extreme climate events and hazards such as storms, waves, floods, tsunamis and cyclones (Gómez-Baggethun & Barton, 2013). It is important, therefore, to protect mangrove ecosystems, which are under continual threat from coastal development.

Green infrastructure such as green roofs, green walls and street trees can act as a buffer to the extreme temperatures of heatwaves, increasing the resilience of urban areas in the face of climate change. The potential value of urban green infrastructure has been captured in the term 'insurance value', which is the contribution of urban green infrastructure to enhancing the capacity of cities to respond and adapt in the face of disturbance and change and reducing the risk of (for example) flooding (Elmqvist *et al.*, 2015).

## **5.7 How can urban ecology be integrated into the built environment?**

### **Conceptual frameworks**

A number of conceptual frameworks exist for introducing natural elements into built environments. The history of creating, understanding and interpreting ecological networks in the urban context extends back centuries (Ignatieva *et al.*, 2011). There are numerous examples in Europe and America dating to the sixteenth century, as well as examples from the ancient world, such as the Hanging Gardens of Babylon and Ancient Roman infrastructure. In the nineteenth and twentieth centuries, adding natural elements to built environments arose initially out of ideas of aesthetics, political dominance and public health but moved towards an acknowledgment of the ecological value of such interventions. Examples include much of the work of Frederick Law Olmsted, including Central Park in New York and the Emerald Necklace in Boston (Ignatieva *et al.*, 2011).

In Australia, ecologically sustainable development was part of the national government's strategy for sustainability in the 1990s. The Australian Government endorsed the following definition of ecologically sustainable development in 1990: '... using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased' (Sustainable Built Environment Centre for Design, 2006, p. 4).

Landscape ecology is a conceptual framework centred on the idea of the landscape as a matrix of patches and corridors, which link to each other and create a network for species distribution throughout landscapes (Forman & Godron, 1986). Landscape ecology establishes a series of principles with the potential to inform the conservation, planning and design of landscapes in urban and rural areas.

Green infrastructure has been defined in the literature in various ways. Originally, it was associated with parklands, forests, wetlands, greenbelts and floodways in and around cities that improved the quality of life and provided ecosystem services such as water filtration and flood control (Foster *et al.*, 2011). Today, the concept is more closely aligned with sustainability goals and technological advances and is used as an umbrella term encompassing a broad range of elements, such as green roofs, green walls, parks, street trees, urban forests, green corridors, residential gardens, school grounds, cemeteries, golf courses, wetlands and intertidal zones.

The three most common approaches to green infrastructure focus on the role of ecosystem services, green engineering and linked green spaces (**Table 5.5**) (Pitman & Ely, 2015). An ecosystem services approach focuses on the ecosystem services produced by nature, both internationally and locally. A green engineering approach aims to replace grey infrastructure with green infrastructure. A linked green-spaces approach emphasises the importance of connected green networks throughout landscapes.

**Table 5.5.** Key points for the three approaches to green infrastructure. Source: Summarised from Pitman & Ely (2015).

APPROACH TO GREEN INFRASTRUCTURE	FOCUS OF APPROACH
Ecosystem services	<ul style="list-style-type: none"> <li>• Acknowledges that ecosystems operate locally, nationally and internationally</li> <li>• Ecosystem services are provided by nature</li> <li>• Linked to concepts of sustainable development and urban ecology</li> </ul>
Green engineering	<ul style="list-style-type: none"> <li>• Replaces conventional infrastructure elements with 'green' elements which provide ecosystem services</li> <li>• Replaces traditional grey infrastructure with nature-based elements, including WSUD</li> </ul>
Linked green spaces	<ul style="list-style-type: none"> <li>• Connectivity provides value for both people and local ecosystems</li> <li>• Linked to the concept of landscape ecology</li> </ul>

In this review, the term 'green infrastructure' is used to describe an array of products, technologies and practices that use natural systems – or designed systems that mimic natural processes – to provide mutually beneficial outcomes in enhancing environmental sustainability and human liveability. Green infrastructure is made up of built elements and more natural elements. Built interventions include green roofs, green walls, bioswales and constructed wetlands. Natural elements include creek restoration and parks based around remnant vegetation and greenways.

Urban ecological interventions in the built environment can be made at a range of scales and, for greatest efficacy, multiple scales are required. Green infrastructure can be implemented in centralized public 'macro' projects and in decentralized 'micro' applications on private properties (Foster *et al.*, 2011). At the large scale, landscape planners can design green infrastructure elements such as greenways and parks and the protection of remnant bushland and creek corridors into urban developments. Comprehensive water management and street-tree plantings can be designed at a precinct scale and, at a still smaller scale, individual buildings can be designed to integrate elements of green infrastructure, such as green roofs and green walls.

Green infrastructure has a hierarchy of interventions (**Figure 5.25**). In areas that contain remnant vegetation, the protection and conservation of such areas is crucial; in the face of the continued expansion of urban areas, remnant bushland and waterways provide important diversity. Where ecosystems have already been disturbed, restoration such as through bush regeneration and weed management may be required. If restoration is not possible because an entire ecosystem has been lost, enhancing green space is the next option, which can be done by increasing areas of green space and the density of tree planting. If none of these options is available, creating new habitats may be required, such as green roofs and bioswales.

Each of these interventions can be applied at different scales and is influenced by built-form density and street patterns. Protecting and conserving remnant ecosystems typically applies in rural land and peri-urban lands on the fringes of cities, where land is yet to be developed. The restoration of existing ecosystems takes place in low-density urban areas, such as outer suburbs, where remnant ecosystems exist in degraded condition. Existing remnant ecosystems and green spaces can be enhanced in medium-density urban areas such as established suburbs. In high-density urban areas, such as central business districts and older inner-city suburbs, new habitats can be created through green infrastructure interventions and retrofits. In addition to density, existing or proposed street patterns play significant roles in determining how green infrastructure can be implemented in the built environment.



**Figure 5.25.** Diagram showing green infrastructure hierarchy of intervention and its relation to built form density.

### Types of urban ecology interventions

The following section outlines the key built-environment interventions that facilitate urban ecological outcomes in urban renewal and redevelopment areas.

#### Urban planning

Professionals involved in preparing master plans for urban areas have key roles to play in facilitating urban ecological outcomes in urban renewal and redevelopment projects. Urban planning should consider the complex ecological and social processes operating at different times and scales in a region (Faehnle *et al.*, 2015). The provision of ecosystem services can be supported by integrating green infrastructure in the urban context. This will also improve the resilience of a city in the face of climate change and extreme weather events (Ahern, 2013).

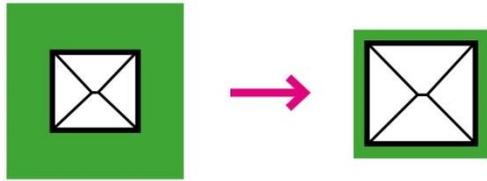
Landscapes can be thought of as series of habitat patches and corridors, and these need to be integrated into the design and development of urban areas. Planning for such integration should extend from large-scale regional plans through to small-scale local plans, enabling an integrated, holistic approach to achieving urban ecological outcomes.

The Rouse Hill Town Centre Master Plan, prepared by Oculus for the GPT Group, is an example of urban planning that integrates green infrastructure and WSUD throughout the urban fabric (**Figure 5.26**). The master plan for this 120-ha site preserves and enhances Caddies Creek (which runs through the centre of the site), establishes a network of street-tree corridors, and creates 'patches' of green and open space for ecological and social outcomes.



**Figure 5.26.** The Rouse Hill Town Centre Masterplan (Source: Oculus, 2008) and the built outcome: an example of the street-tree corridor with WSUD along Caddies Boulevard. Source: N. Pelleri (2016).

Changing urban planning trends have resulted in declines in biodiversity and the quality of green spaces in urban areas. For example, privately owned green spaces are subdivided as lots are split, resulting in what has been called 'the death of the Australian back yard' (Hall, 2010). The average lot size for new growth areas in Sydney has decreased from 587m<sup>2</sup> in 1999 to 546m<sup>2</sup> in 2008 (NSW Department of Planning, 2009), and house sizes almost doubled in the 25 years to 2010, from 162m<sup>2</sup> to 248m<sup>2</sup> (ABS, 2010; Gallagher, 2015). In contemporary suburbs, buildings cover much larger areas than they did in the traditional suburbs of previous generations (**Figure 5.27**). Buildings in contemporary suburbs in NSW cover, on average, 36% of the lot, compared with 15% in traditional suburbs (Ghosh & Head, 2009). Lots in contemporary suburbs also have significantly smaller backyards than in traditional suburbs (35% compared with 52%), significantly less tree cover (4% compared with 20%) and twice as much impermeable surface (16% compared with 8%) (Ghosh & Head, 2009).



**Figure 5.27.** A depiction of a traditional lot (left) and contemporary lot (right), in plan view. Lot sizes (shown in green) are decreasing and dwelling sizes are increasing.

In Australia, these changes to the urban form have been linked to reduced environmental performance (Gallagher, 2015). The subdivision of lots often means an increase in paved surfaces, which may reduce an area's capacity for water retention and flood mitigation (Sutton & Anderson, 2016). Some argue that traditional suburbs are more capable of supporting environmental and ecological functions because of the better connectivity of green spaces and the availability of onsite land for local food production, but others argue for compact, dense development within a broad green matrix of development (see section 3.5).

### Patches and corridors

Green open spaces such as parks and bushland reserves are patches within the urban matrix that provide species habitat and diversity. They may be owned publicly or privately: examples of the latter include golf courses, cemeteries and the grounds of private schools. The edge condition, length, depth and configuration of patches are important determinants of biodiversity outcomes.

Greenways, green streets (street-tree plantings) and backyards can act as corridors or 'stepping stones' between patches (**Figures 5.29 and 5.30**), facilitating the movement and dispersal of species through the landscape; their size and edge condition are very important in determining biodiversity outcomes. Urban ecological networks are defined differently in ecology, urban planning and landscape ecology; in urban planning and design, urban ecological networks establish physical, visual and ecological connectivity between built-up areas of a city and surrounding natural areas and green spaces (Ignatieva *et al.*, 2011).



**Figures 5.29 and Figure 5.30.** Street-tree planting can create corridors in urban landscapes, as seen on Newington Boulevard, Newington (left) and Bourke Street, Surry Hills (right). Sources: N. Pelleri (2010) (left); Group GSA (n.d.-a) (right).

Backyards constitute unique opportunities for the provision of wildlife habitat corridors and biodiversity (figures 5.31 and 5.32), but the aesthetic preferences of property owners have significant impacts on the potential for increasing biodiversity in suburbs. Native plants are seen by some as messy, limited in availability, high maintenance and difficult to grow. For these and other reasons, many frontyards and backyards are planted with exotic species that provide only limited biodiversity benefits. Resources such as Backyards for Wildlife (Bathurst Regional Council, 2012) and Backyard Biodiversity (Boroondara City Council, 2010) help guide local residents in creating gardens that will attract and provide habitat for local flora and fauna. Gardens using Australian native plants can be created in a variety of styles, from formal through to contemporary.



Figures 5.31 and 5.32. Frontyard (left) and backyard (right) biodiversity. Sources: Forrest (n.d.) (left); Brockhoff (n.d.) (right).

### Green walls

Green wall is the general term for a variety of vertical greening systems, of which there are two main categories (Madre *et al.*, 2015): 'green facades'; and 'living walls'. Green facades use climbers to spread over wall surfaces (Francis & Lorimer, 2011). Living walls use felt layers or modular hydroponic systems to form a living cover over wall structures.

In green facades, climbing plants such as ivy are encouraged to grow up walls, often on a wire or trellis framework, to form a green covering over the surface of the wall (Francis & Lorimer, 2011). Usually, the plants grow in the ground adjacent to the wall, or in planter boxes. Green facades normally require less intensive maintenance than living walls (Pérez-Urrestarazu *et al.*, 2015) because of the lower number and diversity of plants used.

Living walls use felt layers, irrigated containers attached to a frame, or modular hydroponic systems to form a living cover over the wall structure. Living walls differ from green facades because they support vegetation that is rooted in containers or substrates attached to the wall, rather than being rooted at the base of the wall (Francis & Lorimer, 2011). Living-wall systems allow the use of a far greater range of species than green facades, increasing their potential to support biodiversity outcomes and to incorporate plant species that might otherwise be missing in the urban environment (Köhler, 2008).

Another category of green walls is 'biowalls' or 'active living walls'. These are located indoors and enhance the atmosphere and indoor environment (Francis & Lorimer, 2011). Biowalls, which are becoming increasingly popular, are discussed further in 'emerging technologies' below.

In any type of green wall, a range of technical issues needs to be considered, requiring inputs from structural, civil and hydraulic engineers; as with any garden, green walls require maintenance, the extent of which depends on the type of green wall.

Green walls and green roofs are increasingly common in cities worldwide. They are installed for a variety of reasons, including aesthetic and economic, and they have the potential to significantly influence urban ecological outcomes in cities and towns, especially in light of design and technological advances.

Green wall technologies continue to evolve. The provision of adequate watering is essential for maintaining green walls, and automatic irrigation controls are helping ensure this. Temperature and moisture sensors, as well as flow meters, can be embedded in green walls to measure water and temperature conditions and provide water to plants as needed.

Green walls in Central Park in Sydney's central business district use innovative techniques (**Figure 5.32**). The green facade is based on a hydroponic system, removing the requirement for plants to grow in soil (and the engineering needed for that), although the hydroponic system needs to be managed. Planter boxes supported by floor slabs are used to create green walls. Each horizontal and vertical planter has its own irrigation system, controlled by a building management system that also monitors environmental conditions. The felt growing medium is made of recycled polyamide cloth, which is non-biodegradable and will not require significant maintenance (Tello, 2013). Water from the planter boxes and green walls is collected and recycled for treatment and re-use in the Central Park development.



**Figure 5.32.** Green walls at Central Park. Source: P. Osmond (2016).

Green walls are also being developed for urban agriculture. Known as vertical farms, these use green wall technology for local food production. Green facades lend themselves to climbing plants such as beans and passionfruit, and living wall systems can support herbs and some vegetables and fruit. Nutrient and water management is especially important in vertical farms.

### **Green roofs**

Green roofs provide economic, social and environmental benefits. They reduce the cost of heating and cooling, increase the longevity of the roof membrane, reduce the UHI effect, improve air quality, increase sound insulation and fire resistance, improve stormwater management, increase human health and wellbeing and provide habitat for flora and fauna (Oberndorfer *et al.*, 2007). The quality

of habitat is closely related to the diversity of plant species and designs that create different soil depths and microhabitats.

A green roof is a layered system comprising a waterproofing membrane, a growing medium and a vegetation layer. Green roofs often also include a root barrier layer, a drainage layer and, where the climate necessitates, an irrigation system (Castleton *et al.*, 2010).

There are two main types of green roofs: extensive and intensive. An extensive roof is characterised by a thin growing medium (6-25cm), small plants and minimal maintenance. Intensive green roofs are heavier and thicker (15-70cm), require more maintenance and support a wider variety of plants. Semi-intensive roofs have characteristics of both intensive and extensive roofs (Silva *et al.*, 2016).

Extensive roofs have a range of purposes, including biodiversity, stormwater management, thermal insulation and fireproofing (Oberndorfer *et al.*, 2007). The substrate used in extensive green roofs is lightweight, with high porosity and typically low levels of organic matter. Due to the properties of the substrate, this type of green roof cannot support large plants. Low-growing species of plants are specified, often comprising Australian native species. Extensive roofs are generally low-maintenance, with access required for those maintenance purposes (**Figures 5.34-5.36**).



**Figures 5.34, 5.35 and 5.36.** Extensive green roofs at MONA, Hobart (left), on the Victorian Desalination Plant (middle), and on a residential property in the Sydney central business district (right). Sources: P. Osmond (2016) (left); Aspect Studios (n.d.-b) (middle); Green Roofs Australasia (2014) (right).

Intensive roofs have functional and aesthetic purposes, as well as useable open space (**Figure 5.37 and 5.38**) (Oberndorfer *et al.*, 2007). The substrate used on intensive green roofs is deeper and can therefore support a wider range of plant species. Plant species need to be hardy enough to withstand the potentially harsh rooftop conditions.



**Figures 5.37 and 5.38.** Intensive green roofs provide recreational opportunities and biodiversity outcomes. Sources: OEH (2014) (left); Wuttke (n.d.) (right).

Brown roofs are a type of extensive green roof that attempt to simulate brownfield conditions, often using resource-poor substrates such as gravel or rubble. An aim is to encourage the establishment of species that are often displaced by more competitive species (Francis & Lorimer, 2011), although this is contested.

To maximise invertebrate biodiversity in green roofs, a Sydney-based study showed that roofs need to be at least 24m<sup>2</sup> in size (Berthon *et al.*, 2015). The study also found that, to maximise overall invertebrate richness, the total roof area must be greater than 746m<sup>2</sup> and contain both vegetated and bare earth areas at a threshold of at least 30% green cover (Berthon *et al.*, 2015).

Many resources are available to help landscape architects, project managers, property managers and other built environment professionals implement green roof (and green wall) designs, including:

- *Living Wall and Green Roof Plants for Australia* (Perkins & Joyce, 2012)
- *Urban Green Cover in NSW Technical Guidelines* (NSW Office of Environment and Heritage, 2015)
- *Growing Green Guide: a guide to green roofs, walls and facades* (VIC Department of Environment and Primary Industries, 2014)
- *Green Roofs and Walls RICS Professional Guidance Note* (RICS, 2016).

With any type of green roof, engineering aspects must be taken into consideration, requiring inputs from structural, civil and hydraulic engineers to ensure the structural integrity of the roof.

### **WSUD**

WSUD is a framework for sustainable urban water management that aims to incorporate water-cycle management initiatives in the design of urban landscapes (**Figure 5.39**) (CSIRO, 1999; Wong & Brown, 2009; Ely & Pitman, 2014). WSUD is an Australian concept similar to low-impact development in the US and sustainable urban drainage systems in the United Kingdom. WSUD 'aims to ensure that water is given due prominence within the urban design process through the integration of urban design with the various disciplines of engineering and environmental sciences associated with the provision of water services including the protection of aquatic environments in urban areas' (Wong & Brown, 2009, p. 674).

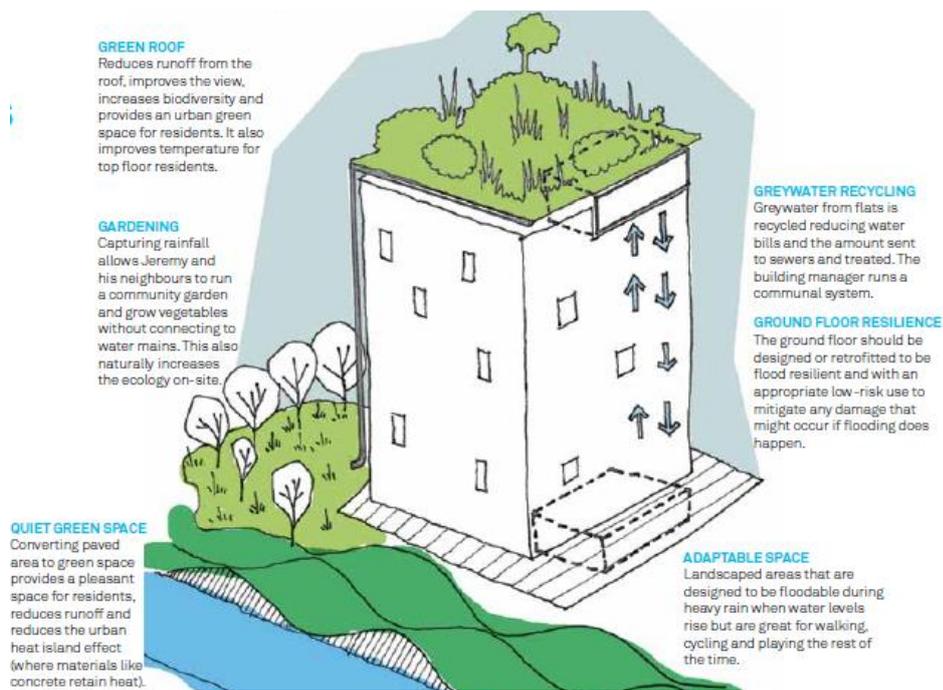


Figure 5.39. WSUD at a site scale. Source: Construction Industry Research and Information Association (2013).

Although the potential impacts of stormwater runoff have been recognised since the 1980s, legislation wasn't put in place or best management practices adopted until the 1990s (Greenway, 2016). The first WSUD guidelines in Australia were produced in Western Australia in 1994 (Greenway, 2016). NSW does not have an overarching statutory WSUD policy that applies generally across the state (Choi & McIlrath, 2016) (Chapter 4 provides more detail on the planning framework for WSUD in NSW). Initially, WSUD was valued for its potential to control runoff flows, mitigate floods, store water and remove contaminants to improve downstream water quality. It is now acknowledged, however, that WSUD also has habitat and social benefits (Greenway, 2016).

Australia's Cooperative Research Centre for Water Sensitive Cities is helping change the way in which urban areas are designed, built and managed through research into urban water management. Its document *Stormwater Management in a Water Sensitive City* (2012) outlines approaches to urban stormwater management to help create water-sensitive cities that harness the potential of stormwater to alleviate water shortages, reduce the UHI effect and improve urban waterway health and landscapes (Wong *et al.*, 2012).

Figure 5.40 shows the framework for WSUD taken by a NSW state government agency, Landcom. The agency has played a strong role in advancing the implementation of WSUD in NSW. Figure 5.40 shows that the potential for enhancing urban biodiversity through WSUD lies at the stage of urban design and built form, as well as in the design of stormwater management and potable water conservation.

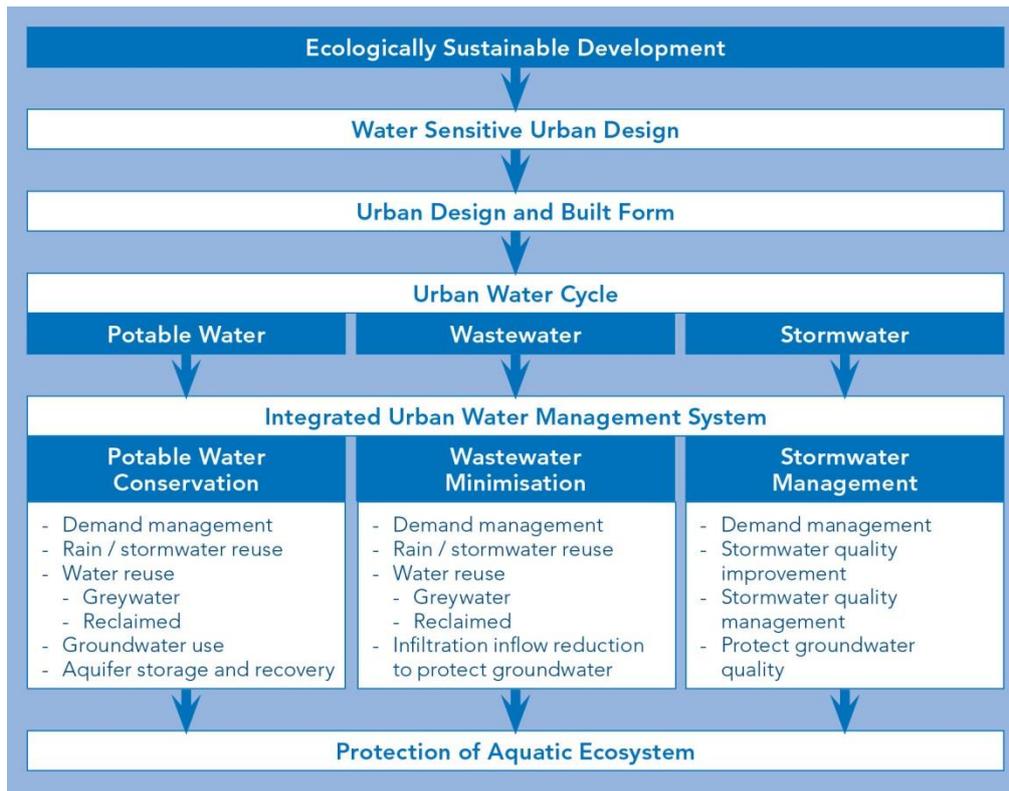


Figure 5.40. WSUD framework in Landcom's WSUD policy. Source: Landcom (2009a).

In practice, WSUD consists of various elements (Figure 5.41), such as:

- Biofiltration systems, including bioretention swales, raingardens and vegetated swales
- Passive landscape irrigation
- Permeable surfaces such as porous pavements
- Constructed wetlands and ponds.

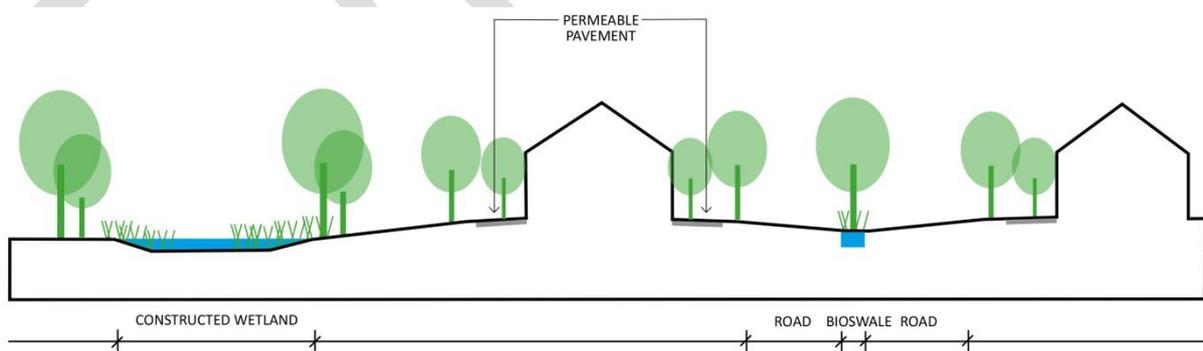


Figure 5.41. Diagrammatic section showing typical WSUD elements found in the urban context.

Biofiltration systems help improve the quality of urban stormwater runoff and protect aquatic ecosystems (Ely & Pitman, 2014). They comprise vegetation, soil/filter media and a drainage layer. Vegetation is an important component because it enhances the soil/filter media through physical, biological and chemical processes (Ely & Pitman, 2014). The soil/filter media is typically composed of sandy loam.

Bioretention swales treat and convey stormwater. Coarse to medium sediments are removed from stormwater runoff as the water passes through the plants, filter media, transition layer and drainage layer. Raingardens slow urban stormwater flows by capturing and slowly releasing water. Vegetated swales can be used instead of pipes to convey stormwater, and they provide a 'buffer' between the impervious areas of a catchment and the receiving water (Landcom, 2009a). The longitudinal slope of swales is an important design consideration. Swales with less than a 1% fall can become waterlogged and have stagnant ponding (Landcom, 2009a). The optimal design for a biofilter is that it covers at least 2% of its catchment area, possesses a sandy loam filter media, and is planted with *Carex appressa* or *Melaleuca ericifolia* (Bratieres *et al.*, 2008).

Swales can be located throughout a landscape, including in roadside verges, medians and open green spaces (**figures 5.42-5.44**).



**Figures 5.42, 5.43 and 5.44.** Bioswales manage urban stormwater flows and reduce pollutant loads, and they have the potential to increase urban biodiversity outcomes when designed appropriately. Source: NSW Government Architect's Office (n.d.) (left); Skoor (n.d.) (middle); All Terrain Consulting Ltd. (n.d.) (right).

Raingardens are another form of WSUD used in urban areas to help manage urban stormwater flows and reduce the pollutant loads entering streams and rivers. Located in road reserves, raingardens collect urban and slow stormwater flows. Plants and drainage layers in raingardens help remove pollutants from the water and clean it before it is released slowly into the urban stormwater system.

Constructed wetlands have been employed widely since their first full-scale application in the late 1960s (Yang *et al.*, 2008). They have been applied to treat domestic sewage, agricultural wastewater, industrial effluent, mine drainage, landfill leachate, urban runoff and polluted river water (**figures 5.45 and 5.46**) (Liu *et al.*, 2015). Constructed wetlands make use of the biodegradation ability of plants and their associated microorganisms, and they have low construction and maintenance costs (Yang *et al.*, 2008).



**Figures 5.45 and 5.46.** Constructed wetlands at Sydney University (left) and Sydney Park (right). Source: F. van den Berg (2016) (left); City of Sydney (2014) (right).

Constructed wetlands have three zones: an inlet zone, a macrophyte zone, and a high-flow bypass channel. The inlet zone is a sediment basin that removes coarse sediments. The macrophyte zone is a shallow, heavily vegetated area that removes fine particulates and takes up soluble pollutants. The bypass channel protects the macrophyte zone (Landcom, 2009a).

Wetlands can also be used to treat sewage. Technologies such as artificial aeration, flow direction reciprocation, membrane bio-reactors, electrochemical oxidation and microbial fuel cells have emerged in recent years to maximise the individual advantages of constructed wetlands in their treatment of wastewater (Liu *et al.*, 2015). Coupling constructed wetlands with such technologies helps resolve issues that cause deteriorating environmental or discharge standards.

WSUD elements require (minimal) regular maintenance to ensure that the system is functioning (Landcom, 2009b; Melbourne Water Corporation, 2013) and to ensure that optimal infiltration and pollutant removal properties are sustained. In swales and raingardens, pollutant particulate matter and leaves can clog the soil, filter media and drainage layers, and 'contaminated' soil or filter media needs to be replaced periodically. In constructed wetlands, routine checks involve checking inflow and outflow paths and vegetation management (Landcom, 2009b). In situations where plants are removing pollutants such as heavy metals, pesticides and organic pollutants, they need to be harvested regularly and disposed of appropriately.

Many resources are available to help landscape architects, projects managers, property managers and other built-environment professionals to implement WSUD, including:

- *Stormwater Management in a Water Sensitive City* (Wong *et al.*, 2012)
- *WSUD Technical Guidelines for Western Sydney* (URS, 2004)
- *Managing Urban Stormwater: harvesting and reuse* (NSW Department of Environment and Conservation, 2006)
- *WSUD Strategy*, books 1 to 4 (Landcom, 2009a)
- *Evaluating Options for Water Sensitive Urban Design: a national guide* (BMT WBM Pty Ltd, 2009)

## Coastal development

Coastal development replaces natural ecosystems with urban and industrial developments that cannot provide the same ecosystem services. It is crucial, therefore, that when urban waterfront developments such as marinas, jetties, seawalls, bridges and wharfs are installed they are designed in such a way as to allow the continuation of ecosystem functioning. Where coastal conditions have already been disrupted, shoreline and marine habitat restoration, and shoreline replacement and continuation, can help improve ecosystem functioning. Where waterfront developments extend over the surface of the water, they can be designed with light-penetrating surfaces to ensure that light reaches the water below (**figures 5.47 and 5.48**).



**Figures 5.47 and 5.48.** The Seattle Waterfront Park pier (left) and seawall (right) are examples of sensitive waterfront designs that have improved coastal ecosystem functioning. Source: Mah (2015).

## Emerging technologies

Emerging technologies are helping in the implementation of urban ecology principles in built environments.

### Living walls

New approaches and technologies are moving toward the integration of green walls (both indoors and outdoors) with the air conditioning and ventilation systems of buildings (**figures 5.49 and 5.50**) (Pérez-Urrestarazu *et al.*, 2015). This type of green wall is known as an ‘active living wall’ or a breathable green wall, in which air currents are forced to pass through the green wall. The air that is cooled, filtered and humidified by the plants and growing media in the wall is then added to the building’s interior air supply. Indoor air quality and healthy buildings have become flourishing fields for research and practice.



Figures 5.49 and 5.50. Breathable green wall testing in Canada (left) and an example of a living green wall at Barangaroo South (right). Sources: P. Osmond (2015) (left); The Urban Developer (2016) (right).

### Urban tree management

Urban trees are crucial for the delivery of urban ecosystem services, but urban tree management can be complex, with many issues needing consideration (Figure 5.51). There is often limited space available to accommodate the height and width of a tree's canopy and the area and depth of its roots. In highly urbanised areas, access requirements for vehicles and services and pedestrians need to be considered.

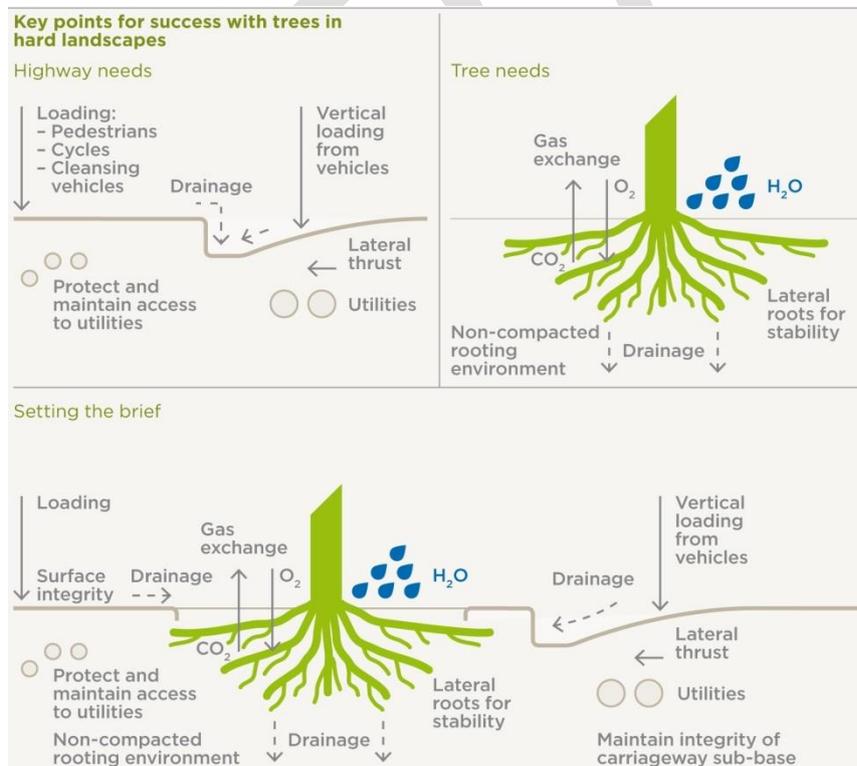


Figure 5.51. Considerations for urban tree management. Source: Trees and Design Action Group Trust (2014).

Recent technological advances are assisting with urban tree root management. Traditionally, trees have been planted straight into tree pits in the subgrade. In some cases, this has led to the destruction of pavements through cracking and uplift. Tree pits need to provide large volumes of uncompacted soil for root growth while also supporting vertical loads from a range of vehicles.

Various 'cell' products are now on the market that enable the better management of urban tree roots. These are modules that interlock and help protect and limit damage to pavements; they have an open structure to accommodate soil and roots as trees grow. Cells are designed to withstand loads from a range of vehicles, and they have both vertical and lateral strength. One of several products on the market in Australia is Strata Cell (**figures 5.52 and 5.53**), which is made from recycled polymers. The interlocking modules mean that the cells can be configured to suit each site.



**Figures 5.52 and 5.53.** StrataCell in City Street, Dandenong (left), ready for tree planting, and in South Dock on Navy Pier, Chicago, US (right). Sources: Maslog-Levis (2012) (left); Landscape Online (n.d.) (right).

### **Urban soil management**

Soil is the foundation for much of the biodiversity in urban areas. Urban soil is the medium in which vegetation grows, providing habitat for fauna, and it is important, therefore, that it provides appropriate qualities to ensure ideal conditions for plant growth. Urban soil science studies the composition of soil in relation to its chemical and physical properties (Leake, n.d.); it is a growing field as urban landscapes and development sites become more complex. With greenfield development sites (i.e. undeveloped lands) becoming increasingly uncommon, many new urban development sites are brownfields (i.e. lands previously used for industrial or certain commercial purposes), which may be contaminated with pollution or hazardous waste.

The chemical and physical properties of urban soils are important for plant growth, and they are affected by a range of influencing factors (Ossola & Livesley, 2016). Important chemical properties of soils include pH, salinity and cation exchange properties, phosphorus, oxygen and redox potential (Leake, n.d.), and compaction and drainage properties are important physical qualities. In the urban context, soil structure and fertility can be poor. Without suitable growing conditions, vegetation will fail and urban landscapes will be unsuccessful.

The main problems with urban soil are compaction and anoxia. Soils can be heavily compacted as a result of years of pedestrian and vehicle movements. The original structure of the soil is often

completely destroyed, and soils might contain unsuitable growing materials such as debris from building sites. These problems are prevented by the use of gap-graded soils, which range from sandy turf underlay materials to specially designed structural soils (Leake, n.d.). Systems similar to tree cells also improve soil structure while providing strength for pedestrian and vehicle movement. Structural soils comprise large-sized gap-graded aggregates; they are capable of taking the full compressive force of roads and footpaths while maintaining sufficient pore space and size between the aggregate particles for root extension (Leake, n.d.). In highly urban contexts, concrete slabs suspended a minimum of 50mm above the top of the soil medium may be used around tree plantings to allow soil aeration and prevent soil compaction and anoxia.

Innovative urban soil science was deployed at the Barangaroo Headland Park using almost completely recycled resources. Crushed sandstone originating from building excavations in Barangaroo South commercial developments, recycled sand from building excavations, green garden waste compost, and composted wood mulch screened from green garden waste collections were used to create the soil profiles at Headland Park (Figure 5.54). Recycled materials (crushed sandstone) were also used to create soil profiles for bush regeneration sites at the Sydney Olympic Parklands (SESL, 2016).

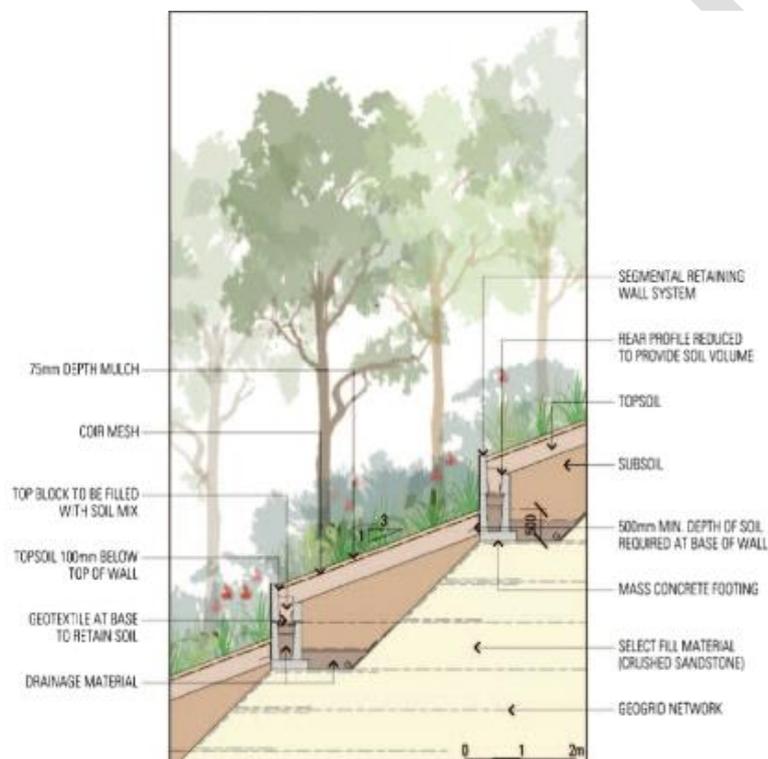


Figure 5.54. Section showing the soil profile developed for Barangaroo Headland Park. Source: SESL (2016).

### Permeable pavements

Permeable or porous pavements include gravels and unit paving systems with either cut-outs that allow water to permeate through or porous pavers that allow water to filter through the pavers themselves (NSW Office of Environment and Heritage, 2015). Permeable pavements have many environmental benefits: they allow rainwater to percolate through into soils, facilitate groundwater recharge, reduces stormwater runoff and slow down stormwater flows into receiving waters.

Permeable pavements are increasingly being used as a WSUD strategy in urban areas. In Sydney, the first large-scale use of permeable pavements was along roads and in plazas and building forecourts

at Sydney Olympic Park (**Figure 5.55**). Permeable pavements can be used for both vehicular and pedestrian applications, such as pedestrian malls, driveways, car parks and courtyards.



**Figure 5.55.** Permeable unit pavers at Sydney Olympic Park. Source: Adbri Masonry (n.d.).

Permeable pavement technologies continue to improve with ongoing industry research and development. Various types of permeable pavement exist (**Figures 5.56-5.58**), including resin-bound porous paving, pervious concrete, plastic infiltration pavers, porous asphalt and permeable unit pavers. Permeable ceramic pavers are available in a wide range of colours, including light colours such as light grey that help reduce the UHI effect. Permeable paving systems are laid onto a porous subbase, which facilitates percolation and infiltration into the ground beneath.



**Figures 5.56, 5.57 and 5.58.** Permeable paving includes products such as FlowGrid plastic pavers from Atlantis (left), HydroSTON segmental concrete pavers (middle) and StoneSet resin-bound paving (right). Sources: Atlantis Australia (n.d.) (left); Hydrocon (2016) (middle); StoneSet (n.d.) (right).

Reinforced grass and gravel unit pavers are types of pavement with unbound surfaces (**figures 5.59, 5.60 and 5.61**). They allow filtration of overland water flows and also have the strength to withstand loading from a range of vehicles. Reinforced grass provides a green, highly permeable surface that is ideal for surfaces with occasional vehicle use, such as overflow car parks. Reinforced mesh or porous pavers can be used, depending on traffic and strength requirements.



Figures 5.59, 5.60 and 5.61. Grass reinforcement mesh (left and middle), and permeable pavers with gravel infill (right). Source: All Stake Supply (n.d.).

### Parklets

Parklets are emerging as an innovative way to increase urban green space. These urban interventions originated in San Francisco and have spread throughout cities worldwide. Parklets use existing parking lanes along roads and re-purpose them as urban green spaces (figures 5.62-5.64). They are removable/recyclable installations that increase urban social space and urban greening. If minimum planted areas were adopted, parklets could contribute to urban biodiversity and the provision of ecosystem services.



Figures 5.62, 5.63 and 5.64. Parklets in Adelaide (left), London (middle) and San Francisco (right). Sources: Troppo (2013) (left); Wang (2015) (middle); Miss Design Says (2015) (right).

### Coastal development

New environmentally sensitive technologies are helping restore ecosystem functioning in disturbed coastal areas. New seawall materials and technologies are emerging. Concrete mixes with ecological designs (such as EONcrete) have been shown to increase the abundance, richness and diversity of invertebrates and fish in breakwaters (Perkol-Finkel & Sella, 2015). EONcrete can also be used for marine elements such as armouring units, tide pools and seawalls (EONcrete, 2012); it is designed to provide habitat in urban marine areas through modifications in the surface texture and shape of the product (Figures 5.65 and 5.66).



Figures 5.65 and 5.66. EConcrete panels support marine biodiversity. Source: EConcrete (2012).

## 5.8 Discussion

Increased urbanisation places pressure on natural systems in and around cities and contributes to biodiversity loss. Conflicts between the natural and built environments arise in urban areas as urban development takes place, such as conflicts between urban ecology aims and CPTED guidelines and conflicts between services and vegetation and urban stormwater management. **Figure 5.67** illustrates some of the key ways in which the built environment and its associated impacts can lead to biodiversity loss. The built environment has both direct and indirect impacts on biodiversity and ecological functioning in urban areas.

Urban ecosystems are enhanced by green infrastructure, which includes products, technologies and design approaches that mimic natural processes and extend green cover in otherwise built-up urban environments. Green infrastructure has the potential to significantly enhance urban ecology through a hierarchy of interventions. This hierarchy can be summarised as:

- Protect and conserve
- Restore
- Enhance
- Create.

There are opportunities to integrate urban ecology in the built environment at all scales, from the state through to the lot. The use of green infrastructure can support urban ecosystem renewal at a range of scales. Indeed, it is necessary to integrate urban ecology in the built environment at all scales to achieve comprehensive urban ecological outcomes.

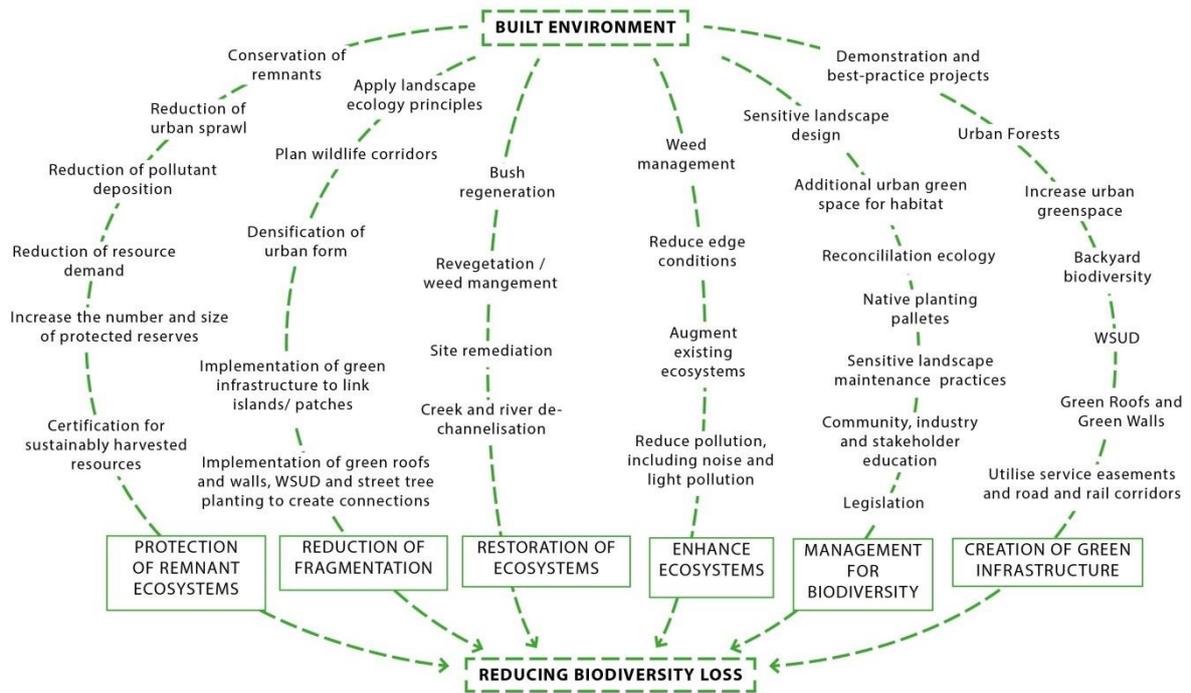


Figure 5.67. Built environment responses to reducing biodiversity loss. Source: Adapted from Zari (2014).

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## 5.9 Chapter references

- Abraham, A., Sommerhalder, K., & Abel, T. (2010). Landscape and well-being: a scoping study on the health-promoting impact of outdoor environments. *International Journal of Public Health*, 55(1), 59-69. doi:10.1007/s00038-009-0069-z
- ABS (Australian Bureau of Statistics) (2010). *Building Approvals*. Available at <http://www.abs.gov.au/AUSSTATS/abs@.nsf/0/829B38F5721103BCCA257847000DBFB0?opendocument>
- ABS (Australian Bureau of Statistics) (2013). *Population Projections Australia*. Available at [http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/13D196FB0DBECC3BCA257C2E00173FAD/\\$File/32220\\_2012%20\(base\)%20to%202101.pdf](http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/13D196FB0DBECC3BCA257C2E00173FAD/$File/32220_2012%20(base)%20to%202101.pdf)
- Adbri Masonry (n.d.). Permeable Concrete Pavers from Adbri Masonry. Available at <http://www.architectureanddesign.com.au/suppliers/adbri-masonry/permeable-concrete-pavers-from-adbri-masonry>.
- AECOM (n.d.). Sydney Park Wetlands Stormwater Harvesting. Available at <http://202020vision.com.au/project/?id=217>.
- Ahern, J. (2011). From fail-safe to safe-to-fail: sustainability and resilience in the new urban world. *Landscape and Urban Planning*, 100(4), 341-343.
- Ahern, J. (2013). Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. *Landscape Ecology*, 28(6), 1203-1212. doi:10.1007/s10980-012-9799-z
- Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E., & Depledge, M. H. (2014). Longitudinal effects on mental health of moving to greener and less green urban areas. *Environmental Science and Technology*, 48(2), 1247-1255. doi:10.1021/es403688w
- Alexandri, E., & Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*, 43(4), 480-493. doi:http://dx.doi.org/10.1016/j.buildenv.2006.10.055
- All Stake Supply (n.d.). Grass reinforcement. Available at <http://www.grassreinforcement.com.au/>.
- All Terrain Consulting Ltd. (n.d.). Rain Garden and Bioswale Design. Available at <http://atconsulting.ca/services/rain-garden>.
- Amati, M., Ghosh, S., McManus, P., Shrestha, K., Brack, C., Kachenko, A., Yung, S.-H., Wang, M., Saldarriaga, N., & Gomez, A. M. (2013). *Understanding the Carbon and Pollution Mitigation Potential of Australia's Urban Forest*. Available at [http://www.ngia.com.au/Attachment?Action=Download&Attachment\\_id=364](http://www.ngia.com.au/Attachment?Action=Download&Attachment_id=364)
- Argüeso, D., Evans, J. P., Fita, L., & Bormann, K. J. (2014). Temperature response to future urbanization and climate change. *Climate Dynamics*, 42(7), 2183-2199. doi:10.1007/s00382-013-1789-6
- Argüeso, D., Evans, J. P., Pitman, A. J., & Luca, A. D. (2015). Effects of city expansion on heat stress under climate change conditions. *PLoS ONE*, 10(2). doi:10.1371/journal.pone.0117066
- Aspect Studios (n.d.-a). Darling Quarter. Available at <http://aspect.net.au/?p=361>.
- Aspect Studios (n.d.-b). Victorian Desalination Plant and Ecological Reserve. Available at <http://aspect.net.au/?p=462>.
- Atlantis Australia (n.d.). Atlantis Flo-Cell. Available at <http://atlantiscorporation.com.au/product-1/>.

- Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, *81*(2), 169-193. doi:10.1890/10-1510.1
- Barbosa, A. E., Fernandes, J. N., & David, L. M. (2012). Key issues for sustainable urban stormwater management. *Water Research*, *46*(20), 6787-6798. doi:http://dx.doi.org/10.1016/j.watres.2012.05.029
- Bass, B., & Baskaran, B. (2003). *Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas*. Available at [http://www.roofmeadow.com/wp-content/uploads/Evaluating\\_Rooftop\\_and\\_Verticle\\_Gardens.pdf](http://www.roofmeadow.com/wp-content/uploads/Evaluating_Rooftop_and_Verticle_Gardens.pdf)
- Bathurst Regional Council (2012). *Bathurst Backyards for Wildlife Booklet*. Available at <http://www.lgns.w.gov.au/files/imce-uploads/35/backyard-birds-bathurst.pdf>
- Beggs, P. J. (2010). Adaptation to impacts of climate change on aeroallergens and allergic respiratory diseases. *International Journal of Environmental Research and Public Health*, *7*(8), 3006-3021.
- Bell, J. F., Wilson, J. S., & Liu, G. C. (2008). Neighborhood greenness and 2-year changes in body mass index of children and youth. *American Journal of Preventive Medicine*, *35*(6), 547-553. doi:http://dx.doi.org/10.1016/j.amepre.2008.07.006
- Beninde, J., Veith, M., & Hochkirch, A. (2015). Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters*, *18*(6), 581-592. doi:10.1111/ele.12427
- Berardi, U. (2016). The outdoor microclimate benefits and energy saving resulting from green roofs retrofits. *Energy and Buildings*, *121*, 217-229. doi:http://dx.doi.org/10.1016/j.enbuild.2016.03.021
- Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science*, *19*(12), 1207-1212. doi:10.1111/j.1467-9280.2008.02225.x
- Berman, M. G., Kross, E., Krpan, K. M., Askren, M. K., Burson, A., Deldin, P. J., Kaplan, S., Sherdell, L., Gotlib, I. H., & Jonides, J. (2012). Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders*, *140*(3), 300-305. doi:10.1016/j.jad.2012.03.012
- Berthon, K., Nipperess, D., Davies, P., & Bulbert, M., (2015). *Confirmed at Last: green roofs add invertebrate diversity*. Paper presented at the State of Australian Cities Conference, Queensland, Australia.
- Bila, R. (n.d.). Urban Farming at Sydney Park. Available at <http://www.dhub.org/urban-farming-at-sydney-park/>.
- BMT WBM Pty Ltd (2009). *Evaluating Options for Water Sensitive Urban Design: a national guide*. Available at <https://www.environment.gov.au/system/files/resources/1873905a-f5b7-4e3c-8f45-0259a32a94b1/files/wsud-guidelines.pdf>
- Boardman, B. (2010). Rouse Hill Town Centre wins global urban design award. Available at <https://www.australiandesignreview.com/news/rouse-hill-town-centre-wins-global-urban-design-award/>.
- Boardman, B. (2013). Prince Alfred Park + Pool Upgrade. Available at <http://architizer.com/projects/prince-alfred-park-pool-upgrade/>.
- Boroondara City Council (2010). *Backyard Biodiversity*. Available at <https://boroondara.vic.gov.au/>

- /media/Files/Our%20city/Environment/Backyard%20biodiversity/BiodiversityBookletcompleteoptimisedpdf.pdf
- Bowen, K. J., & Parry, M. (2015). *The Evidence Base for Linkages between Green Infrastructure, Public Health and Economic Benefit*. Available at <https://www.vu.edu.au/sites/default/files/cses/pdfs/gi-econ-health-paper.pdf>
- Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: a systematic review of the empirical evidence. *Landscape and Urban Planning*, 97(3), 147-155.  
doi:<http://dx.doi.org/10.1016/j.landurbplan.2010.05.006>
- Bradley, C. A., & Altizer, S. (2007). Urbanization and the ecology of wildlife diseases. *Trends in Ecology & Evolution*, 22(2), 95-102. doi:10.1016/j.tree.2006.11.001
- Bratieres, K., Fletcher, T. D., Deletic, A., & Zinger, Y. (2008). Nutrient and sediment removal by stormwater biofilters: a large-scale design optimisation study. *Water Research*, 42(14), 3930-3940. doi:<http://dx.doi.org/10.1016/j.watres.2008.06.009>
- Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences*, 1249(1), 118-136. doi:10.1111/j.1749-6632.2011.06400.x
- Brockhoff, F. (n.d.). Karkalla open for Australian Landscape Conference garden tour. Available at <http://fionabrockhoffdesign.com/karkalla-open-for-australian-landscape-conference-garden-tour/>.
- Bureau of Meteorology, & CSIRO (2014). *State of the Climate*. Available at [http://www.bom.gov.au/state-of-the-climate/documents/state-of-the-climate-2014\\_low-res.pdf?ref=button](http://www.bom.gov.au/state-of-the-climate/documents/state-of-the-climate-2014_low-res.pdf?ref=button)
- Castleton, H. F., Stovin, V., Beck, S. B. M., & Davison, J. B. (2010). Green roofs; building energy savings and the potential for retrofit. *Energy and Buildings*, 42(10), 1582-1591. doi:<http://dx.doi.org/10.1016/j.enbuild.2010.05.004>
- Cavanagh, J. A. E., Zawar-Reza, P., & Wilson, J. G. (2009). Spatial attenuation of ambient particulate matter air pollution within an urbanised native forest patch. *Urban Forestry and Urban Greening*, 8(1), 21-30. doi:10.1016/j.ufug.2008.10.002
- Chang, C.-R., Li, M.-H., & Chang, S.-D. (2007). A preliminary study on the local cool-island intensity of Taipei city parks. *Landscape and Urban Planning*, 80(4), 386-395. doi:<http://dx.doi.org/10.1016/j.landurbplan.2006.09.005>
- Chang, C. (2014). Brisbane the latest council to look at permit for parties of 50 or more in parks. Available at <http://www.news.com.au/lifestyle/food/brisbane-the-latest-council-to-look-at-permit-for-parties-of-50-or-more-in-parks/news-story/84abd7ad2fd6b7745d78b1c8247a6c70>.
- Chaoming, K. L. (2015). Bioswale in London: Queen Elizabeth Olympic Park suds. Available at <https://twitter.com/woshifd123/status/632191343494696960/photo/1>.
- Chaparro, L., & Terradas, J. (2009). *Ecological Services of Urban Forest in Barcelona*. Available at <https://www.itreetools.org/resources/reports/Barcelona%20Ecosystem%20Analysis.pdf>
- Chen, D., Wang, X., Thatcher, M., Barnett, G., Kachenko, A., & Prince, R. (2014). Urban vegetation for reducing heat related mortality. *Environmental Pollution*, 192, 275-284. doi:10.1016/j.envpol.2014.05.002

- Chen, X., Hutley, L. B., & Eamus, D. (2005). Soil organic carbon content at a range of north Australian tropical savannas with contrasting site histories. *Plant and Soil*, 268(1), 161-171. doi:10.1007/s11104-004-0249-9
- Chiesura, A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning*, 68(1), 129-138. doi:http://dx.doi.org/10.1016/j.landurbplan.2003.08.003
- Choi, L., & McIlrath, B. (2016). *New South Wales' Planning Framework for Water Sensitive Urban Design*. Cooperative Research Centre for Water Sensitive Cities. Available at <https://watersensitivecities.org.au/content/new-south-wales-planning-framework-water-sensitive-urban-design/>
- City of Sydney (2015). *Sydney Agenda Setting Workshop*. Available at [http://www.cityofsydney.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0004/241789/Sydney-Agenda-Setting-Workshop-Summary-Report-accessible.pdf](http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0004/241789/Sydney-Agenda-Setting-Workshop-Summary-Report-accessible.pdf)
- Commonwealth of Australia (2009). *Which Plants Store more Carbon in Australia: forests or grasses?* Available at <http://www.chiefscientist.gov.au/2009/12/which-plants-store-more-carbon-in-australia-forests-or-grasses/>.
- Coutts, A. M., White, E. C., Tapper, N. J., Beringer, J., & Livesley, S. J. (2016). Temperature and human thermal comfort effects of street trees across three contrasting street canyon environments. *Theoretical and Applied Climatology*, 124(1), 55-68. doi:10.1007/s00704-015-1409-y
- Coutts, C., & Hahn, M. (2015). Green infrastructure, ecosystem services, and human health. *International Journal of Environmental Research and Public Health*, 12(8), 9768-9798. doi:10.3390/ijerph120809768
- CSIRO (Commonwealth Scientific and Industrial Research Organisation) (1999). *Urban stormwater: best practice environmental management guidelines*. Available at [http://www.publish.csiro.au/?act=view\\_file&file\\_id=SA0601i.pdf](http://www.publish.csiro.au/?act=view_file&file_id=SA0601i.pdf)
- Daily, G. C. (1997). *Nature's Services Societal Dependence on Natural Ecosystems*. Washington DC: Island Press.
- Deep Green Landscaping (2015). Green Roofs. Available at <http://deepgreenlandscaping.com.au/green-roofs/>.
- NSW Department of Planning and Environment (2014). *A Plan for Growing Sydney*. Available at [http://www.planning.nsw.gov.au/~/\\_media/Files/DPE/Plans-and-policies/a-plan-for-growing-sydney-2014-12.ashx](http://www.planning.nsw.gov.au/~/_media/Files/DPE/Plans-and-policies/a-plan-for-growing-sydney-2014-12.ashx)
- Doick, K., & Hutchings, T. (2013). *Air Temperature Regulation by Urban Trees and Green Infrastructure*. Available at [https://www.forestry.gov.uk/PDF/FCRN012.pdf/\\$FILE/FCRN012.pdf](https://www.forestry.gov.uk/PDF/FCRN012.pdf/$FILE/FCRN012.pdf)
- Donovan, G. H., & Butry, D. T. (2010). Trees in the city: valuing street trees in Portland, Oregon. *Landscape and Urban Planning*, 94(2), 77-83. doi:10.1016/j.landurbplan.2009.07.019
- Donovan, G. H., & Butry, D. T. (2011). The effect of urban trees on the rental price of single-family homes in Portland, Oregon. *Urban Forestry and Urban Greening*, 10(3), 163-168. doi:10.1016/j.ufug.2011.05.007
- ECONcrete (2012). Enhanced sea walls. Available at <http://www.econcretetech.com/products/enhanced-seawalls>.
- Edmondson, J. L., Davies, Z. G., McHugh, N., Gaston, K. J., & Leake, J. R. (2012). *Organic Carbon Hidden in Urban Ecosystems*. Scientific Reports, 2. doi:10.1038/srep00963
- Elmqvist, T., Setälä, H., Handel, S. N., van der Ploeg, S., Aronson, J., Blignaut, J. N., Gómez-Baggethun, E., Nowak, D. J., Kronenberg, J., & de Groot, R. (2015). Benefits of

- restoring ecosystem services in urban areas. *Current Opinion in Environmental Sustainability*, 14, 101-108. doi:<http://dx.doi.org/10.1016/j.cosust.2015.05.001>
- Ely, E., & Pitman, S. D. (2014). *Green Infrastructure: life support for humans. The compelling evidence for incorporating nature into urban environments*. South Australia: Botanic Gardens of South Australia
- Escobedo, F., Varela, S., Zhao, M., Wagner, J. E., & Zipperer, W. (2010). Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. *Environmental Science & Policy*, 13(5), 362-372. doi:<http://dx.doi.org/10.1016/j.envsci.2010.03.009>
- Escobedo, F. J., Adams, D. C., & Timilsina, N. (2015). Urban forest structure effects on property value. *Ecosystem Services*, 12, 209-217. doi:10.1016/j.ecoser.2014.05.002
- Escobedo, F. J., Kroeger, T., & Wagner, J. E. (2011). Urban forests and pollution mitigation: analyzing ecosystem services and disservices. *Environmental Pollution*, 159(8-9), 2078-2087. doi:<http://dx.doi.org/10.1016/j.envpol.2011.01.010>
- Faehnle, M., Söderman, T., Schulman, H., & Lehvavirta, S. (2015). Scale-sensitive integration of ecosystem services in urban planning. *GeoJournal*, 80(3), 411-425. doi:10.1007/s10708-014-9560-z
- Fairman, T. A., & Livesley, S. J. (2011). *Estimating the Benefits of Australian Street Trees using i-Tree Stratum: a pilot study*. Technical Nursery Papers. Available at [https://www.researchgate.net/publication/280721606\\_Estimating\\_the\\_benefits\\_of\\_Australian\\_Street\\_Trees\\_using\\_i-Tree\\_Stratum\\_-\\_A\\_Pilot\\_Study\\_Study?\\_sg=PD\\_JDzan0whMu456t-J8Lcf1bRGn7700vct076AoSzM4C7rl0a2TQtoVWVLXxaWCmG5yOENwyoFWpkjlkgp3NA](https://www.researchgate.net/publication/280721606_Estimating_the_benefits_of_Australian_Street_Trees_using_i-Tree_Stratum_-_A_Pilot_Study_Study?_sg=PD_JDzan0whMu456t-J8Lcf1bRGn7700vct076AoSzM4C7rl0a2TQtoVWVLXxaWCmG5yOENwyoFWpkjlkgp3NA)
- Fernandez-Canero, R., & Gonzalez-Redondo, P. (2010). Green roofs as a habitat for birds: a review. *Journal of Animal and Veterinary Advances*, 9(15), 2041-2052. doi:10.3923/javaa.2010.2041.2052
- Floyd, J., Iaquinto, B. L., Ison, R., & Collins, K. (2014). Managing complexity in Australian urban water governance: transitioning Sydney to a water sensitive city. *Futures*, 61, 1-12. doi:<http://dx.doi.org/10.1016/j.futures.2014.04.002>
- Forman, R. T. T., & Godron, M. (1986). *Landscape Ecology*. New York, United States: John Wiley and Sons.
- Forrest, J. (n.d.). Bringing Butterflies Back. Available at <http://www.naturalresources.sa.gov.au/adelaidemtloftyranges/plants-and-animals/native-plants-animals-and-biodiversity/urban-biodiversity>
- Foster, J., Lowe, A., & Winkelmann, S. (2011). *The Value of Green Infrastructure for Urban Climate Adaptation*. Available at [http://www.amwa.net/galleries/climate-change/Green\\_Infrastructure\\_FINAL.pdf](http://www.amwa.net/galleries/climate-change/Green_Infrastructure_FINAL.pdf)
- Francis, R. A., & Lorimer, J. (2011). Urban reconciliation ecology: the potential of living roofs and walls. *Journal of Environmental Management*, 92(6), 1429-1437. doi:<http://dx.doi.org/10.1016/j.jenvman.2011.01.012>
- Frumkin, H. (2001). Beyond toxicity human health and the natural environment. *American Journal of Preventive Medicine*, 20(3), 234-240.
- Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., & Gaston, K. J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biology Letters*, 3(4), 390-394. doi:10.1098/rsbl.2007.0149
- Fytogreen (n.d.). Beare Park. Available at <http://fytogreen.com.au/beare-park/>.

- Gallagher, L. (2015). *Beyond 'Green' Streets: mitigating climate change through residential streetscape design*. Sydney, Australia: Sydney University.
- Ghosh, S., & Head, L. (2009). Retrofitting the suburban garden: morphologies and some elements of sustainability potential of two Australian residential suburbs compared. *Australian Geographer*, 40(3), 319-346. doi:10.1080/00049180903127754
- Gies, E. (2006). *The Health Benefits of Parks*. Available at [http://www.lchc.org/wp-content/uploads/01\\_LCHC\\_ParksRec.pdf](http://www.lchc.org/wp-content/uploads/01_LCHC_ParksRec.pdf)
- Goddard, M. A., Dougill, A. J., & Benton, T. G. (2010). Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology & Evolution*, 25(2), 90-98. doi:<http://dx.doi.org/10.1016/j.tree.2009.07.016>
- Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, 86, 235-245. doi:<http://dx.doi.org/10.1016/j.ecolecon.2012.08.019>
- Gordon-Larsen, P., Nelson, M. C., Page, P., & Popkin, B. M. (2006). Inequality in the built environment underlies key health disparities in physical activity and obesity. *Pediatrics*, 117(2), 417-424. doi:10.1542/peds.2005-0058
- Green Roofs Australasia (2014). Eco Lodge Forest House. Available at <https://greenroofsaustralasia.com.au/projects/eco-house-forest-lodge>.
- Greenway, M. (2016). Stormwater wetlands for the enhancement of environmental ecosystem services: case studies for two retrofit wetlands in Brisbane, Australia. *Journal of Cleaner Production*. doi:<http://dx.doi.org/10.1016/j.jclepro.2015.12.081>
- Group GSA (n.d.-a). Bourke Street Cycleway. Available at <http://www.groupgsa.com/en/work/projects/landscape/bourke-street-cycleway>.
- Group GSA (n.d.-b). Ryde Park Cafe and Recreation Facilities. Available at <http://www.groupgsa.com/en/work/projects/landscape/ryde-park-cafe-and-recreation-facilities>.
- Hale, J., Knapp, C., Bardwell, L., Buchenau, M., Marshall, J., Sancar, F., & Litt, J. S. (2011). Connecting food environments and health through the relational nature of aesthetics: gaining insight through the community gardening experience. *Social Science & Medicine*, 72(11), 1853-1863. doi:<http://dx.doi.org/10.1016/j.socscimed.2011.03.044>
- Hall, T. (2010). *The Life and Death of the Australian Backyard*. Collingwood, Australia: CSIRO Publishing.
- Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity: views from urban planning. *American Journal of Preventive Medicine*, 23(2, Supplement 1), 64-73. doi:[http://dx.doi.org/10.1016/S0749-3797\(02\)00475-0](http://dx.doi.org/10.1016/S0749-3797(02)00475-0)
- Hansmann, R., Hug, S.-M., & Seeland, K. (2007). Restoration and stress relief through physical activities in forests and parks. *Urban Forestry & Urban Greening*, 6(4), 213-225. doi:<http://dx.doi.org/10.1016/j.ufug.2007.08.004>
- Hatt, B. E., Deletic, A., & Fletcher, T. D. (2007). Stormwater reuse: designing biofiltration systems for reliable treatment. *Water Science and Technology*, 55(4), 201-209. doi:10.2166/wst.2007.110
- Hawkesbury-Nepean Catchment Management Authority (CMA) (2013). *Greater Sydney Local Land Service Transition Catchment Action Plan*. Available at [http://archive.ils.nsw.gov.au/\\_\\_data/assets/pdf\\_file/0008/504683/greater-sydney-ils-transition-catchment-action-plan.pdf](http://archive.ils.nsw.gov.au/__data/assets/pdf_file/0008/504683/greater-sydney-ils-transition-catchment-action-plan.pdf)

- Hélène, L. (2016). Becoming biophilic: challenges and opportunities for biophilic urbanism in urban planning policy. *Smart and Sustainable Built Environment*, 5(1), 15-24. doi:10.1108/SASBE-10-2015-0036
- Hester, P. (2010). *The Brochstein Pavilion at Rice University*. Houston USA: American Society of Landscape Architects.
- Holtan, M. T., Dieterlen, S. L., & Sullivan, W. C. (2015). Social life under cover: tree canopy and social capital in Baltimore, Maryland. *Environment and Behavior*, 47(5), 502-525. doi:10.1177/0013916513518064
- Hopkins, G., & Goodwin, C. (2012). *Green Roof Trials Monitoring Report*. Available at [https://www.environment.sa.gov.au/files/sharedassets/public/climate-change/bif\\_completed\\_projects/green-roof-monitoring-waymouth-street-final-report.pdf](https://www.environment.sa.gov.au/files/sharedassets/public/climate-change/bif_completed_projects/green-roof-monitoring-waymouth-street-final-report.pdf)
- Huang, J. (2012). *Bryant Park, New York City*. New York, USA.
- Huisman, E. R. C. M., Morales, E., van Hoof, J., & Kort, H. S. M. (2012). Healing environment: a review of the impact of physical environmental factors on users. *Building and Environment*, 58, 70-80. doi:http://dx.doi.org/10.1016/j.buildenv.2012.06.016
- Hunter, A. M., Williams, N. S. G., Rayner, J. P., Aye, L., Hes, D., & Livesley, S. J. (2014). Quantifying the thermal performance of green façades: a critical review. *Ecological Engineering*, 63, 102-113. doi:http://dx.doi.org/10.1016/j.ecoleng.2013.12.021
- Hydrocon (2016). Permeable Pavements. Available at <http://hydroston.com.au/>.
- Ignatieva, M., Stewart, G. H., & Meurk, C. (2011). Planning and design of ecological networks in urban areas. *Landscape and Ecological Engineering*, 7(1), 17-25. doi:10.1007/s11355-010-0143-y
- Ives, C. D., & Kelly, A. H. (2016). The coexistence of amenity and biodiversity in urban landscapes. *Landscape Research*, 41(5), 495-509. doi:10.1080/01426397.2015.1081161
- Ives, C. D., Lentini, P. E., Threlfall, C. G., Ikin, K., Shanahan, D. F., Garrard, G. E., Bekessy, S. A., Fuller, R. A., Mumaw, L., Rayner, L., Rowe, R., Valentine, L. E., & Kendal, D. (2016). Cities are hotspots for threatened species. *Global Ecology and Biogeography*, 25(1), 117-126. doi:10.1111/geb.12404
- Jaffal, I., Ouldboukhite, S.-E., & Belarbi, R. (2012). A comprehensive study of the impact of green roofs on building energy performance. *Renewable Energy*, 43, 157-164. doi:http://dx.doi.org/10.1016/j.renene.2011.12.004
- Jaganmohan, M., Knapp, S., Buchmann, C. M., & Schwarz, N. (2016). The bigger, the better? The influence of urban green space design on cooling effects for residential areas. *Journal of Environmental Quality*, 45(1), 134-145. doi:10.2134/jeq2015.01.0062
- Jennings, V., & Gaither, C. J. (2015). Approaching environmental health disparities and green spaces: an ecosystem services perspective. *International Journal of Environmental Research and Public Health*, 12(2), 1952-1968. doi:10.3390/ijerph120201952
- Jiang, B., Chang, C.-Y., & Sullivan, W. C. (2014). A dose of nature: tree cover, stress reduction, and gender differences. *Landscape and Urban Planning*, 132, 26-36. doi:http://dx.doi.org/10.1016/j.landurbplan.2014.08.005
- Jim, C. Y. (2015). Thermal performance of climber greenwalls: effects of solar irradiance and orientation. *Applied Energy*, 154, 631-643. doi:http://dx.doi.org/10.1016/j.apenergy.2015.05.077
- Kalkstein, L. S., Sailor, D., Shickman, K., Sheridan, S., & Vanos, J. (2014). *Assessing the Health Impacts of Urban Heat Island Reduction Strategies in the District of Columbia*.

- Available at <http://www.coolrooftoolkit.org/wp-content/uploads/2013/10/DC-Heat-Mortality-Study-for-DDOE-FINAL.pdf>
- Kellert, S. (2016). Biophilic urbanism: the potential to transform. *Smart and Sustainable Built Environment*, 5(1), 4-8. doi:doi:10.1108/SASBE-10-2015-0035
- Kloss, C., & Calarusse, C. (2006). *Rooftops to Rivers: green strategies for controlling stormwater and combined sewer overflows*. Available at <http://www.nrdc.org/water/pollution/rooftops/contents.asp>
- Köhler, M. (2008). Green facades: a view back and some visions. *Urban Ecosystems*, 11(4), 423-436. doi:10.1007/s11252-008-0063-x
- Kuittinen, M., Moinel, C., & Adalgeirsdottir, K. (2016). Carbon sequestration through urban ecosystem services: a case study from Finland. *Science of The Total Environment*, 563–564, 623-632. doi:http://dx.doi.org/10.1016/j.scitotenv.2016.03.168
- Kuo, M. (2010). *Parks and Other Green Environments: essential components of a healthy human habitat*. Available at [http://www.nrpa.org/uploadedFiles/nrpa.org/Publications\\_and\\_Research/Research/Papers/MingKuo-Summary.PDF](http://www.nrpa.org/uploadedFiles/nrpa.org/Publications_and_Research/Research/Papers/MingKuo-Summary.PDF)
- Landcom (2009a). *Water Sensitive Urban Design Book 1 Policy*. Available at <http://greaterSydney.lis.nsw.gov.au/land-and-water/water>
- Landcom (2009b). *Water Sensitive Urban Design Book 4 Maintenance*. Available at <http://greaterSydney.lis.nsw.gov.au/land-and-water/water>
- Landscaping, D. G. (2015). Green Roofs. Available at <http://deepgreenlandscaping.com.au/green-roofs/>.
- Larson, J. S. (1996). The World Health Organization's definition of health: social versus spiritual health. *Social Indicators Research*, 38(2), 181-192. doi:10.1007/bf00300458
- Latty, T. (2016). Biodiversity and green roof retrofit. In S. J. Wilkinson & T. Dixon (Eds.), *Green Roof Retrofit: building urban resilience*. Wiley-Blackwell.
- Leake, S. (n.d.). *Urban Soil Science Principles and Practices related to the Planting and Care of Trees*. Available at [http://www.sesl.com.au/uploads/articles/Urban\\_Soil\\_Science1.pdf](http://www.sesl.com.au/uploads/articles/Urban_Soil_Science1.pdf)
- Lee, K. E., Williams, K. J. H., Sargent, L. D., Williams, N. S. G., & Johnson, K. A. (2015). 40-second green roof views sustain attention: the role of micro-breaks in attention restoration. *Journal of Environmental Psychology*, 42, 182-189. doi:http://dx.doi.org/10.1016/j.jenvp.2015.04.003
- Lee, S.-H., Lee, K.-S., Jin, W.-C., & Song, H.-K. (2009). Effect of an urban park on air temperature differences in a central business district area. *Landscape and Ecological Engineering*, 5(2), 183-191. doi:10.1007/s11355-009-0067-6
- Li, J.-F., Wai, O. W. H., Li, Y. S., Zhan, J.-M., Ho, Y. A., Li, J., & Lam, E. (2010). Effect of green roof on ambient CO<sub>2</sub> concentration. *Building and Environment*, 45(12), 2644-2651. doi:http://dx.doi.org/10.1016/j.buildenv.2010.05.025
- Lin, B. B., Gaston, K. J., Fuller, R. A., Wu, D., Bush, R., & Shanahan, D. F. (2017). How green is your garden? Urban form and socio-demographic factors influence yard vegetation, visitation, and ecosystem service benefits. *Landscape and Urban Planning*, 157, 239-246. doi:10.1016/j.landurbplan.2016.07.007
- Liu, C., & Li, X. (2012). Carbon storage and sequestration by urban forests in Shenyang, China. *Urban Forestry & Urban Greening*, 11(2), 121-128. doi:http://dx.doi.org/10.1016/j.ufug.2011.03.002

- Liu, R., Zhao, Y., Doherty, L., Hu, Y., & Hao, X. (2015). A review of incorporation of constructed wetland with other treatment processes. *Chemical Engineering Journal*, 279, 220-230. doi:<http://dx.doi.org/10.1016/j.cej.2015.05.023>
- Livesley, S. J., Baudinette, B., & Glover, D. (2014). Rainfall interception and stem flow by eucalypt street trees: the impacts of canopy density and bark type. *Urban Forestry & Urban Greening*, 13(1), 192-197. doi:<http://dx.doi.org/10.1016/j.ufug.2013.09.001>
- Livesley, S. J., McPherson, G. M., & Calfapietra, C. (2016). The urban forest and ecosystem services: impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of Environmental Quality*, 45(1), 119-124. doi:10.2134/jeq2015.11.0567
- Loucas, J. (2016). Sydney City Guide. Available at <http://www.travelchannel.com/destinations/australia/sydney/photos/sydney-city-guide/page/5>.
- Lovasi, G. S., Quinn, J. W., Neckerman, K. M., Perzanowski, M. S., & Rundle, A. (2008). Children living in areas with more street trees have lower prevalence of asthma. *Journal of Epidemiology and Community Health*, 62(7), 647-649. doi:10.1136/jech.2007.071894
- Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., Panzer, L., Partelow, S., Rau, A.-L., Sasaki, R., Abson, D. J., Lang, D. J., Wamsler, C., & von Wehrden, H. (2015). A review of urban ecosystem services: six key challenges for future research. *Ecosystem Services*, 14, 98-112. doi:<http://dx.doi.org/10.1016/j.ecoser.2015.05.001>
- Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health and Place*, 15(2), 586-595. doi:10.1016/j.healthplace.2008.09.006
- Maas, J., Verheij, R. A., de Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health*, 63(12), 967-973. doi:10.1136/jech.2008.079038
- Madre, F., Clergeau, P., Machon, N., & Vergnes, A. (2015). Building biodiversity: vegetated façades as habitats for spider and beetle assemblages. *Global Ecology and Conservation*, 3, 222-233. doi:<http://dx.doi.org/10.1016/j.gecco.2014.11.016>
- Mah, N. (2015). New seawall structure complete south of Colman Dock. Available at <http://sdotblog.seattle.gov/2015/01/14/new-seawall-structure-complete-south-of-colman-dock/>.
- Maslog-Levis, K. (n.d.). Citygreen continues to impress Dandenong. Available at <http://citygreen.com/case-studies/citygreen-continues-to-impress-dandenong/>.
- McDonnell, M. J., & Hahs, A. K. (2015). Adaptation and adaptedness of organisms to urban environments. *Annual Review of Ecology, Evolution, and Systematics*, 46(1), 261-280. doi:10.1146/annurev-ecolsys-112414-054258
- McLeod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., & Silliman, B. R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO<sub>2</sub>. *Frontiers in Ecology and the Environment*, 9(10), 552-560. doi:10.1890/110004
- McMichael, A., Woodruff, R., Whetton, P., Hennessy, K., Nicholls, N., Hales, S., Woodward, A. & Kjellstrom, T. (2003). Human health and climate change in Oceania: a risk assessment. *Canberra: Commonwealth Department of Health and Ageing*.

- McPhearson, T., Hamstead, Z. A., & Kremer, P. (2014). Urban ecosystem services for resilience planning and management in New York City. *Ambio*, 43(4), 502-515. doi:10.1007/s13280-014-0509-8
- McPhearson, T., Pickett, S. T. A., Grimm, N. B., Niemelä, J., Alberti, M., Elmqvist, T., Weber, C., Haase, D., Breuste, J., & Qureshi, S. (2016). Advancing urban ecology toward a science of cities. *BioScience*, 66, 198-212.
- Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: a review. *Landscape and Urban Planning*, 147, 38-49. doi:http://dx.doi.org/10.1016/j.landurbplan.2015.11.011
- Mekala, G. D., Jones, R. N., & MacDonald, D. H. (2015). Valuing the benefits of creek rehabilitation: building a business case for public investments in urban green infrastructure. *Environmental Management*, 55(6), 1354-1365. doi:10.1007/s00267-015-0471-7
- Melbourne Water Corporation (2013). *WSUD Maintenance Guidelines: a guide for asset managers*. Available at <https://www.melbournewater.com.au/Planning-and-building/Forms-guidelines-and-standard-drawings/Documents/WSUD-Maintenance-manager-guidelines.pdf>
- Miss Design Says (2015). Urban garden size of a parked car in Copenhagen. Available at <http://missdesignsays.tumblr.com/post/95857414412/urban-garden-size-of-a-parked-car-in-copenhagen>.
- Mitchell, R., & Popham, F. (2008). Effect of exposure to natural environment on health inequalities: an observational population study. *The Lancet*, 372(9650), 1655-1660. doi:http://dx.doi.org/10.1016/S0140-6736(08)61689-X
- MMA Architectural Systems, L. (2017). Green Wall Systems. Available at <http://england.all.biz/green-wall-systems-g52442#.WL4nB000ND8>.
- MMA Architectural Systems Ltd. (2017). Green Wall Systems. Available at <http://england.all.biz/green-wall-systems-g52442#.WL4nB000ND8>.
- Netusil, N. R., Levin, Z., Shandas, V., & Hart, T. (2014). Valuing green infrastructure in Portland, Oregon. *Landscape and Urban Planning*, 124, 14-21. doi:10.1016/j.landurbplan.2014.01.002
- Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: a framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, 134, 127-138. doi:http://dx.doi.org/10.1016/j.landurbplan.2014.10.018
- Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry and Urban Greening*, 4(3-4), 115-123. doi:10.1016/j.ufug.2006.01.007
- NSW Department of Environment and Conservation (2006). *Managing Urban Stormwater: harvesting and reuse*.
- NSW Department of Planning (2009). *BASIX 05-08 Building Sustainability Index Ongoing Monitoring Program*.
- NSW Government Architect's Office (n.d.). Landscape Image Library.
- NSW Office of Environment and Heritage (2015). *Urban Green Cover in NSW: technical guidelines*. Available at <http://climatechange.environment.nsw.gov.au/~media/6AF91E36950E4E06BFC6188A1E7D6343.ashx>

- Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K. K. Y., & Rowe, B. (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. *BioScience*, *57*(10), 823-833. doi:10.1641/b571005
- Oculus (2008). Rouse Hill Town Centre. Available at <http://www.oculus.info/project.php?ID=10>.
- Olmsted, F. L. (1865). The early years, 1864-1918. In L. M. Dilsaver (Ed.), *America's National Park System: the critical documents*. Rowman & Littlefield Publishers.
- Ossola, A., Hahs, A. K., & Livesley, S. J. (2015). Habitat complexity influences fine scale hydrological processes and the incidence of stormwater runoff in managed urban ecosystems. *Journal of Environmental Management*, *159*, 1-10. doi:<http://dx.doi.org/10.1016/j.jenvman.2015.05.002>
- Ossola, A., & Livesley, S. J. (2016). Drivers of soil heterogeneity in the urban landscape. In F. e. al. (Ed.), *Urban Landscape Ecology: science, policy and practice*. Routledge.
- Ostfeld, R. S. (2016). *Biodiversity, Community Ecology, and the Dilution Effect*. Available at <http://www.caryinstitute.org/science-program/research-projects/biodiversity-community-ecology-and-dilution-effect>.
- Pérez-Urrestarazu, L., Fernández-Cañero, R., Franco-Salas, A., & Egea, G. (2015). Vertical greening systems and sustainable cities. *Journal of Urban Technology*, *22*(4), 65-85. doi:10.1080/10630732.2015.1073900
- Pérez, G., Coma, J., Barreneche, C., de Gracia, A., Urrestarazu, M., Burés, S., & Cabeza, L. F. (2016). Acoustic insulation capacity of vertical greenery systems for buildings. *Applied Acoustics*, *110*, 218-226. doi:<http://dx.doi.org/10.1016/j.apacoust.2016.03.040>
- Perini, K., Ottelé, M., Fraaij, A. L. A., Haas, E. M., & Raiteri, R. (2011). Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment*, *46*(11), 2287-2294. doi:<http://dx.doi.org/10.1016/j.buildenv.2011.05.009>
- Perkins, M., & Joyce, D. (2012). *Living Wall and Green Roof Plants for Australia*. Available at [https://www.gbca.org.au/gbc\\_scripts/js/tiny\\_mce/plugins/filemanager/Living\\_Wall\\_and\\_Green\\_Roof\\_Plants\\_for\\_Australia\\_Report\\_230712.pdf](https://www.gbca.org.au/gbc_scripts/js/tiny_mce/plugins/filemanager/Living_Wall_and_Green_Roof_Plants_for_Australia_Report_230712.pdf)
- Perkol-Finkel, S., & Sella, I. (2015). Blue is the new green: ecological enhancement of concrete based coastal and marine infrastructure. *Ecological Engineering*, *84*, 260-272. doi:<http://dx.doi.org/10.1016/j.ecoleng.2015.09.016>
- Philpott, S. M., Cotton, J., Bichier, P., Friedrich, R. L., Moorhead, L. C., Uno, S., & Valdez, M. (2014). Local and landscape drivers of arthropod abundance, richness, and trophic composition in urban habitats. *Urban Ecosystems*, *17*(2), 513-532. doi:10.1007/s11252-013-0333-0
- Pitman, S. D., & Ely, M. E. (2015). Green infrastructure as life support: urban nature and climate change. *Transactions of the Royal Society of South Australia*, *139*(1), 97-112. doi:10.1080/03721426.2015.1035219
- Rajagopalan, P., & Fuller, R. J. (2010). Green Roofs in Melbourne: potential and practice. In *Solar 2010: Proceedings of the 48th AuSES Annual Conference: Bringing business and research together for a better tomorrow* (pp. 1-10). [AuSES]. Available at <https://dro.deakin.edu.au/eserv/DU:30033688/fuller-greenroofs-2010.pdf>
- Razzaghamanesh, M., Beecham, S., & Salemi, T. (2016). The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia.

- Urban Forestry & Urban Greening*, 15, 89-102.  
doi:<http://dx.doi.org/10.1016/j.ufug.2015.11.013>
- ReachOut (2016). What is Mental Health? Available at <http://au.reachout.com/what-is-mental-health>.
- Ren, Z., He, X., Zheng, H., Zhang, D., Yu, X., Shen, G., & Guo, R. (2013). Estimation of the relationship between urban park characteristics and Park Cool Island intensity by Remote Sensing Data and field measurement. *Forests*, 4(4), 868.
- Rezania, S., Taib, S. M., Md Din, M. F., Dahalan, F. A., & Kamyab, H. (2016). Comprehensive review on phytotechnology: heavy metals removal by diverse aquatic plants species from wastewater. *Journal of Hazardous Materials*, 318, 587-599.  
doi:<http://dx.doi.org/10.1016/j.jhazmat.2016.07.053>
- RICS (Royal Institution of Chartered Surveyors) (2016). *Green Roofs and Walls RICS Guidance Note, Australia*. Available at [http://www.rics.org/Global/Green\\_roofs\\_and\\_walls\\_1st\\_edition\\_PGguidance\\_2016.pdf](http://www.rics.org/Global/Green_roofs_and_walls_1st_edition_PGguidance_2016.pdf)
- Rook, G. A. (2013). Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. *Proceedings of the National Academy of Sciences of the United States of America*, 110(46), 18360-18367.  
doi:10.1073/pnas.1313731110
- Rosie, M. (2015). *Green Grow the Cities: islands in the sky in Sydney*. Available at <https://greenroofsaustralasia.com.au/news/green-grow-cities-islands-sky-sydney>.
- Roy, S., Byrne, J., & Pickering, C. (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban Forestry & Urban Greening*, 11(4), 351-363.  
doi:<http://dx.doi.org/10.1016/j.ufug.2012.06.006>
- Santamouris, M. (2016). Cooling the buildings: past, present and future. *Energy and Buildings*, 128, 617-638. doi:<http://dx.doi.org/10.1016/j.enbuild.2016.07.034>
- Scharenbroch, B. C., Morgenroth, J., & Maule, B. (2016). Tree species suitability to bioswales and impact on the urban water budget. *Journal of Environmental Quality*, 45(1), 199-206. doi:10.2134/jeq2015.01.0060
- Scholes, L., Revitt, D. M., & Ellis, J. B. (2008). A systematic approach for the comparative assessment of stormwater pollutant removal potentials. *Journal of Environmental Management*, 88(3), 467-478. doi:<http://dx.doi.org/10.1016/j.jenvman.2007.03.003>
- Scopelliti, M., Carrus, G., Adinolfi, C., Suarez, G., Colangelo, G., Laforteza, R., Panno, A., & Sanesi, G. (2016). Staying in touch with nature and well-being in different income groups: the experience of urban parks in Bogotá. *Landscape and Urban Planning*, 148, 139-148. doi:<http://dx.doi.org/10.1016/j.landurbplan.2015.11.002>
- SESL (Sydney Environmental Soil Laboratory) (2016). Barangaroo Headland Park. Available at <http://sesl.com.au/projects/barangaroo-headland-park/>.
- Sharifi, E., Sivam, A., & Boland, J. (2016). Resilience to heat in public space: a case study of Adelaide, South Australia. *Journal of Environmental Planning and Management*, 59(10), 1833-1854. doi:10.1080/09640568.2015.1091294
- Sharma, A., Conry, P., Fernando, H. J. S., Hamlet, A., F., Hellmann, J. J., & Chen, F. (2016). Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: evaluation with a regional climate model. *Environmental Research Letters*, 11(6), 064004.

- Silva, C. M., Gomes, M. G., & Silva, M. (2016). Green roofs energy performance in Mediterranean climate. *Energy and Buildings*, 116, 318-325. doi:<http://dx.doi.org/10.1016/j.enbuild.2016.01.012>
- Skoor, C. (n.d.). *Raingarden in Ballard*. Seattle, Washington, USA.
- Soares, A. L., Rego, F. C., McPherson, E. G., Simpson, J. R., Peper, P. J., & Xiao, Q. (2011). Benefits and costs of street trees in Lisbon, Portugal. *Urban Forestry and Urban Greening*, 10(2), 69-78. doi:10.1016/j.ufug.2010.12.001
- Soulsbury, C. D., & White, P. C. L. (2015). Human-wildlife interactions in urban areas: a review of conflicts, benefits and opportunities. *Wildlife Research*, 42(7), 541-553. doi:<http://dx.doi.org/10.1071/WR14229>
- Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? *Journal of Epidemiology and Community Health*, 62(5), e9. doi:10.1136/jech.2007.064287
- Sustainable Built Environment Centre for Design (2006). *ESD Design Guide for Australian Government Buildings*. Available at <http://www.apcc.gov.au/ALLAPCC/GPG%20-%20ESD%20Design%20Guide%20for%20Australisn%20Government%20Buildings%20Edition%202.pdf>
- Sutton, P. C., & Anderson, S. J. (2016). Holistic valuation of urban ecosystem services in New York City's Central Park. *Ecosystem Services*, 19, 87-91. doi:<http://dx.doi.org/10.1016/j.ecoser.2016.04.003>
- Swaddle, J. P., & Calos, S. E. (2008). Increased avian diversity is associated with lower incidence of Human West Nile infection: observation of the dilution effect. *PLoS ONE*, 3(6). doi:10.1371/journal.pone.0002488
- Tapper, N. (2014). *Cities as water supply catchments: green cities and microclimate*. Cooperative Research Centre for Water Sensitive Cities. Available at [https://watersensitivecities.org.au/wp-content/uploads/2016/05/FS\\_B3-1\\_CitiesWaterSupplyCatchments\\_GreenCitiesMicroclimate.pdf](https://watersensitivecities.org.au/wp-content/uploads/2016/05/FS_B3-1_CitiesWaterSupplyCatchments_GreenCitiesMicroclimate.pdf)
- Taylor, A. F., Kuo, F. E., & Sullivan, W. C. (2002). Views of nature and self-discipline: evidence from inner city children. *Journal of Environmental Psychology*, 22(1-2), 49-63. doi:10.1006/jevp.2001.0241
- TEEB (The Economics of Ecosystems and Biodiversity) (2010). *Mainstreaming the Economics of Nature: a synthesis of the approach, conclusions and recommendations of TEEB*. Available at <http://www.teebweb.org/publication/mainstreaming-the-economics-of-nature-a-synthesis-of-the-approach-conclusions-and-recommendations-of-teeb/>
- Tello, V. (2013). One Central Park Vertical Gardens: Patrick Blanc. Available at <http://ecopublicart.org/one-central-park-vertical-gardens/>.
- The Glebe Society (2014). Photos of Glebe. Available at [http://www.glebe.org.au/?page\\_id=9952](http://www.glebe.org.au/?page_id=9952).
- The Royal Botanic Gardens Sydney (n.d.). Sports field in The Domain. Available at <https://www.rbg Syd.nsw.gov.au/Venue-Hire/Team-Building>.
- The Urban Developer (2016). Australia's First Breathing Green Wall Lifts Lendlease. Available at <https://www.theurbandeveloper.com/lendlease-barangaroo-junglefy-green-wall/>.
- Trees and Design Action Group Trust (2014). *Trees in Hard Landscapes: a guide for delivery*. Available at [http://www.tdag.org.uk/uploads/4/2/8/0/4280686/tdag\\_trees-in-hard-landscapes\\_september\\_2014\\_colour.pdf](http://www.tdag.org.uk/uploads/4/2/8/0/4280686/tdag_trees-in-hard-landscapes_september_2014_colour.pdf)

- Triguero-Mas, M., Dadvand, P., Cirach, M., Martínez, D., Medina, A., Mompart, A., Basagaña, X., Gražulevičienė, R., & Nieuwenhuijsen, M. J. (2015). Natural outdoor environments and mental and physical health: Relationships and mechanisms. *Environment International*, 77, 35-41.  
doi:<http://dx.doi.org/10.1016/j.envint.2015.01.012>
- Tropo (2013). Foods for Life Parklet, Adelaide, South Australia. Available at <http://www.tropo.com.au/foods-for-life-parklet/>.
- Troy, A., Morgan Grove, J., & O'Neil-Dunne, J. (2012). The relationship between tree canopy and crime rates across an urban–rural gradient in the greater Baltimore region. *Landscape and Urban Planning*, 106(3), 262-270.  
doi:<http://dx.doi.org/10.1016/j.landurbplan.2012.03.010>
- Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, 224(4647), 420-421.
- URS (Upper Parramatta River Catchment Trust) (2004). *Water Sensitive Urban Design Technical Guidelines for Western Sydney*. Available at [http://www.richmondvalley.nsw.gov.au/icms\\_docs/138067\\_Development\\_Control\\_Plan\\_No\\_9\\_-\\_Water\\_Sensitive\\_Urban\\_Design.pdf](http://www.richmondvalley.nsw.gov.au/icms_docs/138067_Development_Control_Plan_No_9_-_Water_Sensitive_Urban_Design.pdf)
- Vandermeulen, V., Verspecht, A., Vermeire, B., Van Huylenbroeck, G., & Gellynck, X. (2011). The use of economic valuation to create public support for green infrastructure investments in urban areas. *Landscape and Urban Planning*, 103(2), 198-206.  
doi:10.1016/j.landurbplan.2011.07.010
- Vaz Monteiro, M., Doick, K. J., Handley, P., & Peace, A. (2016). The impact of greenspace size on the extent of local nocturnal air temperature cooling in London. *Urban Forestry & Urban Greening*, 16, 160-169. doi:<http://dx.doi.org/10.1016/j.ufug.2016.02.008>
- VIC Department of Environment and Primary Industries (2014). *Growing Green Guide: a guide to green roofs, walls and facades in Melbourne and Victoria, Australia*. Available at [http://www.growinggreenguide.org/wp-content/uploads/2014/02/growing\\_green\\_guide\\_ebook\\_130214.pdf](http://www.growinggreenguide.org/wp-content/uploads/2014/02/growing_green_guide_ebook_130214.pdf)
- von Döhren, P., & Haase, D. (2015). Ecosystem disservices research: a review of the state of the art with a focus on cities. *Ecological Indicators*, 52, 490-497.  
doi:<http://dx.doi.org/10.1016/j.ecolind.2014.12.027>
- Wachter, S. M., & Gillen, K. C. (2006). *Public Investment Strategies: how they matter for neighborhoods in Philadelphia*. Available at <http://staging.community-wealth.org/sites/clone.community-wealth.org/files/downloads/paper-wachter-gillen.pdf>
- Walsh, C. J., Fletcher, T. D., & Burns, M. J. (2012). Urban stormwater runoff: a new class of environmental flow problem. *PLoS ONE*, 7(9). doi:10.1371/journal.pone.0045814
- Wang, L. (2015). Portable ParkedBench parklet injects a breath of fresh air in London. Available at <http://inhabitat.com/portable-parkedbench-parklet-injects-a-breath-of-fresh-air-in-london/>.
- Wang, Y., Bakker, F., de Groot, R., & Wörtche, H. (2014). Effect of ecosystem services provided by urban green infrastructure on indoor environment: a literature review. *Building and Environment*, 77, 88-100.  
doi:<http://dx.doi.org/10.1016/j.buildenv.2014.03.021>
- Ward Thompson, C., Aspinall, P., Roe, J., Robertson, L., & Miller, D. (2016). Mitigating stress and supporting health in deprived urban communities: the importance of green

- space and the social environment. *International Journal of Environmental Research and Public Health*, 13(4), 440. doi:10.3390/ijerph13040440
- Ward Thompson, C., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: evidence from salivary cortisol patterns. *Landscape and Urban Planning*, 105(3), 221-229. doi:http://dx.doi.org/10.1016/j.landurbplan.2011.12.015
- Wells, N. M. (2000). At home with nature: effect of 'greenness' on children's cognitive functioning. *Environment and Behaviour*, 32, 775-795.
- Wheeler, T. (Producer). (2010, 29/08/2016). Greening gets down and dirty. [Newspaper Article] Available at [http://articles.baltimoresun.com/2010-08-20/features/bs-gr-subsoiling-20100820\\_1\\_storm-water-pollution-polluted-runoff-pavement](http://articles.baltimoresun.com/2010-08-20/features/bs-gr-subsoiling-20100820_1_storm-water-pollution-polluted-runoff-pavement)
- White, M. P., Alcock, I., Wheeler, B. W., & Depledge, M. H. (2013). Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. *Psychological Science*, 24(6), 920-928. doi:10.1177/0956797612464659
- Whitehead, T., Simmonds, D., & Preston, J. (2006). The effect of urban quality improvements on economic activity. *Journal of Environmental Management*, 80(1), 1-12. doi:http://dx.doi.org/10.1016/j.jenvman.2005.01.029
- Wiedmann, T. O., Chen, G., & Barrett, J. (2015). The concept of city carbon maps: a case study of Melbourne, Australia. *Journal of Industrial Ecology*, 20, 676-691. doi:10.1111/jiec.12346
- Wilkinson, S., & Feitosa, R. (2015). Retrofitting housing with lightweight green roof technology in Sydney, Australia, and Rio de Janeiro, Brazil. *Sustainability*, 7(1), 1081.
- Wilkinson, S., Lamond, J., Proverbs, D., G., Sharman, L., Heller, A., & Manion, J. (2015). Technical considerations in green roof retrofit for stormwater attenuation in the Central Business District. *Structural Survey*, 33(1), 36-51. doi:10.1108/SS-07-2014-0031
- Wilkinson, S. J., & Dixon, T. (2016). Green roof retrofit: building urban resilience. Lamond, J., Wilkinson S. J. & Proverbs, D. . In D. Proverbs & C. A. Brebbia (Eds.), *Stormwater Attenuation and Green Roof Retrofit*: Wiley-Blackwell.
- Wilkinson, S. J., Proverbs, D. G., Lamond, J., & Rose, C. (2014). *Retrofit of Sustainable Urban Drainage (SUDS) in CBD for Improved Flood Mitigation*. Available at <https://opus.lib.uts.edu.au/handle/10453/36660>
- Wohlin, C. (2601268) (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. Paper presented at the Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering, London, England, United Kingdom.
- Wolf, K. (2007). City trees and property values. *Arborist News*, 16(4), 34-36.
- Wolf, K. L. (2009). Strip malls, city trees, and community values. *Arboriculture and Urban Forestry*, 35(1), 33-40.
- Wolf, K. L., & Robbins, A. S. (2015). Metro nature, environmental health, and economic value. *Environmental Health Perspectives*, 123(5), 390-398. doi:10.1289/ehp.1408216
- Wolfe, M. K., & Mennis, J. (2012). Does vegetation encourage or suppress urban crime? Evidence from Philadelphia, PA. *Landscape and Urban Planning*, 108(2-4), 112-122. doi:http://dx.doi.org/10.1016/j.landurbplan.2012.08.006

- Wong, I., & Baldwin, A. N. (2016). Investigating the potential of applying vertical green walls to high-rise residential buildings for energy-saving in sub-tropical region. *Building and Environment*, 97, 34-39. doi:<http://dx.doi.org/10.1016/j.buildenv.2015.11.028>
- Wong, N. H., Kwang Tan, A. Y., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., Chiang, K., & Wong, N. C. (2010). Thermal evaluation of vertical greenery systems for building walls. *Building and Environment*, 45(3), 663-672. doi:<http://dx.doi.org/10.1016/j.buildenv.2009.08.005>
- Wong, T. H. F., Allen, R., Beringer, J., Brown, R. R., Deletic, A., Fletcher, T. D., Gangadharan, L., Gernjak, W., Jakob, C., O'Loan, T., Reeder, M., Tapper, N., & Walsh, C. (2012). *Stormwater Management in a Water Sensitive City*. Available at <https://watersensitivecities.org.au/wp-content/uploads/2016/06/Blueprint2012-ISBN-978-1-921912-01.pdf>
- Wong, T. H. F., & Brown, R. R. (2009) The water sensitive city: principles for practice. *Water Science and Technology*, Vol. 60 (pp. 673-682).
- Wraight and Associates Landscape Architecture and Urban Design (2015). Jellicoe Street, North Wharf and Silo Park. Available at <http://www.waal.co.nz/our-projects/urban/jellicoe-street-north-wharf/>.
- Wuttke, A. (n.d.). The Commons. Available at <http://www.breathe.com.au/the-commons-1/41iecslg3g83xycg2gjar9m34kehxr>.
- Yang, W., Chang, J., Xu, B., Peng, C., & Ge, Y. (2008). Ecosystem service value assessment for constructed wetlands: a case study in Hangzhou, China. *Ecological Economics*, 68(1-2), 116-125. doi:<http://dx.doi.org/10.1016/j.ecolecon.2008.02.008>
- Zari, M. P. (2014). Ecosystem services analysis in response to biodiversity loss caused by the built environment. *S.A.P.I.EN.S*, 7.1, online: <http://sapiens.revues.org/1684>.
- Zhang, B., Xie, G.-d., Gao, J.-x., & Yang, Y. (2014). The cooling effect of urban green spaces as a contribution to energy-saving and emission-reduction: a case study in Beijing, China. *Building and Environment*, 76, 37-43. doi:<http://dx.doi.org/10.1016/j.buildenv.2014.03.003>
- Ziter, C. (2016). The biodiversity-ecosystem service relationship in urban areas: a quantitative review. *Oikos*, 125(6), 761-768. doi:10.1111/oik.02883

## 6 CASE STUDIES

This chapter presents case studies on the integration of urban ecology in landscapes in Australian cities (with an emphasis on Sydney) and in Europe, the US and Asia.

### National

The Sydney Green Grid	Sydney, NSW
Sydney Olympic Park	Sydney, NSW
Rouse Hill Town Centre	Sydney, NSW
Urban Forest Million Trees Program	Adelaide, SA
Urban Forest Strategy	Melbourne, VIC
Desalination Plant	Wonthaggi, VIC

### International

Urban Greening	Stuttgart, Germany
Urban Greening	Paris, France
Blue-Green Grid	Rotterdam, The Netherlands
Royal Sea Port	Stockholm, Sweden
Urban Redevelopment	Malmö, Sweden
Urban Ecology	Seattle, Washington, USA
Urban Greening	Portland, Oregon, USA
Urban Greening Vision	Singapore, Singapore
Qunli Stormwater Wetland Park	Harbin, China
'Lights Out Toronto!'	Toronto, Canada
The City of Cape Town Bioregional Plan	Cape Town, South Africa

The case studies highlight key aspects of programs, policies and regulatory approaches to indicate best practices and lessons learned for future implementation protocols. The case studies are relevant to all three literature reviews presented in this report (i.e. on biodiversity and ecology, planning and policy, and the built environment) and help in understanding the need to consider all three aspects to promote the integration of urban ecology into cities. The case studies show the range of strategies used in other cities to achieve urban ecology objectives. They are discussed in terms of implementation challenges and gaps.

Urban ecology principles feature in all the case studies presented at the site to metropolitan scales. Internationally, the City of Malmö, Sweden, demonstrates how a metropolitan green plan can be used by multiple departments in a city government to guide day-to-day decision-making on land-use planning and urban greening. Similar policy documents have been produced in Australia, such as Melbourne's Urban Forest Strategy; this sets out canopy-cover and tree-diversity targets for the city, which staff use on a daily basis in

making decisions on the management of the city's urban forests. In addition to the policies of local governments, broader metropolitan policies are needed to reform city planning and embed urban ecology. Sydney has the opportunity to do this through the implementation of the Green Grid. The Green Grid, however, provides only a framework and lacks ecological detail. Moreover, implementing the Green Grid is not a legislative requirement, and its success hinges on coordinating the actions of neighbouring local governments. If this is done, the Green Grid has the potential to reform city planning and embed urban ecology in day-to-day decision-making.

A planning framework to connect green and blue networks has been demonstrated in Rotterdam, the Netherlands. Although green corridors now connect open spaces across the city, they lack ecological features and are driven primarily by aesthetic and recreational considerations. Green networks have been established across the city of Stuttgart, Germany, under the Urban Framework Plan. Stuttgart takes planning frameworks a step further via legislation and an incentive program for the establishment of green infrastructure. Adelaide's urban forest program has increased native vegetation by 10% in its open-space network and provides an example of how leadership from a state government can initiate the establishment of green networks.

Unfortunately, few Australian examples exist of methods used at a metropolitan scale to ensure habitats are retained and enhanced in cities. As shown in previous chapters, urban environments in Australia and particularly NSW are largely experiencing habitat losses. Population growth and housing demands have driven urban sprawl since the 1940s, and only recently have planning strategies for urban densification been put forward as a means of stemming urban sprawl in NSW. A challenge in creating compact cities will be to protect, restore and enhance remnant habitats and to create new habitats adapted to urban densification.

Many cities worldwide have much larger populations than Australia, and many lessons can be learned by examining the mechanisms by which other cities have balanced development and environmental needs. Urban greening in Portland, US, for example, has been implemented under a 'grey-to-green' initiative, whereby land has been acquired for use as open or green space. Portland has also put in place regulations and an incentive scheme to encourage the installation of 'ecoroofs' at a building scale to increase the quantity of green infrastructure while allowing development to continue. In Singapore, urban greening has also focused on building-level greening schemes, promoting the installation of green roofs and walls through a similar incentive scheme while meeting the housing needs of a very large population.

The redevelopment of Malmö, Sweden, has been guided by the Green Plan for Malmö, which sees green areas protected from development at the metropolitan scale and the implementation of a 'green area ratio' to enable planning for additional green areas on private land. In Stuttgart, Germany, the city's Urban Framework Plan has enabled the establishment of green 'ventilation' corridors, in which 60% of the city is considered 'green' and nearly 40% of that part is protected from development.

In Australia, no such schemes exist at a metropolitan scale, although the Sydney Green Grid and the GSC's draft district plans go some way in directing governments toward the protection of green corridors and facilitating denser developments. Unlike the cities mentioned above, however, the Green Grid has no legislative support, and no incentive schemes exist to encourage developers and councils to increase green cover. At the scale of master plans, the Rouse House Town Centre project is a good example of urban planning: it has facilitated the provision of 40% open space and 20% restored native vegetation, allowing development to occur around these features. This would not be considered compact development, however; rather, it demonstrates the tendency to prioritise sprawling developments, especially in the outskirts of many Australian cities.

Opportunities exist for the creation of new habitats across scales, from metropolitan, to local, to lot. Broad, multifaceted schemes, such as those employed in Paris, France, can encourage the implementation of small-scale features such as green roofs and green walls through to larger-scale revegetation and urban forest programs and the preservation of green open spaces across a metropolitan area. Although these features are primarily built and managed to support human wellbeing (e.g. through lowered urban heat and increased recreation), opportunities exist, through ecological design and management, to also provide habitat. At the site scale, this has been achieved in the Elliot Bay Seawall project in Seattle and in the Lights out Toronto! project in Canada (described below). These projects have employed ecological principles to create new marine and night-time habitats, which also provide benefits for people in these areas.

In Australia, several cities are implementing plans in LGAs to create habitats. The urban forest program in Adelaide, for example, has several ecological objectives that allow for the creation of new habitats across the city. The City of Melbourne's urban forest program also highlights how tree management across the city can benefit human wellbeing. That strategy, however, lacks a clear ecological objective, despite the potential for the urban forest to be managed to achieve this as a co-benefit. In the Sydney region, the Sydney Olympic Park project perhaps best demonstrates the way in which new habitats can be created at a local scale; at Olympic Park, this has been achieved through a combination of policy and planning, supported by an administering body with ongoing responsibility for managing the park and its habitats to achieve biodiversity and human wellbeing outcomes. The project exemplifies how urban planning and design can be used to guide habitat creation and how land managers can continue to achieve biodiversity and human wellbeing benefits through ongoing eco-friendly management and monitoring.

## 6.1 National case studies

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### THE SYDNEY GREEN GRID

**LOCATION:** NSW, AUSTRALIA

**COMPLETION DATE:** 2014

**SCALE:** METROPOLITAN

**PROJECT TYPE:** STRATEGIC PLANNING REPORT

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### URBAN FOREST - MILLION TREES PROGRAM

**LOCATION:** ADELAIDE, SOUTH AUSTRALIA

**COMPLETION DATE:** 2002-2014

**SCALE:** METROPOLITAN

**PROJECT TYPE:** REVEGETATION PROGRAM

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### SYDNEY OLYMPIC PARK, HOMEBUSH BAY, NSW

**LOCATION:** AUSTRALIA

**COMPLETION DATE:** ONGOING

**SCALE:** DISTRICT (over 500 ha)

**PROJECT TYPE:** MASTER PLANNING & DESIGN

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### VICTORIAN DESALINATION PLANT

**LOCATION:** WONTHAGGI, VICTORIA

**COMPLETION DATE:** 2012

**SCALE:** SITE (263 ha)

**PROJECT TYPE:** MASTER PLANNING & DESIGN

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### ROUSE HILL TOWN CENTRE, SYDNEY, NSW

**LOCATION:** ROUSE HILL, SYDNEY, NSW

**COMPLETION DATE:** 2008

**SCALE:** SITE (120 ha)

**PROJECT TYPE:** MASTER PLANNING & DESIGN

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### MELBOURNE URBAN FOREST STRATEGY, VICTORIA

**LOCATION:** MELBOURNE VICTORIA

**COMPLETION DATE:** VARIOUS

**SCALE:** METROPOLITAN

**CLIENT:** THE CITY OF MELBOURNE

**TYPE:** STRATEGIC PLANNING

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## THE SYDNEY GREEN GRID

**LOCATION:** NSW, AUSTRALIA

**COMPLETION DATE:** 2014

**SCALE:** METROPOLITAN

**PROJECT TYPE:** STRATEGIC PLANNING REPORT

### 1. PROJECT OVERVIEW

The Sydney Green Grid is a framework to create an interconnected network of open space throughout metropolitan Sydney. It aims to increase the quality of open spaces and improve and enhance the quality of life in the region. The Green Grid objectives are to:

- Increase access to open space
- Encourage sustainable transport connections and promote active living
- Create a high-quality and active public realm
- Conserve the natural environment
- Adapt to climate extremes, improve air quality and increase urban greening
- Promote green skills and improve management, maintenance and sustainable green-space design

The Green Grid is based on an idea of the Government Architect's Office to map and establish a network of green space throughout the region. A pilot project was completed for Parramatta City Council before the project was rolled out across Sydney.

The Green Grid was prepared following an audit of open space. Six Sydney Open Space Audits (Government Architect's Office, 2015) provided a review of public lands managed primarily for open-space purposes, including recreation and the protection of natural, cultural and landscape heritage. Active and passive local, district and regional open spaces were mapped, and distributions and deficiencies were identified in relation to population, based on open-space supply

benchmarks contained in the reference standard (the Department of Planning's Recreation and Open Space Planning Guidelines for Local Government, 2010). The audit reports provide the evidence base to support strategic planning for open space across the metropolitan area and by local government.

Based on the assessment of existing open space provision and along with consideration of strategic context and key natural features, the Green Grid outlines strategic opportunities for creating open space across each subregion, building on existing initiatives and creating new opportunities.

### 2. URBAN ECOLOGY FEATURES

The primary focus is the connection of people with open green space to improve liveability. Objectives 4 and 5 relate to the protection of ecosystems and urban greening initiatives. Objective 6 relates to education, professional development and landscape management, which all have a role to play in creating more urban ecosystems in our cities. There is potential to leverage these objectives for urban ecosystem services and biodiversity outcomes.

The Green Grid is embedded in the Action 3.2.1 of *A Plan for Growing Sydney* (NSW Planning and Environment, 2014). NSW Planning's Metropolitan Greenspace Program (MGP) provides AUD 3 million annually to fund the delivery of the Green Grid, including parks, street-tree planting and waterway corridors. The most recent round of funding included funds for the Manly Biodiversity Strategy and the Silver

Beach Shared Pathway in Sutherland Council area.

### 3. CHALLENGES AND SOLUTIONS

Although the Green Grid is supported by the Department of Planning, *A Plan for Growing Sydney* will be reviewed in 2017 and there is no guarantee it will remain part of metropolitan planning.

The Green Grid lists key project opportunities for each subregion to guide implementation across Sydney. Implementation is reliant on the planning and activity of local governments and the GSC. A challenge is to ensure that all councils support the Green Grid and act in a coordinated, consistent manner to achieve its goals.

As detailed design and construction of proposed key projects occur, it is important to carefully consider the impacts on ecosystems. The location and construction methods proposed for new pedestrian and cycle ways may be detrimental to biodiversity. For example, tracks along rivers pass through riparian zones that are important for biodiversity. Increasing human traffic in these areas, and potentially removing riparian

vegetation to build the tracks, could have a negative impact.

### 4. LESSONS LEARNED

The Green Grid provides a framework for the connection and creation of green spaces in Sydney, but its attention to biodiversity outcomes is minimal and there is no evidence that the project has so far achieved any biodiversity outcomes. Enhancing and protecting biodiversity was not the primary aim of the Green Grid. The document was prepared by a team of landscape architects and planners, without consultation with ecologists. In the context of the Green Grid, enhanced connectivity refers to connectivity for people, not biodiversity, and although there may be some biodiversity benefits from its implementation, these were not specified in the original plans. The Department of Planning is preparing an ecological overlay to address this gap.

The addition of monitoring in the open-space network, including new green corridors, would allow the impact on biodiversity to be measured. This would create an evidence base to ensure that the project does indeed 'conserve and enhance biodiversity'.

### WEB LINKS

<http://www.planning.nsw.gov.au/metropolitan-greenspace-program>

<http://www.planning.nsw.gov.au/Plans-for-Your-Area/Sydney/A-Plan-for-Growing-Sydney>

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## URBAN FOREST - MILLION TREES PROGRAM

**LOCATION:** ADELAIDE, SOUTH AUSTRALIA

**COMPLETION DATE:** 2002-2014

**SCALE:** METROPOLITAN

**PROJECT TYPE:** REVEGETATION PROGRAM

### 1. PROJECT OVERVIEW

The Urban Forest - Million Trees Program was part of the South Australian Government's greening agenda from 2003 to 2014. It was managed by the Department for Environment and Heritage in conjunction with the Department of Premier and Cabinet and Planning SA. Its aim was to address the loss of local native biodiversity in metropolitan Adelaide.

The program contributed towards carbon sequestration and biodiversity targets within South Australia's Strategic Plan. It had a target to establish 3 million local native trees throughout greater Adelaide by 2014, which it achieved. Initial funding for the planting of 1 million native trees across Adelaide was AUD 10 million for the 2002-03 to 2006-07 financial years. The program built on the work of the South Australian Urban Forest Biodiversity Program, which was established in 1997 and focussed on conserving remnant vegetation throughout metropolitan Adelaide and increasing the biomass of locally indigenous species.

Project sites ranged in scale and type; they included intensively managed urban sites, broad-acre restoration sites, large parks, water courses, riparian and coastal sites and smaller local reserves. The aim of tree planting was not simply to reach an arbitrary number, but to restore vegetation communities endemic to the area through the use of locally native plants. The projects were planned and delivered in partnership with a range of landowners and managers, including over 20 local councils, state government agencies and not-for-profit organisations,

including the Adelaide City Council and local Friends of Parks groups.

### 2. URBAN ECOLOGY FEATURES

Approximately 2,000 ha of native vegetation was re-established throughout the Adelaide metropolitan open-space system, approximately 600,000 tonnes of CO<sub>2</sub> equivalent emissions over the life of the plantings. The project included habitat reconstruction, revegetation, community projects, education projects and resources, and activities to engage, inspire and involve the community.

The Urban Forest - Million Trees Program was not just about tree planting; it also focused on planting understory plants associated with specific vegetation communities. The vegetation provides vital habitat for wildlife and helps improve air and water quality. The main achievements of the project were to:

- Plant 1 million native plants across Adelaide's metropolitan area (achieved in 2006)
- Establish 3 million native plants across Adelaide by 2014 (goal met)
- work with the Youth Conservation Corps, involving young unemployed people and those completing education and training at risk of disengaging from the community.

Specific projects included:

- Craighburn Farm – shared-use trail network and habitat restoration. The farm was a recently retired grazing property adjacent to residential development and the Sturt Gorge Recreation Park. Various restoration approaches were employed to

transform the site from pasture land into a grassy woodland.

- O'Halloran Hill Recreation Park - large-scale revegetation, weed management and monitoring. The 253-ha park is a key component of Adelaide's metropolitan open-space system. The park was the site of a bluestone quarry used in the construction of many of the old structures in Adelaide and had been cleared for grazing and cropping for more than 90 years. Work on the site navigated a range of considerations, including open-space planning, land zoning, weed management, plant selection, cultural heritage, habitat restoration, monitoring and balancing competing land uses.

Tulya Wodli - Adelaide Parklands, River Torrens Linear Park. Tulya Wodli is managed by the Adelaide City Council. The council partnered with the Million Trees Program to progressively reinstate riparian vegetation across the site. Other site initiatives include stormwater management and recreational trails.

### **3. CHALLENGES AND SOLUTIONS**

Given the scale of the project, engaging with stakeholders and community groups was the key to its success. The program actively involved around 4,000 people each year in around 75 projects. All metropolitan local councils, 12 state government agencies, and over 180 schools were involved in the program. Initiatives such as Grow a Great School, the Local Government Biodiversity Officers' Network, and many planting events held every winter at sites across Adelaide enabled this involvement. The Grow a Great School initiative supported more than 200 schools across Adelaide in creating indigenous gardens for education,

amenity and habitat. In total, over 30,000 people were actively involved in growing and planting seedlings for the program.

A diverse range of land managers and other consultants were involved in various aspects of the program, including open-space planning, habitat restoration, amenity improvements, landscape design, community engagement, recreational development, resource management, residential development, and ecological monitoring and education.

### **4. LESSONS LEARNED**

The program demonstrated the importance of stakeholder engagement and the potential of community engagement in achieving urban greening and biodiversity targets. A high level of consultation and engagement by project directors enabled strong working relationships and effective project implementation.

The program also demonstrated strong top-down environmental leadership from the South Australian state government, as well as a bottom-up approach. It resulted in a 10% increase in the vegetated areas of the Adelaide metropolitan open-space system. Native revegetation has provided environmental benefits and other benefits for the people of Adelaide.

This case study highlights a key issue around policy and restoration ecology: it defined success based on actions rather than outcomes. There has been little monitoring of restoration sites to demonstrate its success. Although vegetation was planted, the effectiveness of these measures in returning biodiversity or preventing species declines, have not been monitored.

## WEB LINKS

<http://parks.asnevents.com.au/newpage-2/newpage-4/>

<http://www.adelaidecitycouncil.com/city-living/sustainable-adelaide/biodiversity/>

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## SYDNEY OLYMPIC PARK, HOMEBUSH BAY NSW

**LOCATION:** AUSTRALIA

**COMPLETION DATE:** ONGOING

**SCALE:** DISTRICT (over 500 ha)

**PROJECT TYPE:** MASTER PLANNING & DESIGN

### 1. PROJECT OVERVIEW

Sydney Olympic Park, the site of the 2000 Olympic Games, is one of NSW's largest urban redevelopment projects. The site has been transformed from one of various industrial uses to an urban development that integrates recreational, commercial and residential uses with a focus on environmental sustainability.

A commitment to the environment was at the heart of the planning, design and construction of facilities, which was managed by the Olympic Coordination Authority. The implementation of ecologically sustainable development was supported by the *Environmental Guidelines for the Summer Olympic Games (1993)* and a framework of policy and planning instruments that included the *Olympic Coordination Authority Act*, *State Environment Planning Policy (SEPP) 38*, the *Sydney Regional Environmental Plan (SREP) 24 Homebush Bay Area* and the Olympic Coordination Authority's *Environment Strategy*, *Environment Policy* and *Environmental Tender Specifications*. Under the direction of the Sydney Olympic Park Authority after the Olympics, the site has continued to be managed and developed in line with sustainability principles.

Sydney Olympic Park incorporates a town centre and various green spaces, including the Millennium Parklands, the Brickpit, the Badu Mangroves and Waterbird Refuge and Wentworth Park. Newington is the

adjacent residential suburb, which was originally the Athletes Village. Two landscape plans were applied to the site. The first was based on an ideal of grass and canopy trees, and the second sought to integrate mid-storey vegetation. The subsequent plan has also assisted in providing habitat for woodland birds, which were in decline.

### 2. URBAN ECOLOGY FEATURES

Sydney Olympic Park demonstrates a wide variety of urban ecology features that improve sustainability and biodiversity outcomes and incorporate environmental management practices such as flora and fauna conservation, water and heritage conservation, energy efficiency, and environmental education and restoration.

The site contained significant sites that were protected or restored through the redevelopment process. These include Haslams Creek, which was de-channelised and reconstructed with natural creek banks, and estuarine environments such as the saltmarshes and mangroves in the Newington Nature Reserve and Badu Mangroves.

A variety of eco-friendly maintenance management practices have been implemented, such as leaving felled trees on the ground to provide habitat, creating tree hollows, restoring mid-storey planting, and ensuring plant species diversity. Today, Olympic Park supports 250 native animal species, over 400 native

plant species and three endangered ecological communities.

Millennium Parklands contains approximately 430 ha of parkland, woodlands, remediated lands and wetlands, such as the Newington Nature Reserve. A network of more than 40km of pedestrian and cycle trails creates an interconnected network throughout the site that allows recreation and education opportunities.

Water management is an integral part of the site's design. This also supports biodiversity outcomes through WSUD elements such as wetlands, ponds and bioswales. The Water Reclamation and Management Scheme collects, treats and stores stormwater and supplies recycled water for non-drinking uses to all residents, commercial premises and sports venues.

Street-tree corridors have been established throughout the Olympic Park town centre, forming green links to the surrounding parklands. The planting palette features native and locally indigenous species, increasing biodiversity. Master planning for Newington integrates street trees, pocket parks and a native plant palette.

### **3. CHALLENGES AND SOLUTIONS**

The design team worked with the existing site conditions in an interdisciplinary setting. This interdisciplinary project team helped work through the site's complexities.

The site has considerable ecological value, providing habitats for native and migratory birds and containing regionally significant remnant eucalypt forest. These habitats have protected and, where appropriate, limited public access has been provided,

through paths, bird hides and lookouts. The discovery of the endangered Green and Gold Bell Frog at the Brickpit site resulted in the site's protection and an innovative piece of built infrastructure, the Brickpit Ring, which provides recreation value while protecting important habitat for the frog species.

Much of the site's land was contaminated by domestic, commercial and industrial waste and needed remediation and rehabilitation. Innovative solutions were developed to deal with these conditions, including the creation of waste burial mounds, which act as 'markers' throughout the site. A shortfall in topsoil resources resulted in the development and use of constructed soil. Careful soil management and plant species selection helped create a low-maintenance landscape. Gap-graded structural soils and permeable pavements were used around urban trees to ensure that sufficient oxygen and water reached tree roots, creating optimal growing conditions. Drought-tolerant native plants were planted to reduce maintenance requirements.

The park runs a variety of environmental education programs for students, the general public and practitioners, demonstrating the holistic approach taken to engaging and educating the public.

### **4. LESSONS LEARNED**

The Sydney Olympic Park redevelopment demonstrates the importance of establishing strong environmental guidelines at the beginning of a project, supported by a robust planning framework. These guided development, resulting in positive environmental outcomes and outstanding innovation.

A holistic consideration of water management throughout the site has

resulted in a series of environmental benefits, including habitat creation. Ongoing research and monitoring of key fauna species, including birds, benthic invertebrates, the Green and Gold Bell frog and mosquitoes, has been implemented to ensure that management practices at Olympic Park encourage biodiversity.

The project improved urban soil science practice. The innovative re-use of waste materials reduced project costs and offsite soil mining and enabled the creation of

soil profiles to which local plant species are adapted.

Sydney Olympic Park demonstrates how designing with ecologically sustainable development principles can provide co-benefits for humans. The Park is now an important recreational destination in Sydney, with cycle ways, pathways, playgrounds, an archery centre and a BMX track providing opportunities for a range of activities.

#### WEB LINKS

<http://sesl.com.au/>

[http://www.sopa.nsw.gov.au/our\\_park/environment](http://www.sopa.nsw.gov.au/our_park/environment)

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## VICTORIAN DESALINATION PLANT

**LOCATION:** WONTHAGGI, VICTORIA

**COMPLETION DATE:** 2012

**SCALE:** SITE (263 ha)

**PROJECT TYPE:** MASTER PLANNING & DESIGN

### 1. PROJECT OVERVIEW

The Victorian Desalination Plant and Ecological Reserve contains a desalination plant and coastal park. The desalination plant was built to 'drought-proof' Melbourne and Geelong from potential water shortages. Completed in 2012, the AUD 4 billion project is located on the Bass Coast in Wonthaggi. The desalination plant was designed to minimise adverse impacts on landscape, cultural heritage, fauna and flora, and local communities. It features a 26,000m<sup>2</sup> green roof, the largest in the Southern Hemisphere.

The coastal park transformed barren, degraded land into coastal and swampy woodlands, wetlands and dune ecosystems, reconnecting remnants and providing a rich visitor experience. The redevelopment of the site has improved its ecological functioning and created a recreation destination.

The project needed to comply with legislation and regulations relating to flora, fauna, land, soil, air, groundwater, water and the marine environment, including the *Environment Protection and Biodiversity Conservation Act 1999* and the *Wildlife (marine mammals) Regulations 2009*. Aspects of pollution, energy efficiency (greenhouse gas emission reductions) and waste were also relevant. Throughout the design and construction phases, compliance with both Commonwealth and Victorian state legislation was required.

### 2. URBAN ECOLOGY FEATURES

The site features numerous urban ecology initiatives, including the restoration of the site, which was degraded as a result of previous mining and farming activities that cleared the existing flora and natural sand-dune landscapes. The project is the state's largest ecological restoration effort, with more than 3.5 million new plants and

150,000 trees, a constructed dune system, and the creation of wetlands and woodlands. These restored areas now link existing small isolated areas of vegetation, increasing habitat and connectivity for a variety of birds and other animals.

The green roof on the desalination plant was constructed with a purpose-designed lightweight high-water-retention planting media and integrated growth support systems. The extensive green roof was constructed with an 80mm substrate (soil media) on a pitch of 3.5-20 degrees. An automated subsoil drip irrigation system and a weather-monitoring station were installed to ensure appropriate watering frequency and volume. Twenty-six indigenous species were selected for use on the roof after significant research to establish a local palette suitable for predicted future conditions. Seeds were collected within 40km of the plant, and trials were conducted to establish whether these species would be suitable for planting on a green roof because they hadn't previously been used for such a purpose. The plant palette includes indigenous ground covers, tussocks and low shrubs. The green roof improves the thermal performance of the building, minimises the noise impacts from the plant, and protects the roof from the harmful effects of solar radiation. It was designed with self-regenerating species to reduce maintenance.

The ecological reserve uses onsite water-capture for irrigation. Local seed collection and onsite propagation were employed to establish millions of plants at the site. The local Landcare group (Bass Coast) was engaged to use local expertise for the regeneration project.

The project has a detailed monitoring and evaluation program, including of water and

air quality and terrestrial and aquatic flora and fauna, demonstrating a commitment to ongoing environmental management at the site.

### **3. CHALLENGES AND SOLUTIONS**

Given the scale of the project, noise and visual impacts needed to be considered. The community was particularly concerned about visual impacts on the coastline. The green roof and constructed dune system was integral to minimising the visual and noise impacts. The dune system used spoil that would otherwise have been taken off the site.

Another challenge was to reduce the impact on marine life. The intake of seawater and release of saline-enriched water from the desalination plant were designed to minimise environmental impact, including by tunnelling the intake and outlet pipes to reduce the impact on sensitive near-shore ecosystems. Long tunnels protect the beach and coastal dune system. Custom-designed seawater intake structures ensure that seawater is drawn into the pipe at very low speeds, so that marine life, such as small fish, can swim against the intake current. The undersea and underground tunnel is fitted with a protective grill to ensure that larger marine life cannot swim into it. Reducing the impact on marine life was part of the project approval conditions. A baseline marine monitoring program was implemented to gather data on the marine environment before the plant's operation.

The potential environmental impacts and improvements were acknowledged from project inception. The impact of the project on the original biodiversity, including threatened species, ecological communities and ecological processes was assessed before the start of the project in a detailed environmental effects

statement, which integrated over 80 specialist supporting reports.

#### 4. LESSONS LEARNED

This redevelopment demonstrates that good planning and design can address community concerns effectively. It also shows that infrastructure projects can improve ecological outcomes, as well as provide co-benefits to humans. The small footprint of the plant resulted in a new park for public use and increased green cover throughout the site. Habitat restoration can improve ecological outcomes. Recreation opportunities in the reserve include 8km of pedestrian, cyclist and equestrian trails, way-finding,

interpretation, boardwalks, bird hides, viewing decks and picnic shelters.

An independent reviewer and environmental auditor was employed to oversee the design, construction and environmental management of the project and to monitor the environmental performance of the desalination plant during operation. This ensures accountability and demonstrates the client's commitment to environmental outcomes. Monitoring will enable the longer-term evaluation of the site and external evaluation and reporting.

#### WEB LINKS

<http://www.depi.vic.gov.au/water/urban-water/desalination-project/desalination-project-overview/the-desalination-plant>  
<https://www.aquasure.com.au/desalination-plant>  
<http://aspect.net.au/?p=462>

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### ROUSE HILL TOWN CENTRE, SYDNEY, NSW

**LOCATION:** ROUSE HILL, SYDNEY, NSW

**COMPLETION DATE:** 2008

**SCALE:** SITE (120 ha)

**PROJECT TYPE:** MASTER PLANNING & DESIGN

#### 1. PROJECT OVERVIEW

Before redevelopment, Rouse Hill Town Centre was a golf course with little biodiversity value, thereby giving the owner, GPT, the opportunity to 'restore' this value. Rouse Hill Town Centre is Australia's first regional retail centre to demonstrate a comprehensive approach to social and environmental sustainability.

The town centre design turns the typical shopping centre box 'inside out' to create open streets. In its first year of operation, the town centre achieved a 34% reduction in energy use compared with an average NSW retail centre of equivalent size. This was achieved by:

- The positioning of buildings to maximise light and airflow, thereby reducing heating, cooling and lighting needs.
- Open streets, which provide 100% natural ventilation.
- A large, highly efficient central plant servicing all tenants.
- Tenant-controlled air conditioning, operating on a 'user pays' basis.
- Energy-efficient lighting throughout.
- Passive solar design using the sun to warm and light buildings and streets.
- The use of trees and shading devices (operated by the Building Management System) to increase

comfort in warm, windy or wet conditions.

- The maximum use of daylight in common areas, reducing artificial lighting.

Rouse Hill Town Centre is a master-planned community delivered by a joint venture between Lend Lease and the GPT Group, in partnership with Landcom and the NSW Department of Planning. Rouse Hill consists of approximately 120 ha of land located on Windsor Road in the Baulkham Hills LGA.

## 2. URBAN ECOLOGY FEATURES

Landscaping in the town centre was undertaken to achieve biodiversity targets consistent with those set for nearby Caddies Creek. The site was designed to minimise artificial watering, with 40% of the site area protected as open space and 20% revegetated with local natural vegetation.

A saline soil management strategy was prepared and implemented as part of the soils plans in each of the site's environmental management plans, which covered environmental issues such as soil erosion, dust, stormwater, waste, recycling, energy conservation through construction, vehicle movement and noise.

A voluntary target required 30% of the site's biodiversity values to be restored through the adoption of an 80% endemic planting target. This target was formally monitored throughout the project delivery process by GPT's development and sustainability management teams.

### Outcomes included:

- The use of bioswales and ponds covering 400m<sup>2</sup> for the removal of toxics from stormwater before it enters Caddies Creek.

- Gross pollutant traps to filter stormwater.
- The planting of over 130,000 trees and plants, with more than 80% indigenous species.
- Limiting rainwater collection tank size to maintain the flows within Caddies Creek.
- A 'secret garden' providing thermal insulation, stormwater management and an extension of green space.
- Working with existing topography and vegetation to minimise the project's impact.
- Communicating messages on stormwater grates to educate visitors and staff on the importance of considering what is put down the drain for the benefit of the flora and fauna in the area.
- Using timbers from sustainably managed forests.

## 3. CHALLENGES AND SOLUTIONS

The challenges in making positive contributions to biodiversity included:

1. The need for a biodiversity measurement tool.
2. Supplier requirements addressing biodiversity.
3. Awareness of biodiversity in property industry.

### Biodiversity measurement tool

Unlike carbon and water, there is no widely used or accepted standard for measuring biodiversity. To overcome this, GPT developed a practical biodiversity measure to enable the establishment of a baseline for onsite biodiversity and allowing the tracking of performance at sites. The process was shared with the Green Building Council of Australia and forms the basis for the biodiversity component of their Green Star Performance Tool.

### Supplier requirements

GPT understood that biodiversity can be directly and indirectly affected by their operations and those of their suppliers. Biodiversity criteria are included in supplier pre-qualifications and the selection process for services. Landscaping service selection criteria include consideration of expertise and experience in relation to:

- Chemical management and selection to minimise environmental impact in use, manufacture and disposal.
- Native and local species selection and management to provide a variety of structures (shrubs and groundcover, mid-storey and over-storey) and a range of fast-, medium- and slow-growing species.
- Irrigation and selection of drought-tolerant and water-efficient plants suitable for local climate, geology and soil type.
- Fauna habitat, including the design of landscapes to be consistent with adjacent lands and other wildlife and waterway corridors.
- Multifunctionality, and the selection of plants with more than one function, such as shading, food-producing (e.g. nectar, fruit or seeds) and habitat for vulnerable

local fauna, such as bats, butterflies and birds.

#### **Raising biodiversity awareness**

Biodiversity is poorly understood in the property industry, but reviews have revealed that it is a topic of interest among GPT employees. Given the potential impact of operations on biodiversity, GPT regularly conducts biodiversity-awareness training for all its operations managers, as well as for contractors such as cleaners and waste companies.

#### **4. LESSONS LEARNED**

This redevelopment demonstrates that good planning and design can improve ecological outcomes, as well as provide co-benefits for humans. The development of the biodiversity measurement tool resulted in a change to the key industry sustainability rating tool.

Recreation opportunities in the development include a nature trail for pedestrians and cyclists.

There is a need to upskill and educate the property profession with respect to biodiversity.

#### **WEB LINKS**

<http://www.gpt.com.au/Sustainability/Our-Environment/Biodiversity>

<http://www.environment.gov.au/epbc/notices/assessments/pubs/sydney-growth-centres-program-report.pdf>

# MELBOURNE URBAN FOREST STRATEGY, VICTORIA

**LOCATION:** MELBOURNE VICTORIA

**COMPLETION DATE:** VARIOUS

**SCALE:** METROPOLITAN

**CLIENT:** THE CITY OF MELBOURNE

**TYPE:** STRATEGIC PLANNING

## 1. PROJECT OVERVIEW

The City of Melbourne faces significant challenges from climate change, population growth and urban heating, placing pressure on the city's built fabric, services and people. A healthy urban forest plays a vital role in maintaining the health and liveability of the city.

The Urban Forest Strategy seeks to manage change and protect against future vulnerability by providing a strategic framework for the evolution and longevity of Melbourne's urban forest. The strategy aims to:

- Adapt the city to climate change.
- Mitigate the UHI effect by reducing inner-city temperatures.
- Create healthier ecosystems.
- Become a water-sensitive city.
- Engage and involve the community.

Significantly, the City of Melbourne recognises the importance of a healthy urban forest in the form of trees, parks, planted plazas, campuses, community gardens, green roofs, balconies and green walls. The City is looking at the cumulative benefits of these ecosystem services and acknowledges the social, environmental and economic benefits such provision brings.

## 2. URBAN ECOLOGY FEATURES

The City of Melbourne aims to achieve the strategic goals listed above by:

- Increasing tree canopy cover from 22% to 40% by 2040.
- Increasing forest diversity with no more than 5% of one tree species, no more than 10% of one genus, and no more than 20% of any one family.

- Improving vegetation health, with 90% of trees classified as healthy by 2040.
- Improving soil moisture to provide healthy growth of vegetation.
- Improving biodiversity to contribute to healthy ecosystems.
- Inform and consult with the community and increase connection to the urban forest.

## 3. CHALLENGES AND SOLUTIONS

Five key challenges for this ambitious program have been identified:

4. Ageing tree population
5. Water and soil moisture
6. Climate change
7. UHI and extreme heat
8. Population increase and urban intensification.

The City has developed a strategy that outlines the ways in which it will manage these challenges. It has put in place governance structures, and identified priority measures and tasks. Measurement criteria and a monitoring and review program has been established to assess progress in the implementation of the strategy to address the key challenges. In this way, the City can determine whether it is on schedule to meet the targets set.

## 4. LESSONS LEARNED

Melbourne enjoys a reputation and status as one of the world's most liveable cities, and it wants to retain this level of liveability. The City also knows that, with predicted climate change, it will be increasingly difficult to maintain comfortable temperatures in densely developed urban settlements. An urban forest requires long-term and ongoing planning and

commitment. The City has consulted widely and raised awareness of the issues it faces. There are many lessons to learn; given the dynamics of changing climate and changing urban densities, lessons learned now may change in the future.

Priorities have been established and principles set out. These are less likely to change over time. There is widespread acceptance and recognition among stakeholders that maintaining a healthy

environment has social and economic costs and benefits. A healthy environment for humans provides habitat for urban ecology and supports biodiversity. Education programs have been put in place to increase community engagement in the strategy. Community engagement is essential if targets to increase canopy cover and urban forest diversity, improve vegetation health, and increase soil moisture and water quality and thus improve urban ecology are to be realised.

#### **WEB LINKS**

<http://www.melbourne.vic.gov.au/community/parks-open-spaces/urban-forest/Pages/urban-forest-strategy.aspx>

<https://www.melbourne.vic.gov.au/SiteCollectionDocuments/urban-forest-strategy.pdf>

<http://melbourneurbanforestvisual.com.au/>

DRAFT

## 6.2 International case studies

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### URBAN GREENING, STUTTGART

**LOCATION:** STUTTGART, GERMANY

**COMPLETION DATE:** VARIOUS

**SCALE:** METROPOLITAN

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** VARIOUS

**DESIGNER:** VARIOUS

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### URBAN GREENING, PARIS

**LOCATION:** PARIS, FRANCE

**COMPLETION DATE:** VARIOUS

**SCALE:** METROPOLITAN

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** VARIOUS

**DESIGNER:** VARIOUS

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### ROTTERDAM'S BLUE-GREEN GRID, THE NETHERLANDS

**LOCATION:** ROTTERDAM, THE NETHERLANDS

**DATE:** SINCE 2005

**SCALE:** METROPOLITAN

**PROJECT TYPE:** VARIOUS

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### STOCKHOLM'S ROYAL SEA PORT, SWEDEN

**LOCATION:** STOCKHOLM, SWEDEN

**COMPLETION DATE:** EXPECTED 2030

**SCALE:** DISTRICT (236 ha)

**PROJECT TYPE:** REDEVELOPMENT

**CLIENT:** STOCKHOLM CITY COUNCIL

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### CITY OF MALMÖ REDEVELOPMENT

**LOCATION:** MALMÖ, SWEDEN

**COMPLETION DATE:** VARIOUS

**SCALE:** DISTRICT

**PROJECT TYPE:** MASTER PLANNING & DESIGN

**CLIENT:** CITY OF MALMÖ

**DESIGNER:** VARIOUS

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### URBAN ECOLOGY IN SEATTLE

**LOCATION:** WASHINGTON, US

**SCALE:** DISTRICT

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** CITY OF SEATTLE

**DESIGNER:** JAMES CORNER FIELD OPERATIONS

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### URBAN GREENING, PORTLAND

**LOCATION:** OREGON, US

**COMPLETION DATE:** ONGOING

**SCALE:** METROPOLITAN

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** CITY OF OREGON

**DESIGNER:** VARIOUS

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## URBAN GREENING VISION, SINGAPORE

**LOCATION:** SINGAPORE, SINGAPORE  
**SCALE:** METROPOLITAN

**PROJECT TYPE:** URBAN PLANNING &  
DESIGN  
**CLIENT:** SINGAPORE GOVERNMENT

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## QUNLI STORMWATER WETLAND PARK, HARBIN

**LOCATION:** HEILONGJIANG PROVINCE,  
CHINA  
**COMPLETION DATE:** 2010  
**SCALE:** SITE (34 ha)  
**DESIGNER:** TURENSCAPE

**PROJECT TYPE:** URBAN PLANNING &  
DESIGN  
**CLIENT:** THE MUNICIPAL GOVERNMENT  
OF HARBIN CITY

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## 'LIGHTS OUT TORONTO!', TORONTO

**LOCATION:** TORONTO, CANADA  
**COMPLETION DATE:** ONGOING  
**SCALE:** METROPOLITAN  
**PROJECT TYPE:** AWARENESS PROGRAM

**COLLABORATION:** THE CITY OF  
TORONTO, FATAL LIGHT AWARENESS  
PROGRAM & BUILDING OWNERS AND  
MANAGERS ASSOCIATION

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## THE CITY OF CAPE TOWN BIOREGIONAL PLAN

**LOCATION:** CAPE TOWN, SOUTH AFRICA  
**SCALE:** METROPOLITAN  
**PROJECT TYPE:** URBAN PLANNING &  
STRATEGY

**CLIENT:** THE CITY OF CAPE TOWN

DRAFT

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## URBAN GREENING, STUTTGART

**LOCATION:** STUTTGART, GERMANY

**COMPLETION DATE:** VARIOUS

**SCALE:** METROPOLITAN

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** VARIOUS

### 1. PROJECT OVERVIEW

Stuttgart in southwestern Germany has a population of approximately 600,000 people; the greater Stuttgart region has a population of approximately 2.6 million. Since 1993, with the introduction of the *Federal Nature Conservation Act (1993)*, the City of Stuttgart has required that all new buildings be 'greened' as compensation for the loss of valuable habitat and green space. At a city scale, the council's urban framework plans (1997, 2007) have established green spaces and green corridors in response to issues of pollution, flooding and the UHI effect.

### 2. URBAN ECOLOGY FEATURES

Stuttgart now has well-established green corridors that regulate the city's climate and air quality. 'Green ventilation corridors' not only improve air quality, they improve the resilience of the city. More than 60% of Stuttgart is green area and more than 39% is protected, the highest percentage in Germany. Planning legislation stipulates that 70% of overall plots should be green. The city has 5,000 ha of forest, with 65,000 trees in parks and 35,000 trees along streets. A programme was established in 1992 to allow residents to adopt trees which has resulted in the protection of all larger trees in the city centre. The city now has over 2 million m<sup>2</sup> of green roofs. Most of these are extensive

(i.e. shallow soil, low maintenance and limited plant species), rather than intensive (i.e. soil depth supports more plant species including trees and shrubs, requires maintenance), and they are found on all types of buildings.

### 3. CHALLENGES AND SOLUTIONS

Greening has been used to reduce pollution, manage water and reduce the UHI effect. To ensure uptake of green roofs, the city introduced a financial incentives program that provides free consultations and informative documentation on the benefits of green roofs and considerations regarding load-bearing capacity and weight, waterproofing and maintenance. The city has subsidised green roofs since 1986, meeting up to 50% of installation costs to a maximum of EUR 17.90/m<sup>2</sup> (AUD 26/m<sup>2</sup>).

### 4. LESSONS LEARNED

Stuttgart is an example of an administration and a city council acting together and agreeing on the ecological and economic benefits of green roofs. Stuttgart demonstrates how research (the 'Climate Atlas') can create strong evidence-based planning and policy frameworks. The case study also shows that the successful implementation of urban greening requires a strong legislative framework.

### WEB LINKS

<http://www.igra->

[world.com/links\\_and\\_downloads/images\\_dynamic/IGRA\\_Green\\_Roof\\_News\\_1\\_2012.pdf](http://www.igra-world.com/links_and_downloads/images_dynamic/IGRA_Green_Roof_News_1_2012.pdf)

[http://wwf.panda.org/wwf\\_news/?204461/Stuttgart-green-corridors](http://wwf.panda.org/wwf_news/?204461/Stuttgart-green-corridors)

<http://climate-adapt.eea.europa.eu/metadata/case-studies/stuttgart-combating-the-heat-island-effect-and-poor-air-quality-with-green-ventilation-corridors>

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## URBAN GREENING, PARIS

**LOCATION:** PARIS, FRANCE

**COMPLETION DATE:** VARIOUS

**SCALE:** METROPOLITAN

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** VARIOUS

### 1. PROJECT OVERVIEW

The City of Paris has encouraged various urban greening initiatives through the Paris greening program. The goals of this program, which commenced in 2007, are that, by 2020, it will have reduced the UHI effect; ensured planting on all new constructions; created 100 additional hectares of vegetated roofs and facades, 30 hectares of new green spaces and 20,000 more trees; and 200 local areas of open space will have been planted. In 2011, the City adopted the Paris Biodiversity Plan to advocate for the preservation and enhancement of nature in the city. This plan contains precise goals in terms of management practice to limit pollution and harmful effects on the environment. Urban biodiversity challenges are different to those in the Paris Climate Plan, but the planting of vegetation is a shared response.

### 2. URBAN ECOLOGY FEATURES

Like many capital cities, Paris has struggled with issues related to urban sprawl and the demand for new developments, with low land availability driving up market prices. Reinvent Paris ('Réinventer Paris') aims to encourage housing that incorporates environmental innovation, reduce energy consumption, promote a 'zero carbon' policy, take advantage of underused spaces (e.g. underground space, roofs and brownfields) for the environment, and connect people to biodiversity. The Promenade Plantée is an example of increasing urban greening in the city. This green corridor connects urban green spaces throughout Paris. Built

in the 1990s on disused elevated train tracks and the associated rail corridor, the park extends for 4.5km, starting near the Bastille. There are numerous examples of green walls and roofs throughout Paris. The Beaugrenelle shopping centre, which opened in April 2014, has 7,000m<sup>2</sup> of green roof, the largest green roof in the city. To highlight the role of bees, some 400,000 bees produce pesticide-free honey, which is sold to shoppers and all proceeds go to charity.

### 3. CHALLENGES AND SOLUTIONS

Paris faces flooding during heavy rains. The city has acknowledged the potential that green roofs and permeable surfaces have in mitigating this problem. The City of Paris is also considering how vegetation, particularly in public facilities, can address the dual challenges of cooling and biodiversity.

### 4. LESSONS LEARNED

The City of Paris has been bold in its efforts to improve the liveability of the city by encouraging citizen-led initiatives and participation and the involvement of corporations and businesses. Paris is a highly urbanised city, with significant development pressures on its land. It has found ways to enhance urban ecology by reducing pollution and supporting greening initiatives. It has also experienced a shift in design and architecture, with architects becoming more aware of the need to change models of urban planning to improve liveability.

### WEB LINKS

<http://www.reinventer.paris/en/home/>

[http://carbonn.org/uploads/tx\\_carbonndata/ParisClimateActionSheet\\_Greeningprogramme.pdf](http://carbonn.org/uploads/tx_carbonndata/ParisClimateActionSheet_Greeningprogramme.pdf)

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## ROTTERDAM'S BLUE-GREEN GRID, THE NETHERLANDS

**LOCATION:** ROTTERDAM, THE NETHERLANDS

**DATE:** SINCE 2005

**SCALE:** METROPOLITAN

**PROJECT TYPE:** VARIOUS

### 1. PROJECT OVERVIEW

Rotterdam is a long-established city and Europe's largest port (the tenth-largest in the world), with many canals and waterways traversing the city. The original port structures have been superseded by larger, containerised facilities and the city is undergoing vast economic and social change. The city centre was nearly completely destroyed in the Second World War, which has resulted in a varied, modern architectural landscape uncommon in other Dutch cities.

### 2. URBAN ECOLOGY FEATURES

Rotterdam is considered one of the 'greenest' larger cities in the Netherlands with over 1700 ha of public parks and green space covering some 19.7% of the total city surface. In 2005, the City's Green Strategy outlines a proposal for establishing two concentric green rings that would cross-link with the city's blue corridors (created by the Rotte and Schie rivers). The strategy prioritises the enhancement of connection between existing and future green spaces, creating more than 500 ha of new green spaces (much of which is used for recreation).

### 3. CHALLENGES AND SOLUTIONS

As in many industrial cities, former means of production led to urban pollution and degradation. This degradation of the urban environment is being addressed through a mix of policy and stakeholder projects aimed at increasing liveability and amenity in the city centre. There is a proactive policy to adopt more green roofs in the city and green infrastructure more generally. Another crucial challenge for the city is climatic pressure, including sea-level rise and heavy rain events. Green surfaces provide a much-needed infiltration service. Rotterdam responded to growing housing demand through a strategy of densification (i.e. building within the existing urban area) in order to preserve ecosystems and green areas.

### 4. LESSONS LEARNED

Rotterdam's planning approach sees green and blue spaces as mainly recreational areas and built elements (i.e. for their technical functionality), rather than as to urban ecosystems, which has resulted in a fragmented approach. The city's vision for urban structure has positioned green infrastructure as an integral part of the city's urban design, but the focus has come from an aesthetical rather than an ecosystem point of view.

### WEB LINKS

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3989510/>

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## STOCKHOLM'S ROYAL SEA PORT, SWEDEN

**LOCATION:** STOCKHOLM, SWEDEN  
**COMPLETION DATE:** EXPECTED 2030  
**SCALE:** DISTRICT (236 ha)

**PROJECT TYPE:** REDEVELOPMENT  
**CLIENT:** STOCKHOLM CITY COUNCIL

### 1. PROJECT OVERVIEW

The Royal Sea Port in Stockholm is undergoing substantial redevelopment as it transitions from a former industrial sea port to a highly liveable and desirable inner-city medium-to-high-density residential area.

### 2. URBAN ECOLOGY FEATURES

The completed project aims for regeneration on a large scale, creating a new environment that offers potential for urban ecology to populate the area. Some of this space uses water-sensitive sustainable urban drainage concepts to manage runoff from heavy rains.

### 3. CHALLENGES AND SOLUTIONS

High levels of pollutants have seeped into the ground and the minimal remaining green spaces require substantial remediation. The area is bordered by two parks on the north and south. The new development will create corridors to connect the two parks and enhance overall biodiversity.

### WEB LINKS

<http://www.stockholmroyalseaport.com/>

Generally, Stockholm's urban ecology is minimal. The city government and planners are implementing sustainability policies to increase green infrastructure. They are using the Green Space Index, which allows stakeholders to calculate the ratio of green space in a development, with a higher score (up to 1) indicating a higher amount of green space.

### 4. LESSONS LEARNED

A key in achieving the Royal Sea Port sustainable redevelopment has been collaboration. Close collaboration between the City's development, planning and traffic administration, the Port of Stockholm authority, the Swedish Road Administration (national authority), Stockholm Public Transport, and a leading energy company, Fortum, is helping create a sustainable and profitable urban development that addresses housing needs.

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## CITY OF MALMÖ REDEVELOPMENT

**LOCATION:** MALMÖ, SWEDEN  
**COMPLETION DATE:** VARIOUS  
**SCALE:** DISTRICT

**PROJECT TYPE:** MASTER PLANNING & DESIGN  
**CLIENT:** CITY OF MALMÖ

### 1. PROJECT OVERVIEW

Located in southern Sweden, Malmö is the third-largest city in Sweden. In the last 15 years, it has been transformed from an industrial city to a best-practice model for economically, environmentally and socially

sustainable urban development. The Green Plan for Malmö (2003) was developed to provide guidance for the protection and conservation of existing and future public green spaces. The Malmö Planning Office uses a green area ratio as a tool for

planning green spaces on private land. It also ensures that green spaces are not removed by future development.

Implementation of the Green Plan is the responsibility of Malmö's Street and Parks Department, which coordinates the design, maintenance and renewal of public green spaces.

## **2. URBAN ECOLOGY FEATURES**

The redevelopment of Malmö was implemented in stages. 'Bo01' was the first district to use a local green space factor to promote biodiversity, incorporating local vegetation, as well as rainwater collection and filtration through open stormwater management (including WSUD elements such as swales and ponds) and connection to the sea. Bo01 also implemented a Green Points system to ensure that developers incorporated site sustainability measures.

Originally built in the 1950s, the Ekostaden Augustenborg district was retrofitted with a comprehensive stormwater management system that include green infrastructure elements. The Augustenborg Botanical Roof Garden is a public-private partnership that demonstrates and researches living roof types, including extensive sedum roofs, display gardens and a special roof for endangered species. The establishment of Lindängelund Park helps enhance biodiversity by featuring a

variety of habitats across more than 100 hectares.

## **3. CHALLENGES AND SOLUTIONS**

The City of Malmö faced a number of challenges throughout the redevelopment process. A key challenge was around land use and the conflict between land use for development and green space.

Redevelopment agencies engaged local communities and developers early in the process. The City discovered that although funding can be obtained from developers, such funding is limited, and Malmö could benefit from public financing. Planning regulations allow the City to claim financial compensation from developers to design and install green spaces in new development projects, which helps in implementing the regional green space plan.

## **4. LESSONS LEARNED**

Involving local residents was one of the crucial success factors in the Augustenborg redevelopment. Strong political ambition and leadership has driven the redevelopment of Malmö, along with higher-level goals set. Collaboration within the council and with other key stakeholders such as businesses and universities has also been crucial. Malmö has used ecological development as a driving force for economic growth and social innovation.

## **WEB LINKS**

[http://www.climateactionprogramme.org/climate-leader-papers/ilmar\\_reepalu\\_mayor\\_city\\_of\\_malmoe\\_sweden](http://www.climateactionprogramme.org/climate-leader-papers/ilmar_reepalu_mayor_city_of_malmoe_sweden)

[http://www.collegepublishing.us/jgb/samples/JGB\\_V8N3\\_a02\\_Austin.pdf](http://www.collegepublishing.us/jgb/samples/JGB_V8N3_a02_Austin.pdf)

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## URBAN ECOLOGY IN SEATTLE

**LOCATION:** WASHINGTON, US

**SCALE:** DISTRICT

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** CITY OF SEATTLE

**DESIGNER:** JAMES CORNER FIELD OPERATIONS

### 1. PROJECT OVERVIEW

The City of Seattle has introduced a range of urban greening plans and initiatives. The 2007 Urban Forest Management 30-year Plan outlined a series of steps that the City of Seattle should take to encourage tree preservation and planting across the city, such as improving tree care on City property, enhancing community outreach, and strengthening incentives and regulations during development.

In 2013, the Urban Forest Stewardship Plan was adopted by Council to provide a long-term vision for increasing the city's tree-canopy cover, building on the Urban Forest Management Plan.

Waterfront Seattle is a multiyear program to rebuild Seattle's waterfront after removal of the Alaskan Way Viaduct. Sustainable strategies were developed to improve the urban waterfront ecologically, environmentally, economically and socially. It involves upgrades to parks and a new seawall.

### 2. URBAN ECOLOGY FEATURES

The City of Seattle's Stormwater Code requires projects to implement onsite stormwater best management practices, including green stormwater infrastructure. The council has established a number of public engagement and education programs, including 'ReLeaf', the Green Seattle Partnership (similar to Landcare in Australia), tree ambassador programs and traffic circle volunteers.

The new Elliot Bay Seawall replaces the existing seawall to protect critical

infrastructure and utilities while enhancing habitat in the area. The design is based on scientific evidence on marine ecosystems and the built environment (e.g. creating light wells for juvenile salmon migration and adding fins to seawalls to enhance the abundance and richness of invertebrates).

### 3. CHALLENGES AND SOLUTIONS

The waterfront site is highly contested. There are issues of contamination, multiple public and private landowners, access and circulation, and operations management. In-depth negotiations between public and private landowners were required to ensure the support of all stakeholders.

The City of Seattle acknowledges that the majority of Seattle's urban forest is on private property. Therefore, public appreciation of the benefits of and need for trees, engagement in planning and policy development, and knowledge of tree planting and care are essential for the long-term health of this important asset.

### 4. LESSONS LEARNED

Although the project is yet to be completed, the Elliot Bay Seawall demonstrates innovative seawall design and construction. The design of habitat enhancements on the seawall (fins) is a scaling up of smaller-scale pilot studies that demonstrated considerable ecological benefits of adding such habitat complexity to seawalls. The project possibly represents the largest-scale habitat enhancement of seawalls ever undertaken. The project has a strong focus on aesthetics (given the highly public nature

of the space) as well as ecological values. It also demonstrates the importance and

potential of community consultation in ensuring successful project outcomes.

#### WEB LINKS

<http://waterfrontseattle.org/>  
<http://www.seattle.gov/trees/>

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## URBAN GREENING, PORTLAND

**LOCATION:** OREGON, US

**COMPLETION DATE:** ONGOING

**SCALE:** METROPOLITAN

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** CITY OF OREGON

### 1. PROJECT OVERVIEW

Portland, in northwestern US, is the largest city in Oregon, with a population of about 630,000 people. In the early 1970s, Oregon adopted a state-wide land-use policy to restrict urban sprawl by establishing urban growth boundaries. This has encouraged cities such as Portland to develop urban neighbourhoods more densely while conserving remnant green space.

### 2. URBAN ECOLOGY FEATURES

Portland's Ecoroof Incentive Program was introduced in 1996 with the aim of improving sustainable stormwater management, supporting the municipality in promoting green roofs, and providing additional benefits to habitat and biodiversity. Ecoroofs can reduce stormwater fees if properties can manage stormwater on location. In 2008, the City of Portland started the Grey to Green initiative to expand stormwater management techniques that mimic natural systems, protect and restore natural areas, and improve catchment health. The initiative included land acquisition, green streets, ecoroofs, street and yard trees, replacing culverts, revegetation and invasive weed control.

### 3. CHALLENGES AND SOLUTIONS

Funding for the Ecoroof program has come from local and state public agencies, which are also in charge of implementing and managing the initiatives and programs. To encourage uptake of Ecoroofs, the city embedded incentives into its planning regulations. The City's Central City Plan District has a set of floor-area ratio development bonuses whereby Ecoroofs that meet requirements grant a larger development footprint or additional floor area than the City's zoning provisions and guidelines allow.

To further support green infrastructure and provide a robust evidence base, the City of Portland published, in February 2010, a report quantifying the ecosystem benefits of green infrastructure, with a focus on social and economic benefits. Coupled with flow management analyses, the report has become part of infrastructure decision-making considerations.

### 4. LESSONS LEARNED

The Portland experience shows the importance of sustained engagement with urban greening. The City's programs have evolved over time, and they have used a range of approaches focused on public and private infrastructure using regulation, education and incentives. The City has also sought to change the behaviours of

residents by providing supportive

infrastructure.

#### WEB LINKS

<http://www.urbangreenbluegrids.com/projects/portland-oregon-us/>

<https://www.portlandoregon.gov/bes/47203/>

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## URBAN GREENING VISION, SINGAPORE

**LOCATION:** SINGAPORE, SINGAPORE

**SCALE:** METROPOLITAN

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** SINGAPORE GOVERNMENT

### 1. PROJECT OVERVIEW

Singapore is a compact, high-rise, high-density city with a high level of infrastructural and industrial development in a tropical climate. It is one of the world's most densely populated countries, with about 5.5 million people living on 697 km<sup>2</sup>, and area 17 times smaller than Sydney.

Urban greening has been a key part of the government's plan for Singapore since 1968, when the country's founding prime minister, Lee Kuan Yew, announced his vision centred around the idea that Singapore would not be a 'concrete jungle' but a 'garden city' with the aim of attracting foreign investment and increasing liveability. This reflects the issues facing the city in terms of land scarcity, water shortages and energy generation. The first Green Plan, produced in 1992, aimed to strengthen performance in being 'Clean and Green'. The Green Plan 2020 goes beyond Clean and Green, focusing on the sustainability of the Singapore development process, especially in providing a quality environment while pursuing economic progress.

### 2. URBAN ECOLOGY FEATURES

Sustainable water management plays an important role in driving Singapore's urban ecology. Singapore is working towards becoming water-independent to end its

reliance on Malaysia for its water supply. Singapore's central catchment, which consists of rainforest, streams and lakes interconnected by overgrown canals, can supply freshwater. Strict regulations prohibit hunting and fishing, and wildlife – including aquatic and terrestrial wildlife such as otters, pythons, monitor lizards, pangolins and hornbills – is prevalent.

Given the density of the urban form and the strong demands on land, the city has encouraged vertical greening. There are many examples of green roofs and walls throughout the city. The Punggol Waterway Terraces is an example of an eco-friendly high-rise complex. It is significant for its integrative response to local climatic conditions and urban greening.

### 3. CHALLENGES AND SOLUTIONS

One of the main challenges for Singapore is the limited availability of land and the large population. This has led to a highly dense city and innovative approaches to urban greening via rooftops and walls. Various incentive programs help implement the city-state's garden city vision. In 2009, the government introduced an incentive scheme called the Skyrise Greenery Incentive Scheme to help implement its urban greening policies. The goal of this scheme is reaching 50 ha of new skyrise greenery areas by 2030. The

Skyrise Greenery Incentive Scheme finances up to 50% of green roof and green wall installation costs. Since its introduction the scheme has assisted in greening more than 110 existing buildings by retrofitting them with extensive green roofs, edible gardens, recreational rooftop gardens, and green walls.

In 2009, the Urban Redevelopment Authority introduced the Landscaping for Urban Spaces and High-Rises program, which aims to consolidate existing and new green initiatives and encourage more skyrise greenery in private developments. The program encourages building owners and developers to provide well-designed communal green spaces at the ground level and upper levels of buildings, such as sky terraces.

The Green Mark 2015 was released in 2015 to provide a platform for the recognition

and mainstreaming high-performance green buildings. To further encourage urban greening, NParks' Streetscape Greenery Master Plan provides a blueprint for optimising available green space along roads for landscape treatment. It sets out planning and design guidelines for maximising the landscaping of streets for variety and character.

#### 4. LESSONS LEARNED

Political drive has played an important role in Singapore, demonstrating the power of a clear vision backed by effective urban planning policies and a supporting legal framework, along with effective governance. The development of institutions to operationalise greening policies has supported Singapore's goal to become a garden city. The integration of urban biodiversity into these initiatives are minimal, however, with most having an anthropogenic focus.

#### WEB LINKS

<http://blog.conservation.org/2015/01/urban-jungle-singapore-leads-the-way-on-green-space/>  
<https://www.ura.gov.sg/uol/circulars/2014/jun/dc14->

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## QUNLI STORMWATER WETLAND PARK, HARBIN

**LOCATION:** HEILONGJIANG PROVINCE, CHINA

**COMPLETION DATE:** 2010

**SCALE:** SITE (34 ha)

**PROJECT TYPE:** URBAN PLANNING & DESIGN

**CLIENT:** THE MUNICIPAL GOVERNMENT OF HARBIN CITY

**DESIGNER:** TURENSCAPE

### 1. PROJECT OVERVIEW

Heilongjiang Province is in far northeastern China, bordering Russia. Harbin, in the south of the province, is the most populated city in the region and the eighth most-populated Chinese city. Qunli Park is a 34-ha park in the centre of the new city, Qunli New Town. This new development is expected to house more than 330,000 residents. Land in Qunli New Town was reserved for a public park, but it contained a wetland

listed as a protected regional wetland. Through a careful design approach, Turenscape designed a park that focuses design interventions on the outer edge of the site, allowing views into and across the wetland while maintaining the area's ecosystem functioning.

### 2. URBAN ECOLOGY FEATURES

The Qunli Stormwater Park addresses issues of urban stormwater management through the creation of a 'stormwater

park', which provides ecosystem services as well as recreational benefits for the citizens of Harbin City. The park acts as a sponge, capturing, absorbing, cleansing and filtering urban water to provide benefits such as the protection of native habitats, aquifer recharge, recreational use and mental health benefits. The wetland also provides habitat for local fauna, including birds and fish. Birdlife has increased at the site, with locals reporting seeing 20 new species of bird using the wetlands.

### **3. CHALLENGES AND SOLUTIONS**

One of the main challenges with this project was related to urban water management. The city experiences heavy rainfall each year between June and August, when it faces flooding challenges. The area was also known to have a highly variable groundwater system, with issues of waterlogging and groundwater table depletion. The design of the park turned a problem into a positive by creating a place for water to be collected and filtered through the ground. Stormwater is now an asset that helps the ecological functioning of the wetland. A key design challenge was to preserve a disappearing wetland in the middle of the city when its ecological and biological processes have been cut off by the urban context. To achieve this, the designers created a series of ponds and mounds surrounding the former wetland using cut-and-fill to create a stormwater filtering and cleansing buffer zone for the

core wetland. Stormwater from the newly built urban area is collected into a pipe around the edge of the wetland and released evenly into the wetland after filtering through the ponds. Native wetland grasses and meadows are grown in the ponds, which are of various depths. The mounds and their tree plantings also serve as organic screens between nature and the urban sprawl.

The park was the site of a protected regional wetland. The landscape architects designed platforms and skywalks on the outer edge of the park to provide the community with views into and across the wetland while limiting access into the centre of the park. In this way, fauna is undisturbed by human encroachment.

### **4. LESSONS LEARNED**

The Qunli Stormwater Park demonstrates the use of landscape architecture and environmental restoration to re-establish wetlands in an urban context. The park's ecosystem services enhance Harbin city's water-resilience and provide co-benefits for urban biodiversity and a green space for recreation. After the completion of the park project, the site was listed as a national wetland park. Its significance has increased and it has been recognised as nationally important. The park has also increased the value of local properties, with real estate values doubling since the completion of the park.

#### **WEB LINKS**

<http://www.archdaily.com/446025/qunli-stormwater-wetland-park-turenscape/52799ca2e8e44e8654000095-qunli-stormwater-wetland-park-turenscape-design-concept>  
[http://www.un.org/waterforlifedecade/waterforlifevoices/cases\\_qunli\\_china.shtml](http://www.un.org/waterforlifedecade/waterforlifevoices/cases_qunli_china.shtml)

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## 'LIGHTS OUT TORONTO!', TORONTO

**LOCATION:** TORONTO, CANADA

**COMPLETION DATE:** ONGOING

**SCALE:** METROPOLITAN

**PROJECT TYPE:** AWARENESS PROGRAM

**COLLABORATION:** THE CITY OF

TORONTO, FATAL LIGHT AWARENESS

PROGRAM & BUILDING OWNERS AND

MANAGERS ASSOCIATION

almost all new developments in the city incorporate bird-friendly elements, making it the first city to mandate bird-friendly planning standards.

### 1. PROJECT OVERVIEW

The 'Lights Out Toronto!' initiative (or 'LOT!' for short), initiated in April 2006, encourages home and commercial occupiers to turn out their lights at night, in response to the large number of birds that were flying into buildings at night and killing or injuring themselves. Commercial owners and occupiers in particular are encouraged to turn out lights when they leave the premises. A co-benefit is perceived to be a reduction in energy use and associated greenhouse gas emissions.

### 2. URBAN ECOLOGY FEATURES

The initiative aims to promote bird conservation, especially during the migration season. LOT! is part of Toronto's migratory bird protection policies, including the Bird-Friendly Development Guidelines, for which Toronto's City Planning department received an Excellence in Planning Award in 2008.

In 2010, Toronto launched the Toronto Green Standard, which requires that

### 3. CHALLENGES AND SOLUTIONS

A challenge in assessing the success of such initiatives is gathering data. The Fatal Light Awareness Program (FLAP), one of the leading organisations to have collaborated on LOT!, has made a 'FLAP Mapper' available for individuals to record bird collisions in real time. In so doing, they have developed an accurate database of bird collision statistics across Canada, providing an evidence base and raising awareness.

### 4. LESSONS LEARNED

Details on the success of LOT! are unavailable, but the initiative shows how people can act to reduce injuries to city wildlife, raise awareness in the community, and make them proactive participants in urban ecosystem protection.

### WEB LINKS

<http://www.flap.org/toronto-lights-out.php>

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## THE CITY OF CAPE TOWN BIOREGIONAL PLAN

**LOCATION:** CAPE TOWN, SOUTH AFRICA

**SCALE:** METROPOLITAN

**CLIENT:** THE CITY OF CAPE TOWN

**PROJECT TYPE:** URBAN PLANNING & STRATEGY

### 1. PROJECT OVERVIEW

Cape Town's 2001 Integrated Metropolitan Environmental Policy informs all of the city's conservation policies and has led to the creation of the Biodiversity Strategy and the Local Biodiversity Strategy and Action Plan.

Cape Town has been approved as a 'bioregion', allowing for bioregional planning. The Cape Town Bioregional Plan was adopted in 2015 to provide guidance in planning and management decisions affecting biodiversity.

### 2. URBAN ECOLOGY FEATURES

The Bioregional Plan includes a map of biodiversity priorities (BioNet) and guidelines for land-use planning and decision-making. Critical biodiversity areas (CBAs) have been mapped as requiring conservation to ensure the long-term survival of remnant natural areas.

The Cape Town Spatial Development Framework aims to manage and control urban growth. The framework explicitly states the need to 'increase efforts to protect and enhance biodiversity networks at all levels of government'. It also acts as a guide on the need for careful assessment of the impacts of proposed developments on CBAs and endangered species. The Framework includes coastlines and urban edges that will support the preservation of urban biodiversity.

### 3. CHALLENGES AND SOLUTIONS

The direct threats to biodiversity in the bioregion were identified as ranging

from climate change to altered hydrology, pollution, overexploitation of resources (e.g. overgrazing and unsustainable harvesting), urban development and habitat fragmentation.

Growth in urban areas has led to the conversion of habitat at a rapid rate that could see up to 12% of the Cape Town Municipality natural areas lost by 2020. The CBAs are essential for reducing the loss of these natural areas.

As a member of Local Action for Biodiversity, the City of Cape Town benefits from a program that is exploring best practices in engaging local governments on urban biodiversity conservation and enhancements, as well as on management and land use.

Urbanisation has led to the canalisation or channelisation of most rivers and the drainage of most wetlands on the Cape Flats. In some cases, seasonal wetlands were made permanent, resulting in a loss of seasonal habitat for fauna. In 2008, a consulting group completed the City Wetlands Map based on a desktop spatial wetlands layer (mostly by assessing aerial photography and some field verification). A 2009 report was used to outline priority wetlands, which in turn were classified as CBAs.

### 4. LESSONS LEARNED

As in many urban centres, major land-use and resource-use pressures are key threats to urban biodiversity. Cape Town associates high immigration rates with inappropriate development (urban

sprawl), which encroaches on remaining biodiversity in the Cape Town bioregion.

Strong collaboration with national and provincial conservation stakeholders has been key in implementing the innovative measures put in place in the Cape Town municipality.

The incorporation of a systematic biodiversity plan into spatial development plans has proved to be a good spatial planning procedure for minimising urban development conflicts and for giving priority to the

implementation of conservation measures.

The Stewardship Programme, a voluntary conservation initiative on private lands identified as conservation priorities, has shown good results. Creating a relationship with landowners and informing them of the ecological significance of their lands and potential access to financial and other conservation incentives enables parties to enter into an agreement; alternatively, the land is marked as a site for land acquisition.

#### **WEB LINKS**

<http://www.capetown.gov.za/Explore%20and%20enjoy/nature-and-outdoors/Be-an-eco-tourist/Our-conservation-strategies-and-plans>  
[http://resource.capetown.gov.za/documentcentre/Documents/City%20strategies%2c%20plans%20and%20frameworks/Biodiversity\\_Strategy.pdf](http://resource.capetown.gov.za/documentcentre/Documents/City%20strategies%2c%20plans%20and%20frameworks/Biodiversity_Strategy.pdf)  
[http://resource.capetown.gov.za/documentcentre/Documents/Bylaws%20and%20policies/Bioregional\\_Plan\\_CCT\\_FINAL\\_2015-08-19\\_policy\\_number\\_44854.pdf](http://resource.capetown.gov.za/documentcentre/Documents/Bylaws%20and%20policies/Bioregional_Plan_CCT_FINAL_2015-08-19_policy_number_44854.pdf)  
<http://www.ecologyandsociety.org/vol17/iss2/art28/#threats>

## 7 DISCUSSION

There are many drivers of biodiversity loss in cities (e.g. Zari, 2014), such as the removal of habitat, increased disturbance, invasive species and the pollution of land, air and waterways. Climate change and the associated impacts of extreme weather events, a warming climate and sea-level rise, will add to the pressure on biodiversity. Biodiversity loss is the outcome of a combination of past and present laws and policies of government and the collective actions of residents, industry and government agencies. The management of biodiversity, therefore, is a political, economic, social and environmental issue.

Ecosystem services play vital and interconnected roles in supporting socioeconomic functions and makes cities liveable (Tzoulas, Korpela, Venn, Yli-Pelkonen & Kaźmierczak *et al.*, 2007; Taylor & Hochuli, 2015; Parris, 2016). For urban biodiversity to be properly valued and sustained, there is a need to transform how city residents connect with the natural environment.

Reducing the incremental loss in biodiversity, or its 'death by a thousand cuts' (Bradsen, 1992; Laurance, 2010), and ultimately improve the ecology of cities requires multidimensional approaches. These need to be framed around four areas: 1) engaging and coordinating at multiple spatial and temporal scales; 2) addressing the functional needs of the natural environment; 3) adjusting the socio-ecological-economic-political systems; and 4) influencing the operational decision-making and actions of individuals and institutions.

Understanding is limited of the governance practices influencing urban biodiversity outcomes. Complex and interrelated approaches and drivers adversely affect urban ecological outcomes (Lawlor *et al.*, 2006). A coordinated and consistent approach is needed that addresses the drivers of biodiversity loss; makes use of various approaches (e.g. short-and long-term planning, laws, policies, regulation, incentives and education); monitors the urban and natural environment; reviews the efficacy of approaches; identifies current and emerging threats and opportunities; and develops new, adaptive approaches to arrest biodiversity loss and enhance liveability (**Figure 7.1**). Such an approach must consider ecological and human needs, reflecting that cities are modified systems and that there is an inherent connection between natural and human systems, even if ecological services are not yet fully valued in decision-making processes.

The protection and management of biodiversity as a focal point of policies, laws and practices has proved an unsuccessful mechanism for arresting biodiversity loss in cities. The complexity of cities in both form and interactions requires a new approach. City planning and day-to-day decision-making can better incorporate urban ecology using a decision-making prism that places liveability, sustainability and resilience as central tenets rather than a reductionist view that economic and biodiversity outcomes are conflicting. To this end, planning and decision-making must recognise the following:

- Urban population growth will continue to increase, as reflected in forward metropolitan and district plans. In Sydney, for example, the population is expected to increase by 1.6 million people by 2034, with 900,000 of this population growth occurring in western Sydney (NSW Department of Planning and Environment, 2014).
- Urban sprawl, or greenfield development, is an important strategy for housing people and industry. This is particularly true for peri-urban areas in the South Creek catchment across much of southwest and northwest Sydney.

- The development of new suburbs will result in the further loss of habitat, despite existing mechanisms for protecting endangered ecological communities such as the Cumberland Plain woodland.
- Urban consolidation offers opportunities associated with a compact and liveable city but also intensifies land use and can reduce the area of green space and biodiversity within the city. Urban planning and the management of public and private land must, therefore, consider how to maximise urban ecological outcomes through the integrated management of road corridors, parks, reserves, backyards and other green spaces, such as in the Sydney Green Grid.
- The natural environment provides a wide range of ecosystem services and increases the resilience of a city. For example, vegetation can improve air quality, reduce the impacts of the UHI effect, and sequester carbon while also providing habitat for wildlife.
- Urban green spaces provide places for recreation, social gatherings, rest and relaxation. Many studies show that green spaces improve physical, social and mental health and can have a positive impact on property values.

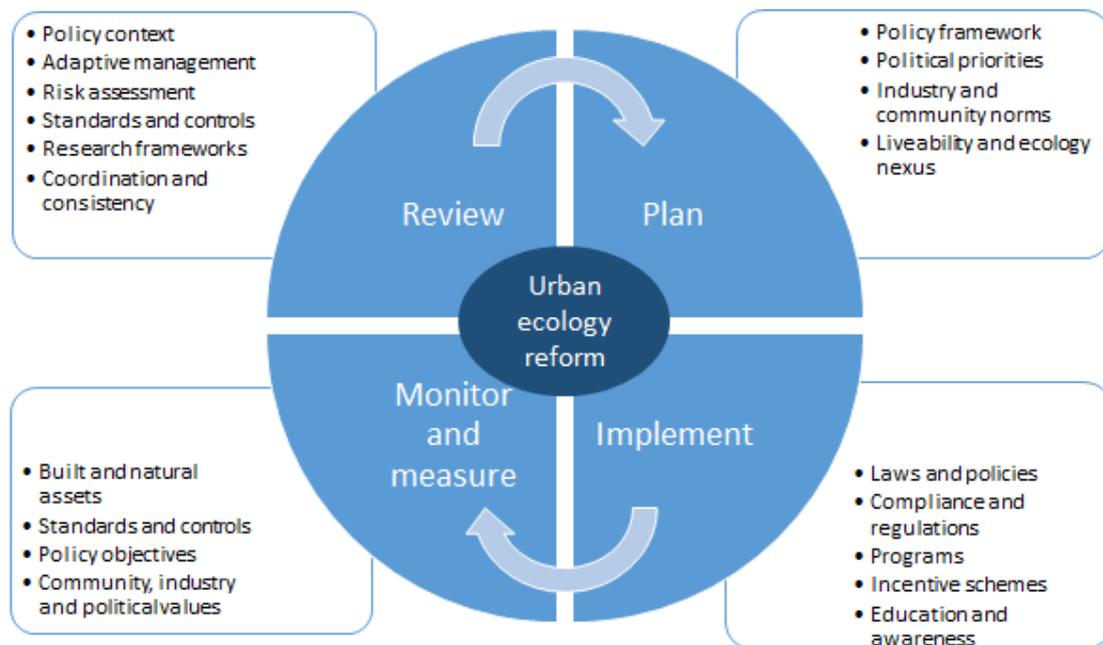


Figure 7.1. Conceptual diagram demonstrating the process of urban ecology reform.

Below, we draw on the information gathered in this desktop review to discuss how cities can better integrate urban ecology into their current infrastructure in incremental and transformative ways. First, we discuss the loss of nature in cities and the need to connect humans with nature. Second, we review the policies and laws that now govern urban ecological renewal. Third, we present spatial and temporal considerations for future planning. Finally, we provide key recommendations.

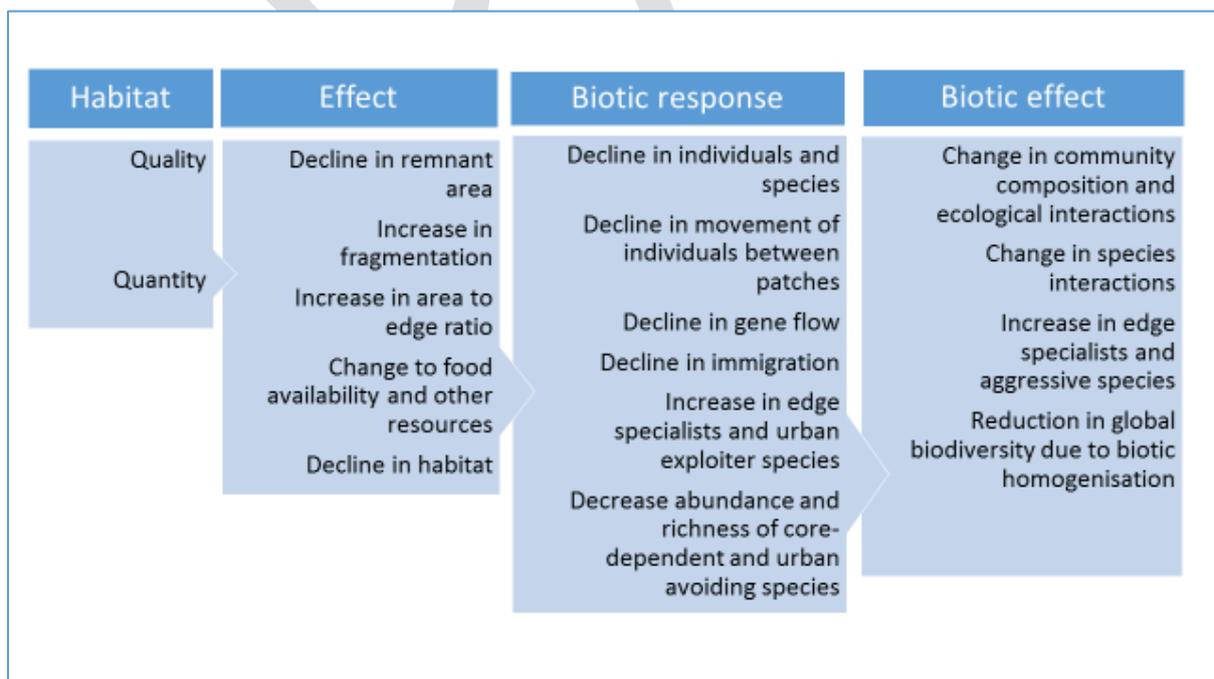
## 7.1 The loss of urban nature in cities

The urban matrix is a heterogeneous landscape made up of a mosaic of land uses, all of which differ in their capacity to support biodiversity (Wu, 2014). Even within a land-use type, there can be considerable variation in the capacity to provide habitat for biodiversity. For example, residential

gardens can differ substantially in the biodiversity they can support based on the resources – for example, food, shelter and water – they make available for wildlife.

The capacity of urban landscapes to support biodiversity is determined by the area of conserved natural areas (Primack, 2010) and their relationships with other habitats (Fahrig, 2003), how species relate to urban habitats (McDonnell & Hahs, 2015), the ways in which sites are valued and managed (McDonald *et al.*, 2016), the legislative and regulatory systems, and strategic policy and planning (Ives *et al.*, 2010; Soga *et al.*, 2014). For example, it is known that perceptions of nature significantly influence urban ecological outcomes, and these can be influenced by cultural backgrounds and personal experiences and values, among other factors. Trees in urban areas are valued and planted by some and actively removed by others; the latter may reflect concern about the damage trees may do to private and public property in storms and the ‘mess’ caused by leaf and bark litter. But trees also provide significant ecosystem services, including cooling on hot days, and their aesthetic appeal can add to property values. Preferences for ‘neat and tidy’ gardens and town centres, often referencing English-style cottage gardens and formal city squares, can favour exotic plant and animal species rather than the original native species. A fear of nature (e.g. as embodied by spiders and snakes) can also drive declines in urban ecosystems by influencing the landscaping and management of public and private places.

Values are important because they help in setting policies and laws and, in turn, decision-making at the political, institutional and personal levels. For cities such as Sydney, Wollongong and Newcastle, economic growth and housing supply have long been the dominant metrics shaping the way in which the cities have grown. This is seen in the priority given to infill versus greenfield development and the way in which urban ecosystems are considered and weighted in strategic and development assessment processes. As discussed in Chapter 4 and summarised in **Figure 7.2**, increasing urbanisation has long been directly related to declines in habitat quantity and quality, thereby driving a range of adverse biotic outcomes.



**Figure 7.2.** Trends in responses of biodiversity to urbanisation.

The loss of nature in cities is becoming recognised as an undesirable outcome of past and current city planning and construction. As urban densities increase and backyards become smaller or non-existent, residents are placing greater value on and a desire to interact with green spaces. This may reflect an instinctive realisation of the benefits of green spaces for health and wellbeing (Chapter 5) and, more broadly, a desire for a liveable city not captured in the traditional metrics of housing supply (dwellings per year) and housing type. Although green spaces do not necessarily deliver better ecological outcomes, there is indisputable, long-standing evidence connecting the value of urban green spaces with health and wellbeing (chapters 3 and 5), and this should not be ignored. The presence of trees around homes and along streets has been shown to reduce indoor air temperature and protect residents from heat stress in extended heat events (Norton *et al.*, 2015; Pitman & Ely, 2015). The presence of street trees has been linked to improved health outcomes for the elderly because it promotes activities such as walking and cycling. In addition to the physical health benefits of green spaces, benefits for mental health (e.g. reduced anxiety, stress and depression) and community wellbeing (e.g. social cohesion) have all been tied to the presence of green spaces and associated increased human interactions, as indicated by the strong support for community-based regeneration programs such as Bushcare.

At the lot-to-city scale, there is growing recognition of the need to reposition and place greater priority on urban ecology. Participatory involvement in, and social connections with, urban ecosystems are increasing, and community participation is a mandatory requirement in many government planning strategies and plans. Community-driven and government-supported initiatives such as the 'Swim in Parramatta River by 2025' provide aspirational motivation for environmental protection and management within an explicitly anthropocentric framework (for example, linking environmental outcomes, such as swimming in a river, with saving an 'iconic' Australian species), while also having strong conservation potential. The Bioblitz program in the Melbourne City Council's Urban Forestry Plan encourages citizen science and invites the public to visit parks and help with biodiversity surveys. As noted in the review of existing laws and policies (Chapter 4), a strong platform already exists for prioritising urban ecology in decision-making.

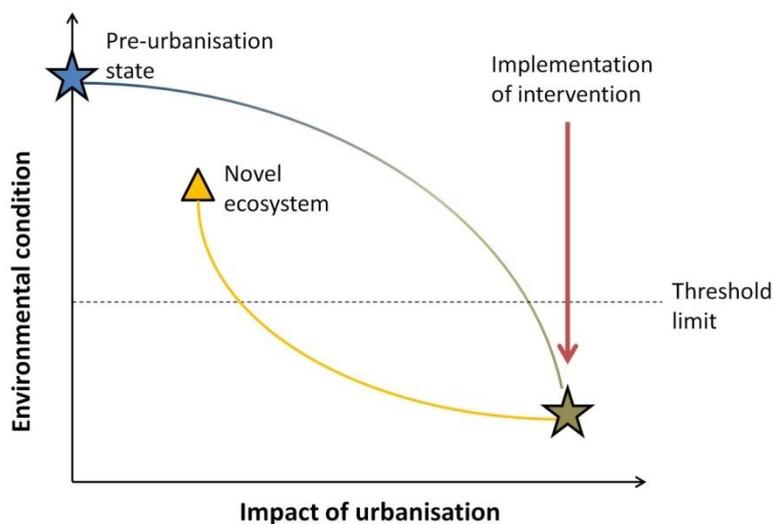
The processes in place, and those making decisions, have been unable to effectively 'balance' the environmental, social and economic impacts of development proposals to arrest the ongoing decline of urban biodiversity. This is despite a clear and inclusive definition of ecologically sustainable development (see the *Protection of the Environment Operations Act*, s 6(2)) and references to this in the objects of many NSW laws that inform how land and water resources are to be used and managed. A re-think is needed, along with changes to decision-making processes. Greater emphasis must be placed on the value of urban ecosystems and creating a liveable city (Cilliers *et al.*, 2015), rather than a narrow focus on the immediate cost of development. The evidence suggests that a strategic land-use approach supported by mandatory, performance-based controls are likely to result in better urban ecological outcomes and provide the development sector (including government agencies) with certainty.

Changing business-as-usual planning, design, construction and maintenance can be enabled by promoting examples of best (or better) practices. Many examples exist internationally, Australia-wide and in Sydney, Wollongong and Newcastle of high-quality, innovative urban ecology projects, policies, procedures and practices. To a large extent, however, such efforts have been unable to transition to the mainstream and therefore have been unable to achieve broader impacts in improving urban ecological outcomes. This lack of broad impact is due to many underlying factors best summarised in the literature as 'path dependence' – simply, a reluctance to change. If business-as-usual approaches are to change, it is essential to address causes, barriers and other obstacles

from multiple perspectives (e.g. planning, design, construction and maintenance); through multiple actors (e.g. government, industry and community); and at multiple scales (lot-to-city and in the short to long terms).

Best (or better) practices need to be encouraged and supported across multiple dimensions (e.g. perspectives, actors and scales) and underpinned by robust and transparent monitoring and evaluation frameworks.

It is crucial to recognise that cities are highly modified landscapes. An objective of returning the environment to a pre-development condition is unrealistic, therefore, and likely to result in policy failure, which, in turn, would risk future political and public capital and resources. Rather, urban ecology can be directed towards creating new or novel ecosystems that improve ecological outcomes and integrate ecosystems within city landscapes (**Figure 7.3**).



**Figure 7.3.** Different impacts of implementation of an urban ecology renewal intervention. The blue star represents the environmental condition of an ecosystem before urbanisation (i.e. pre-urbanisation state). The brown star represents the degraded environmental condition of an ecosystem at the point where the intervention is implemented. The blue/brown line represents the trajectory of the environmental condition decline in the ecosystem as the impacts of urbanisation increase. For many cities or parts therein, the environmental condition has passed the threshold limit. Where the degradation of environmental condition in an ecosystem exceeds the threshold limit, interventions should use rehabilitation (yellow line) to improve the environmental condition of an ecosystem, while acknowledging that the ecosystem will never return to a pre-urbanisation state and accepting the emergence of a novel ecosystem that may not reflect the pre-urbanisation state (after McDonald *et al.*, 2016).

International and other examples of best practices should be used as evidence for reducing the impact of urbanisation on the environment, supported by local case studies that the community, industry and politicians can see directly and learn from. In turn, this will provide the confidence and evidence needed for an ecological transition.

## 7.2 Biodiversity governance

Urban ecological outcomes and biodiversity are deeply affected by the business-as-usual practices and traditions of the many actors involved in city planning, infrastructure provision, building and construction, regulation and residents. The interactions between these actors are highly complex

and subject to formal (laws and policies) and informal (practices) rules and behaviours. Within and between those government agencies and utilities with ecologically sustainable development as an objective in their governing laws, there are vast differences in processes, procedures and behaviours. Such differences mean considerable inconsistency in approaches, which manifest in the continued loss of urban biodiversity – to the frustration of many individuals in government agencies, industry and the community who are sufficiently motivated, interested and even empowered to protect and manage natural ecosystems in cities.

There exist multiple biodiversity governance structures (e.g. Buizer *et al.*, 2015; Hansen *et al.*, 2016), which operate across spatial (e.g. local, district and metropolitan planning), organisational (e.g. internal decision-making processes) and functional (e.g. planning, transport and utilities) scales. Understanding in this area is extremely poor and research is lacking, which may account for the low priority given to biodiversity conservation and management in NSW.

The political desire for reforms that place more value on and enforce urban ecology in cities is unknown, and the decision-making processes that would lead to such reforms are opaque. Accountability and (tied to this) the metrics for tracking and reporting on changes in the condition of urban ecosystems is, at best, inconsistent and arguably is lacking in a vertically meaningful way.

Term-of-government reporting and annual reports by agencies and government departments, including councils, offer mechanisms for taking account of strategic and operational performance. Presently, these mechanisms have no direct link to urban ecology, and nor are there robust targets or monitoring and evaluation processes.

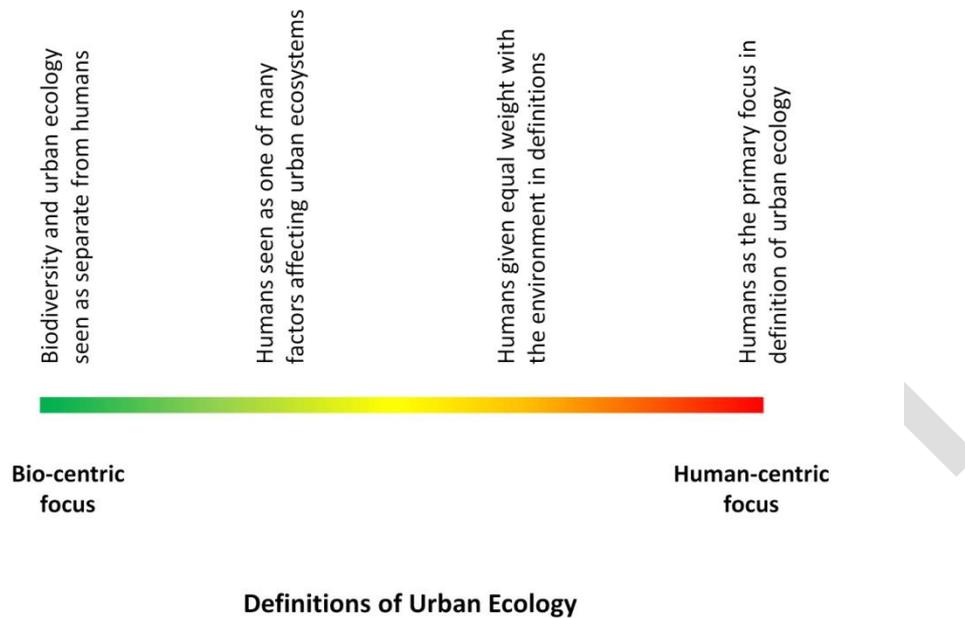
The way in which urban biodiversity is prioritized and financed requires detailed examination, too. A range of mechanisms is available to government, such as direct budget allocations from treasury (for state agencies), rates (local government), grants, development agreements and related schemes such as development contribution systems (EP&A Act, s 94). The conditions that determine what such funding streams can and cannot fund are variable, however, and often tied to organisational determinations of what are core and non-core activities and whether a service or capital expenditure can be ‘cost shifted’ within an organisation or to another. These aspects underscore the need to first understand existing decision-making processes and then provide clear guidelines on the best mechanisms for protecting and managing urban ecosystems.

### **7.3 The challenges of protecting urban nature through policy and planning**

Science can play a vital role in informing environmental policy and restoring or renewing urban nature. The degree to which scientific evidence can influence legislation, policies, values and behaviours on conserving and managing urban ecosystems depends on many factors, including the interests, motivations and commitment of governments and others in the community.

Research is showing that biodiversity provides societies with significant benefits; this is captured in the way in which urban ecology is defined from eco-centric and human-centric perspectives (**Figure 7.4**). Although the term ‘environment’ is defined in the EP&A Act as an anthropocentric concept incorporating both natural and built components (s 4), a critique of biodiversity planning suggests that it has focused too heavily at the eco-centric end and has not incorporated, or has been unwilling to incorporate, more human-centric elements. International studies demonstrate a positive relationship between a street lined with canopy trees and higher lot-based property values (and a similar relationship between the proximity of a property to a park and its value), but these benefits are not factored into ‘environmental’ support in undertaking strategic or neighbourhood

planning and design or even in the way in which maintenance practices are undertaken. Locally based research on the socioeconomic advantages of urban ecological outcomes is needed, therefore, to shift towards a more human-centric connection to nature to complement the intrinsic value of nature, as reflected in the current eco-centric focus.



**Figure 7.4** The spectrum of definitions of urban ecology.

### Environmental planning and regulation

Cities are environmental and developmental planning conundrums for governments. Although ecologically sustainable development is defined and required by planning and environmental laws in NSW, there is ample evidence that economic drivers such as jobs, infrastructure and housing approvals are given greater priority in the strategic shaping of cities (such as in A Plan for Growing Sydney) and in development approval processes. Where infrastructure is considered ‘critical’ or development ‘significant’, assessments are not bound by controls otherwise embedded in environmental planning instruments (as can occur in the Exempt and Complying Development SEPP and the State Infrastructure SEPP).

The cumulative watering down of regulations designed to protect remnant bushland and riparian areas in recent years has meant increases in the clearing of habitats in both greenfield and infill development (e.g. Davies *et al.*, 2011; Ives & Kelly, 2016). This has culminated in the socialised loss of urban biodiversity, with land development profits privatized and accrued by landowners, developers, industry and sometimes government. Where biodiversity and urban water management controls have been applied, they have typically focused on the lot or subdivision under investigation and not on how the development will integrate with adjacent parks and reserves or the terrestrial or aquatic landscape.

Changing provisions in the EP&A Act and developing subordinate environmental planning instruments and associated laws that require more than just ‘consideration of’ or ‘having regard to’

the environmental consequences would be the first of many steps necessary for ensuring that development outcomes support urban ecological outcomes. There is a precedent in NSW to require mandatory consideration of the environment and subsequent development controls to protect it. The 'neutral and beneficial effect' test is applied to new developments in Sydney's drinking-water catchments through the SEPP (Drinking Water Catchment) 2011, combined with a special provision in the EP&A Act (s 34B). In Western Australia, strategic-level attention to the natural environment is incorporated in the metropolitan planning of the city of Perth and the region of Peel, which recognises that 'good urban growth management should be applied to the planning of new areas to reduce any negative impacts on water resources; to avoid the loss of a sense of place; and to protect our natural habitats ...' (Western Australian Planning Commission, 2010, p. 5). The role of the GSC in developing statutory-based strategic plans may enable stronger and mandatory consideration of its sustainability and liveability principles (Chapter 4). Legal reforms could also be more direct – for example by replacing 'should consider' with 'must apply' in relevant policies.

In recent years there has been a general trend in environmental and planning law to reduce the regulatory burden on industry, households and government agencies (e.g. Lawlor *et al.*, 2006; Choi & McIlrath, 2016; Josh Byrne & Associates, 2016). This is achieved through a move from a merit-based approach to development assessment to market-, performance-, code- or design-based approaches. Examples include BioBanking and bio-certification (market), the Building and Sustainability Index (performance), exempt and complying development (code) and bushfire protection (design). For biodiversity, BioBanking and related schemes can set protection and maintenance obligations through property titles and formal agreements, but they are selective in their application (for example focusing on endangered ecological communities or critical habitats) by placing a monetary value on land if it passes an ecological significance test. Such schemes are enabled through tradeoff mechanisms that allow development on land considered to be less ecologically significant. This essentially means a net reduction in habitat area, which is known to be one of the crucial drivers of urban biodiversity loss. Performance-based approaches to promote urban biodiversity are emerging (and are evident internationally, see Chapter 6). In NSW, existing performance-based approaches that support urban ecological outcomes fall within a voluntary category because they are discretionary (e.g. in local government policies such as DCPs) and have far less traction and impact than mandatory approaches. Three common themes emerged from the desktop review of good-practice biodiversity and landscaping controls in local government DCPs presented in Chapter 4: 1) the inclusion of explicit targets or minimum performance standards; 2) the need for controls that recognise the importance of scale, significance and connectivity; and 3) that plans and policies are based on evidence-based principles.

Achieving a city with high levels of biodiversity and that is also more liveable will require new and possibly hybrid regulatory models, which correspondingly will demand greater coordination and integration between and within government, industry and at the lot or site level. The use of environmental planning instruments, enabled under the EP&A Act, such as a new and strengthened Bushland SEPP (referred to in Chapter 4 as an Urban Ecology SEPP), could be established to set mandatory minimum performance targets designed to increase urban greening, protect habitats and strategically link developments to corridors such as the Green Grid. Controls could, for example, prescribe minimum landscape areas for individual lots (including roofs and walls), accompanied by a requirement for functional biodiversity elements such as ground-storey, mid-storey and canopy vegetation (Beninde *et al.*, 2015) while also achieving aesthetic and amenity outcomes (Ives & Kelly, 2016). With the use of spatial information technology, controls can vary according to where a lot (or subdivision) is located with respect to adjoining or nearby 'core' or remnant bushland, and to

provide for future green corridors across urban landscapes. **Table 7.1** provides examples of controls that could be used to promote urban ecological outcomes.

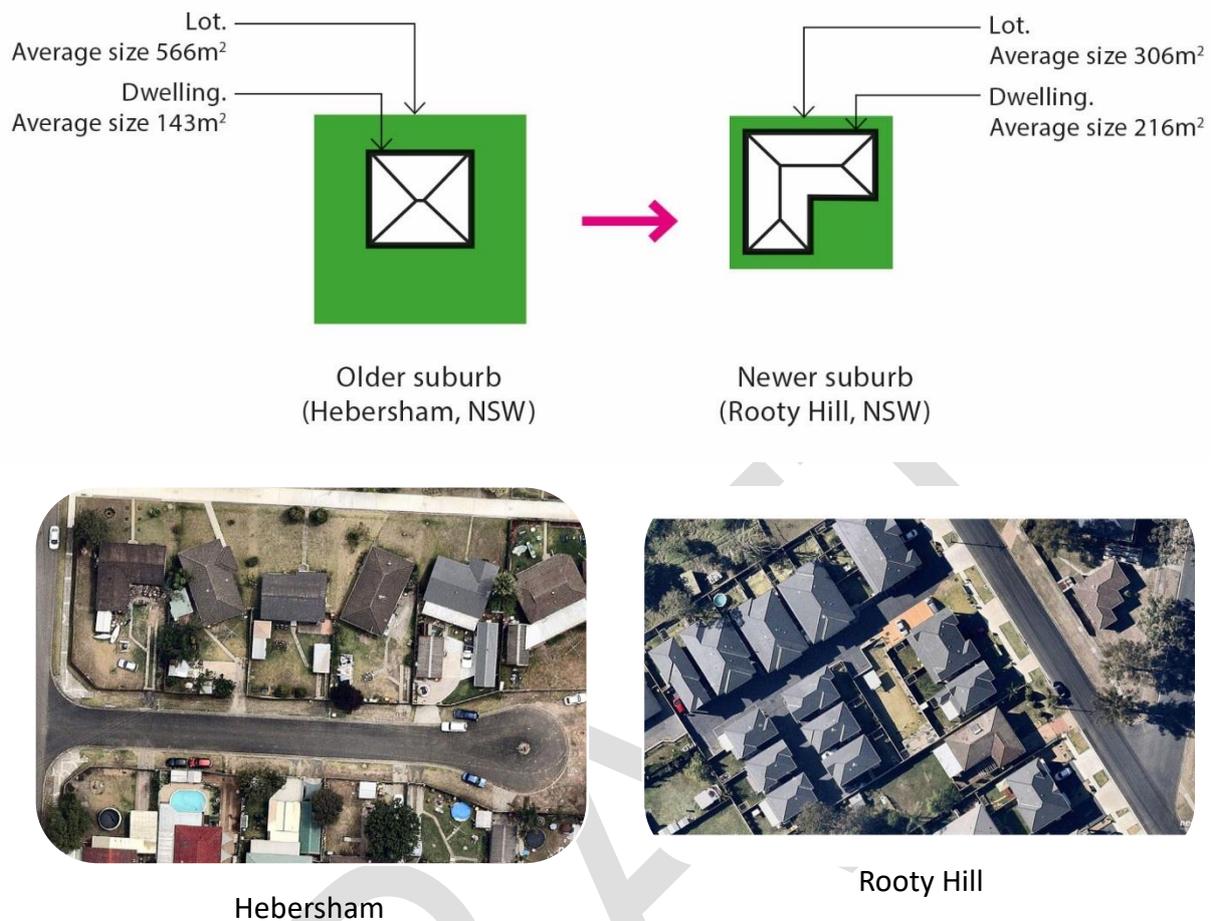
**Table 7.1** Examples of planning controls that could be used to advance urban ecological outcomes.

Aspect	Controls	Comments
Lot coverage	Outer/low density: max. 50% impervious coverage Middle/medium density: max. 65% impervious coverage Inner city/high density: 80% impervious coverage (can include green roofs)	The area of a lot covered by impervious surfaces (such as buildings, pathways and driveways, excluding pervious pavements)
New tree planting (number of new tree plantings where there are no existing trees)	Lot size up to 250m <sup>2</sup> : 1 medium tree Lot size 250-500m <sup>2</sup> : 2 medium trees Lot size 500-850m <sup>2</sup> : 3 medium trees Lot size 850-1,500m <sup>2</sup> : 1 large tree or 4 medium trees Lot size over 1,500m <sup>2</sup> : 2 large trees or 5 medium trees	Number of new tree plantings where there are no existing trees (figures adopted and modified based on the Apartment Design Guide; NSW Department of Planning and Environment, 2015a)
Tree replacement (where an existing tree is removed)	For every mature tree removed from the site, 3 new trees are to be planted. If they are unable to be accommodated on the site, the cost of planting offsite are to be covered by the developer/owner	Figure modified from Draft Apartment Design Policy (Design WA, 2016)
Deep soil area	Large tree = 80m <sup>3</sup> Medium tree = 40m <sup>3</sup> Small tree = 15m <sup>3</sup>	Area of deep soil required for tree planting (minimum 1m depth) (figures adopted from Apartment Design Guide; NSW Department of Planning and Environment, 2015a)
Street verge width (width of the area between the road and the front of the lot boundary)	Minimum 4m width to support street-tree planting and mass planted garden beds	Will require a change to road and footpath design to enable and prioritise landscaping within the street verge where otherwise compromised due to front set-back controls on private land
Street setback of buildings (alignment of buildings along street frontage to provide space for street-tree planting)	Middle/medium density: 6m Inner city/high density: 15m	Control to complement street verge width (figures adopted from Draft Medium Density Design Guide; NSW Department of Planning and Environment, 2016)
Biodiversity requirements for open	Minimum 25% of total area to be planted with vegetation of a variety of	Figure adopted from City of Melbourne's draft Urban

space	heights and species to create onsite habitat and ecological corridors	Ecology and Biodiversity Strategy (City of Melbourne, 2016)
Green roof	Buildings with roof area greater than 1000m <sup>2</sup> must have extensive green roof Buildings with roof area greater than 1500m <sup>2</sup> must have intensive green roof	Likely to be most relevant and beneficial for medium-to-higher density areas Application to public buildings is needed to support industry skill development and acceptance of this green infrastructure technique

Arguably, many robust mechanisms and requirements exist for considering biodiversity in land-use planning and development control, but a clear limitation is a lack of strategic allocation of land for private and public landscaping (or low priority is given to this) and the limited enforcement and regulation of landscape and related biodiversity controls. Although there is no empirical evidence of this in NSW, the literature and planning frameworks indicate that compliance with development conditions is not well regulated; for landscaping, this means that what is planned or intended may not be delivered or might otherwise be replaced by hard-stand areas providing limited habitat and ecological value. The importance of gardens and landscaping for biodiversity outcomes is well documented (Thompson *et al.*, 2003; Loram *et al.*, 2007), but the contribution at the lot level is being eroded through code-based development standards that, on the whole, do not mandate landscape plans. In NSW, SEPP (*Exempt and Complying Development Codes*) 2008 only requires landscaping for certain subdivisions (Part 3A, Division 3, Subdivision 4), leaving the bulk of development types enabled by this planning instrument to go unregulated with respect to landscaping. Complementary planning strategies are used, however, and should be further supported to enhance urban greening. For example, minimum front- and side-boundary setbacks not only provide aesthetic outcomes for streetscapes but can also integrate with road verge controls (minimum widths from the road edge to front boundary) to support canopy trees and other vegetation as part of street-tree plantings and urban forest strategies. This would support the known relationship between high-percentage tree cover and urban biodiversity (Stagoll *et al.*, 2012).

Regulation is not the only path to increasing the quality and quantity of a city's green spaces. In many parts of a city there exists a strong 'garden' culture that supports ongoing greening and, with this, urban biodiversity. A range of education and other outreach programs provide consumers with knowledge on the best species for positive biodiversity outcomes, and these should be further encouraged. If new houses and suburbs lack the space for gardens (**Figure 7.5**), however, it will become increasingly difficult, if not impossible, to maintain and increase green spaces in a city and, in turn, to maintain and increase urban biodiversity.



**Figure 7.5.** Schematic diagram and accompanying aerial photo illustrating the lot to built area of an older (Hebersham) and newer (Rooty Hill) subdivision. The diagram shows a plan view, to scale, of dwelling size in relation to lot size, demonstrating that dwelling size has increased over time as lot size has decreased. Satellite imagery source: Nearmap LTD (2017).

Market-based approaches such as BioBanking are likely to play a continuing role in the planning system in NSW. These approaches were discussed in the review of biodiversity laws in NSW (Byron *et al.*, 2014) that culminated in the *Biodiversity Conservation Act 2016*. Ecologically, there is little evidence to suggest that these market-based trading approaches work (Hanford *et al.*, 2016; Maron *et al.*, 2016). As a complementary and necessary policy outcome, important ecological habitats – more than those listed under the *Biodiversity Conservation Act 2016* – should be able to be protected and managed under similar banking or reserve systems.

#### 7.4 Spatial and temporal issues for planning

Disturbance is a natural and regularly occurring dynamic process in ecological systems. Urbanisation can change the frequency and intensity of some disturbances, which can have adverse ecological impacts. For example, more frequent and intense stream flows affect the reproduction cycle and habitat needs of certain aquatic invertebrates (Paul & Meyer, 2001; Davies *et al.*, 2010). The rate of impact of urbanisation on ecosystems can be immediate, such as in the direct clearing of a critical habitat for a less-mobile species, or it may take decades, such as the incremental habit loss and

fragmentation of habitat of highly mobile species, such as the critically endangered powerful owl. The time required for an ecosystem to return to a pre-disturbance state is often much greater than that of the period of disturbance (Chapter 3). For example, the abrupt process of habitat removal can have an immediate impact on a species or population but recovery, if achieved, might be measured over the medium (decades) to long (multiple decades to centuries) term. Given this, poor planning and policy decisions, as well as the actions of individuals and institutions, can result in 'legacy impacts' on biodiversity in which there is a continued decline of habitats and species over decades. At worst, a species may have an extinction debt, meaning, in effect, that it is on a one-way path to extinction as a result of the impacts of urbanisation (Hahs *et al.*, 2009). For these reasons alone, standardised, long-term monitoring and research is crucial for understanding ecological and species thresholds, measuring the state of biodiversity, identifying pressures and evaluating the actions (response) that may reverse losses.

### **Spatial dimensions of planning for urban ecosystem renewal**

Spatial and temporal dimensions, particularly the effects of cumulative disturbance, have not been adequately integrated into assessments of the impacts of urban development on ecosystems (e.g. Folke *et al.*, 2005; Borgström *et al.*, 2006; Andersson *et al.*, 2014). There is a crucial need, therefore, for a strategic, long-term framework in planning and managing cities. Spatially, strategic planning must account for biodiversity management at the scale of bioregions down to individual lots (**Figure 7.6**). The district planning undertaken by the GSC emphasises the importance of a metropolitan-wide approach to the protection and enhancement of the natural environment and the way in which this vertically informs the future metropolitan plan for Sydney and the LEPs and detailed controls to be prepared by councils.



Figure 7.6. Schematic diagram of the application of biodiversity planning at multiple scales. Source: Modified after Ives *et al.* (2010).

Large and small remnant habitats play important roles in biodiversity conservation and need to be protected. As a principle, ecologists will argue that ‘no net loss of habitat’ should be the basis for future planning (Palmer *et al.*, 2008; Barth *et al.*, 2015). For cities that are constantly growing and changing, however, this is neither practical nor feasible. Nevertheless, planners should strategically identify, protect and maintain large, good-quality and connected remnant habitats to form a core reserve system, supported by green and blue corridors to facilitate biodiversity movement (as emerging in the Green Grid and intermittently in LGAs through urban forest strategies). Some councils recognise the value of buffers around core habitats in their local controls, for example by increasing the proportion of native species in landscape plans for land near national parks. Such approaches are applied inconsistently by local and state governments, however, usually as a discretionary policy (e.g. DCPs), and recently they have been overruled by higher-priority laws and policies, such as the 10/50 vegetation clearing rules designed primarily to protect life and property through the clearing of understories and tree canopies. Such developments point to the need for greater understanding of the biodiversity governance arrangements in NSW, especially as they apply to cities.

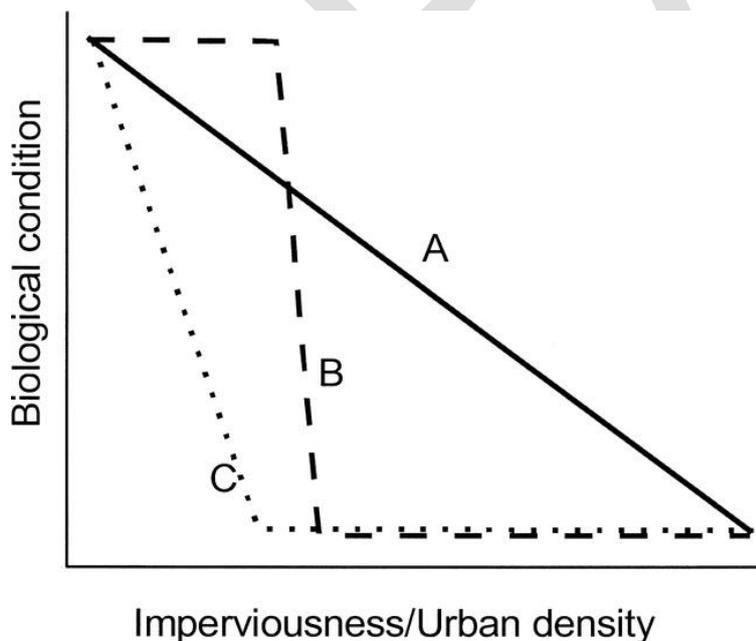
Although metropolitan and district planning necessarily focuses on larger habitats and waterways, smaller reserves will play an increasingly important role as habitats for isolated and less-mobile species and as stepping stones as part of biodiversity corridors (Marzluff, 2005). Such smaller reserves with high area-to-edge ratios will require greater maintenance per area, and this must be factored into the operational budgets of councils, utilities and others. Justification for such resources

is provided in the literature. It is well documented that species' losses have a non-linear relationship to habitat loss (Chapter 3); thus, vegetation cleared in a small reserve will have a disproportionately greater impact on species decline than the same amount removed from a larger reserve.

The form of urban development in a city, loosely apportioned as infill (compact) or greenfield, has a significant bearing on where and how remnant habitats are protected and maintained. It is well documented that greenfield development is the main cause of habitat loss and species decline in cities. But it is also important to consider a city's development and evolution over time, in which inner- and middle-ring suburbs were once peri-urban and greenfield locations and are now the subject of more compact development that has resulted in some species and vegetation communities, such as the blue gum high forest, becoming critically endangered. As for the critically endangered Cumberland Plain woodland, the preferred sites of the blue gum high forests are flatter, more fertile soils, which also continue to be the preferred sites for housing and development. Thus, although there is an ecological preference for infill and compact development to reduce the large-scale habitat clearing associated with greenfield development, the ecological impacts, especially at the level of communities and species, is not proportional because the smaller the total remaining area and the size of individual patches, the greater the impact.

#### Temporal dimensions of planning for urban ecosystem renewal

The impact of urbanisation on biodiversity loss can take a long time to become evident because organisms can persist at unsustainably low levels for long periods (Hahs *et al.*, 2009). Thresholds, or tipping points, at which a species or population becomes locally or regionally vulnerable or, worse, extinct, can be difficult to predict. Tipping points most often play out over differing time scales depending on the species and community. As illustrated in **Figure 7.7**, the impact of urbanisation on biodiversity loss is unlikely to be linear (Line A); rather, it will follow a steep decline (Line B) when one or a combination of thresholds is exceeded (as predicted by King *et al.*, 2005; Walsh *et al.*, 2005).



**Figure 7.7.** Three models of stream biological condition in response to increased impervious surface (i.e. urbanisation): A = A linear decline with increasing urban density (e.g. Booth *et al.*, 2004). B = An upper threshold switching to a lower

threshold (e.g. King *et al.*, 2005).  $C = A$  linear decline with increasing urban density to a lower threshold (Walsh *et al.*, 2005). Source: Walsh *et al.* (2005).

When a tipping point has been reached and the species or ecological system has adjusted to the new biodiversity condition, it can take significant time and resources to recover to a pre-disturbance state. It may be impossible to restore some urban ecosystems to a pre-disturbance state, regardless of the level of intervention or the time allowed. In these circumstances, acceptance of a functional novel ecosystem may be required (McDonald *et al.*, 2016).

In general, the greater the impact, the longer ecosystems will take to recover. Ultimately, this can create a time lag between the implementation of an urban ecology renewal intervention and biodiversity recovery. For example, tree plantings to replace removed large trees that once provided habitat for fauna through hollows or provided canopy connectivity may take decades to grow large enough to be used as habitat by some species (Le Roux *et al.*, 2014). Thus, lag time is an important factor to consider in developing metrics or targets for urban ecology transformation. Crucially, monitoring and evaluating the impacts of interventions will most often exceed political and organisational planning cycles.

Conservation strategies also vary in their permanence. At one end of the spectrum are 'permanent' land uses such as national parks established for conservation and protected by their statutory designation. Other land uses, such as regional parks and cemeteries, can also provide important areas for biodiversity and are relatively permanent because significant policy and social pressure would be required to change their use. At the other end of the spectrum are short-term interventions, such as pop-up parklets, that may be present for days or weeks and provide benefits (such as pollination opportunities) that are also measured in days or weeks. Given the diversity and intensity of land use in cities, it is foreseeable that temporary and shorter-term green infrastructure initiatives may become increasingly important components of integrated approaches to the protection and improvement of urban ecosystems, complementing permanent assets such as large parks, waterways and bushland reserves.

Urban ecology renewal efforts will need to consider future conditions such as climate change and predicted extreme weather events. For example, although urban greening can be used as a strategy to ameliorate the impacts of the UHI effect by reducing temperatures on hot days, the benefits will be best realized if canopy-cover measures are undertaken at a precinct or neighbourhood scale. This is another example of the socioeconomic and environmental benefits of urban biodiversity, but such benefits must also be balanced against the costs of maintaining the tree cover and the risks that may accrue, such as those associated with storms and bushfires.

Climate change will result in a shift in the preferred habitats of some species and ecological communities. In Sydney, Wollongong and Newcastle, this may require the identification of species to the north and northwest that are more tolerant of warmer and possibly drier conditions.

## 7.5 Managed environments

There are wide-ranging, measurable benefits to be gained when the intrinsic value of urban biodiversity is acknowledged explicitly from the earliest stages of urban development. The benefits derived from protecting and enhancing urban ecosystems include carbon sequestration, improvements in air quality, local climate and stormwater management, reduced energy use and the provision of habitat. These are complemented by a range of benefits for mental, physical and social health and wellbeing linked to the concept of biophilia (Kellert, 2016). For example, green spaces

contribute to mental health and wellbeing through attention restoration, stress reduction, and the evocation of positive emotions (e.g. Bowen & Parry, 2015; Triguero-Mas *et al.*, 2015).

Green spaces also contribute to physical health and wellbeing through the promotion of physical activity and to social wellbeing by encouraging integration, engagement and participation through enhanced social support networks and an increased sense of personal security (Abraham *et al.*, 2010). This range of benefits is supported by evidence from a variety of international research projects reviewed in this document. For example, research in the United Kingdom found measurable positive associations between the reported wellbeing of visitors to green spaces and the species richness of those spaces. The degree of psychological benefit was positively related to the species richness of plants and to a lesser extent of birds (Fuller *et al.*, 2007).

Urban green spaces also provide economic benefits. Urban greening has been demonstrated to increase property values, economic activity and consumer spending and reduce spending on energy and infrastructure. In Australia, the Real Estate Institute of Queensland found that the values of homes in 2004 were up to 30% higher in leafy streets than in streets without trees in the same suburb (Ely & Pitman, 2014). Placing a monetary value on the economic benefits of urban ecology can help persuade communities, stakeholders and policymakers to increase urban ecological outcomes (Vandermeulen *et al.*, 2011).

Integrating urban development and urban ecology increases a city's capacity to withstand and absorb change (i.e. its resilience), including the effects of climate change and the UHI effect. There are many opportunities in the built environment to enhance urban ecological outcomes, both in newly established developments (greenfields) and in existing urban areas with the potential for remediation and restoration (brownfields). The use of green infrastructure approaches can support urban ecological renewal at various scales, from individual sites to the metropolitan scale.

Green infrastructure provides a design framework for implementing urban ecological renewal. Interest in, and the application of, green rather than grey infrastructure continues to increase. As new projects are commissioned, there is potential to extend design briefs for green infrastructure elements to specify that they deliver biodiversity outcomes. For example, biodiversity outcomes can be increased by including a greater diversity of species in planting palettes. Collaboration between built-environment professionals and scientists, including ecologists and biologists, is required to implement high-performing green infrastructure that will maximise biodiversity outcomes.

Although artificial night lighting is necessary to improve the safety of people using public spaces after dark, this should be balanced with the needs of wildlife (which can be affected by night lighting; Chapter 3). A review of CPTED guidelines and lighting standards in NSW to encourage consideration of both human and non-human needs would help improve biodiversity outcomes. CPTED also requires the maintenance of sightlines in public spaces, which has led to a reduction in shrub plantings in urban areas and a consequent reduction in the diversity of plant species and habitat options, favouring some fauna species over others.

Across a metropolitan region, each development site presents opportunities for implementing green infrastructure and protecting or restoring urban ecology, depending on the density of the built form, ranging from rural and peri-urban to highly dense urban areas such as central business districts. The ongoing success of urban ecological renewal will also depend on the maintenance and resources available to sustain sites in the face of development pressures in adjacent areas and more widely in catchments. Opportunities for urban ecological renewal can be considered in a hierarchy of interventions, summarised as:

- Protect and conserve
- Restore
- Enhance
- Create.

### **Protect and conserve**

Urban ecological outcomes are typically most successful when urban ecology principles are integrated from the start of projects. Considering urban ecology in the inception phase is crucial for setting the foundation and framework of development projects. The Rouse Hill Town Centre in Sydney's northwest, with its focus on the natural values of Caddies Creek, is a good example of this.

Park and open-space planning can improve urban biodiversity by protecting important remnant vegetation and increasing plant diversity. The management of such spaces needs to acknowledge the importance of 'messy landscapes' (Nassauer, 1995) for ensuring enhanced urban ecological outcomes.

### **Restore**

WSUD can restore urban ecosystems by replacing traditional grey infrastructure (pipes and pits) with green infrastructure features such as bioswales, raingardens and constructed wetlands. Although all green infrastructure improves urban ecological outcomes, even better outcomes are achieved when WSUD is designed for biodiversity. Landscape architects, engineers and ecologists need to work together to provide stormwater management and support urban biodiversity. Increasing the diversity of plant palettes as well as surface treatments, materials and topography can improve biodiversity. Opportunities to replace or substitute hard surfaces (e.g. concrete, unit paving and bitumen) with natural surfaces capable of supporting vegetation can provide ancillary benefits, such as for stormwater management. Permeable pavements allow water infiltration while also supporting pedestrian and certain vehicular traffic.

### **Enhance**

Green walls and roofs can enhance urban ecological functioning. These can be retrofitted onto existing buildings or designed and constructed as part of new developments. Intensive green roofs are better than extensive green roofs at enhancing urban biodiversity (Oberndorfer *et al.*, 2007) because of the diversity of plant species, materials and microclimatic conditions they can accommodate. Of the various types of green wall, 'living walls' have the most potential for improving urban biodiversity because of their complexity. Integrating habitat boxes such as bee hotels or hives and bird boxes into the structure and design of buildings can also encourage and increase urban biodiversity.

### **Create**

A variety of artificial habitats can be created and integrated into developments in built environments using green infrastructure elements such as green roofs and green walls, land bridges and tunnels for wildlife crossing, constructed ponds and wetlands and other WSUD technologies, habitat gardens and protective items such as bat boxes and street-tree plantings with natural verge treatments. Collectively, these features can help increase urban biodiversity.

Increasing the species diversity of plant palettes and creating habitat gardens for local flora and fauna species supports urban ecology. In highly urban areas, 'parklets' can provide new

opportunities for plantings as well as increase liveability. Parklets have been constructed in Adelaide's city centre. In inner-city Sydney, mobile parklets have been deployed with support from the Sydney, Waverly and Randwick councils.

DRAFT

## 8 RECOMMENDATIONS

There are many opportunities to integrate urban ecology into built environments. The recommendations made here apply at various geographic scales, from the lot to the state. They are based on the following hierarchy of interventions: protect and conserve remnant habitats; restore existing ecosystems; enhance remaining ecosystems; and create new habitats through green infrastructure.

The recommendations are tied to the following seven themes in the *Blueprint for Living Cities: policy to practice*, which serve as the strategic outcomes for making cities liveable and sustainable:

1. **Retain** and enhance habitats to support biodiversity and healthy cities.
2. **Reform** strategic planning to embed urban ecology.
3. **Connect** biodiversity across cities through green and blue networks.
4. **Design** and deliver a green and blue city.
5. **Create** new habits to support biodiversity and human health and wellbeing.
6. **Develop and implement** ongoing engagement programs to increase education and involvement across the sectors.
7. **Align** urban ecology policies and practices between levels of government.

### STATE

No.	Recommendation	Strategic outcome	Comment
1	Set an overarching target in an apex policy to promote the implementation of urban ecology	Align	This needs support across and between state and local governments and to tie into a coordinated monitoring program
2	Establish a monitoring program to evaluate the change in condition of ecological assets and green infrastructure and use this to assess the efficacy of plans and policies	Reform, engage and align	This should link to the State Plan as the apex strategy guiding the strategic decisions and priorities of government
3	Review urban biodiversity governance structures and systems	Align	To reveal the strengths and weaknesses of existing laws, policies and practices within and between levels of government and to recommend a framework for greater coordination

### REGIONAL

No.	Recommendation	Strategic outcome	Comment
4	Identify, protect and conserve remnant ecosystems, including riparian and coastal ecosystems and habitats	Retain	To include land in public and private ownership and encourage protection via current market-based policies and other conservation agreements
5	Develop a performance-based design and construction rating tool that supports and advances urban ecological outcomes	Reform	This should be based on an environmental planning instrument that considers outcomes at the lot-to-regional scale and has enforceable controls
6	Monitor the habitat quality of remnants and identify and address regional-level impacts	Reform, engage and align	This can relate to the GSC dashboard and have increasing levels of detail at the local to bioregional scale for individual species

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and communities

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## METROPOLITAN

No.	Recommendation	Strategic outcome	Comment
7	Prioritise a compact city development pattern rather than lower-density greenfields as a way of minimising habitat loss	Retain and reform	City planning should preference infill development and be based on the GSC's pillars of a productive, liveable and sustainable city
8	Undertake a systematic, spatially explicit mapping program to identify opportunities for green and blue corridors at multiple scales to connect existing and newly created habitats	Connect, design and create	Integrate bioregional to locally based mapping and data to form a hierarchy of green and blue grids that are embedded within the metropolitan, district and local planning hierarchy
9	Create green corridors with minimum width requirements that connect patches of habitat and encourage species movement	Connect	To be supported by state and regional funding programs (for capital and ongoing maintenance) and integrated into metropolitan and district planning
10	Develop a spatial information biodiversity layer that identifies the extent and condition of habitats	Reform and align	This should bring together vegetation, riparian and marine monitoring at the metropolitan to local level
11	Use road, rail and infrastructure easements and corridors as green corridors	Align and connect	Integrate urban ecology principles into the design, operational and maintenance practices of utilities
12	Establish a metropolitan-wide policy to support the design, construction and maintenance of green infrastructure	Reform and create	This needs to clearly define green infrastructure and its role in delivering ecological and liveability outcomes to cities
13	Designate buffer zones around key remnant bushland areas and green and blue corridors	Retain and design	Buffer zones should seek to the reduce impacts and disturbances caused by adjacent land uses and, where possible, provide opportunities for the community to engage with the natural environment
14	Where possible, include and restore riparian vegetation in planned green corridors and networks	Retain and connect	Riparian areas should support the movement of water and biodiversity and, where relevant, provide passive recreation opportunities
15	Develop and implement a policy to put power lines underground to reduce conflict between tree canopies and power lines	Reform and align	Funding for this strategy should be considered by IPART in the context of the benefits that can be accrued at the metropolitan-to-local level

## DISTRICT

No.	Recommendation	Strategic outcome	Comment
16	Establish and enforce planning controls that support urban ecology,	Reform and protect	Embed specific planning controls for natural areas of significance within

	such as a performance-based rating tool		district and local plans. These controls should also integrate with a spatial layer in the performance-based design and construction rating tool (recommendation 5)
17	Enhance existing degraded remnant ecosystems in urban areas	Retain	Priority should be given to sites with high recoverable potential that are valued by the community and form important habitats and corridors
18	Integrate WSUD in master planning for new subdivisions	Design	Controls need to reflect local stream condition, recovery potential and opportunities to enhance waterways for recreation and biodiversity
19	Reduce the total amount of impervious area and the connectedness of impervious surfaces	Design	Support infiltration, reduce the hydraulic impact on local streams, and protect riparian and instream habitats
20	Implement bush revegetation and restoration programs with set benchmarks that address the original causes of decline, and actively monitor them to enable the assessment of outcomes	Retain	Provide a robust evaluation process to measure the success and impact on regeneration activities to enable natural areas to be allocated maintenance funding, as occurs in the management of grey infrastructure assets
21	Implement green infrastructure, including green roofs, with high habitat complexity and resources that encourage biodiversity	Reform and create	Apply innovative solutions to advance the update of green infrastructure within the urban fabric. This is particularly important for infill development

## LOCAL

No.	Recommendation	Strategic outcome	Comment
22	Ensure that local government community strategic plans and operational and delivery programs allocate resources to achieve positive urban ecological outcomes	Reform and align	Link community values and priorities to the budgetary and operational processes of councils
23	Support participatory planning processes to set local planning controls that encourage liveability and urban ecological outcomes	Reform	Enable communities to identify what they value about their local areas and planners to support the protection and enhancement of these attributes in local policies
24	Require all local councils to establish and implement urban forest strategies	Reform and connect	Urban forests, including street trees, provide important habitats and ecological connections. The planting and maintenance of trees and other vegetation must integrate with the practices of utilities (recommendation 15). Planting should be structurally complex; where relevant and supported by the community, replace turf with native gardens on street verges
25	Establish and enforce planning controls that support urban ecology	Reform	Local government planning policies should be developed and tailored to

			support the specific needs of local ecology across public and private lands
26	Develop incentive mechanisms to promote and maximise urban ecological outcomes as part of local policy and development assessment	Reform	Incentives may vary and form part of development agreements at the lot-to-subdivision scale and support additional development yields where urban ecological outcomes are guaranteed in the long term
27	Prioritise compliance and regulation programs in councils to ensure compliance with development approval conditions and local environmental policies	Engage	Compliance programs should link with broader education and engagement strategies
28	Create novel ecosystems that benefit local biodiversity, support ecosystem services and promote human health and wellbeing	Create	Novel ecosystems such as green roofs, walls and planter boxes for apartments can be used to increase green cover and support the ecological needs of specific species that are highly valued by the community) (e.g. mascots) or are threatened by urbanisation processes
29	Establish and implement green roof and green wall policies for infill and compact development sites	Create	The policy should link with the creation of novel ecosystems and support the local Green Grid and urban forest strategies and relate to the size and function of buildings (that should also support liveability outcomes that enable occupants to use green roofs as a recreation space)
30	Establish community education and awareness programs to raise the importance and value of urban ecology in cities	Engage	Local programs should be tailored to reflect socio-demographic characteristics and priorities
31	Plan open spaces to capture the ecosystem services and ecological benefits of informal green spaces	Create	This could include street verges, rail corridors, vacant lots, power lines and spaces between buildings and fences
32	Support design and maintenance guidelines that enable the creation of habitat complexity in informal green spaces	Create	This could include street verges and roundabouts and be enabled by decreasing mowing and planting native species with complex ground-storey and mid-storey layers
33	Revise local street design and building set-back controls to support canopy planting and complement lot-based landscape outcomes	Reform and create	Street trees will become increasingly important for providing supportive canopy cover as lot sizes decrease and urban densities increase; an increase in street trees can be enabled by local-to-regional road and footpath design standards
34	Develop local park design and maintenance guidelines that support urban ecology and sustainability principles	Retain, design and create	Landscape design and maintenance should aim to maximise planting areas with complex vegetation structures, enable novel habitats, integrate succession planting (to maintain canopy levels over the long term), minimise pesticides and maximise liveability

			outcomes that also enable residents to connect with nature
35	Support ecological engineering projects that replace grey (conventional) infrastructure	Design and create	This is relevant to the longer-term management and asset replacement of conventional stormwater drainage systems and coastal protection structures, where there is potential to de-channelise rivers and creeks and modify coastal revetments
36	Implement soft/ecological engineering practices for shoreline protection and coastal revetment structures	Design and create	This can incorporate approaches based on living shorelines, where soft engineering practices will be more beneficial for urban biodiversity than hard engineering practices, and it can include structures that support complex habitats (e.g. sloped versus vertical walls)
37	Encourage the establishment of community gardens and parkcare programs	Engage	Community engagement programs should complement the maintenance programs of councils and other public authorities
38	Establish best-practice demonstration projects on publically owned land	Create and engage	Public authorities should take a leadership role in designing, building and maintaining projects that support urban ecology and liveability principles. These should provide opportunities for practitioners to develop new skills and techniques and for industry groups to develop and test new standards of ecological design
39	Make use of interpretative features (including signage) to inform the public of the ecological reasons behind management decisions	Engage	Education programs should be developed in collaboration with the local community, and sites should form 'living labs' serving as opportunities to engage with the natural environment

## LOT

No.	Recommendation	Strategic outcome	Comment
40	Establish maximum built-lot coverage requirements to ensure sufficient area for landscaping and pervious surfaces	Reform	The land-to-built-area ratio should reflect zoning, proximity to local and district open space and street verge design
41	Establish deep-soil requirements to support canopy plantings on private land	Create	Deep-soil areas should integrate with canopy tree planting, as identified in landscape plans. Deep-soil planting areas and canopy trees must also consider adjacent private and public planting areas and opportunities
42	Retain large, mature, hollow-bearing trees	Retain	On public land, these trees should be encouraged and managed from the perspectives of public risk and urban ecology. On private land, tree preservation order policies need to support ecologically and aesthetically significant trees

43	Encourage the planting of native gardens that include structural complexity and the provision of habitat resources	Create	Policy should enable trees, shrubs, grasses and groundcovers and habitats (e.g. water features, nesting boxes and rock piles) and discourage the use of exotic plants that might have adverse impacts on remnant bushland areas and prolifically flowering varieties of native plants (that favour certain adaptive species) in private gardens
44	Ensure lot-based stormwater and WSUD controls to minimise pollution and hydraulic impacts on local streams	Reform and create	The application of controls at the lot-to-subdivision level should be flexible to enable integration with local and district open spaces that support productive, liveable and sustainable outcomes
45	Reduce noise impacts on environmentally sensitive areas through vegetation buffers	Design	
46	Reduce light pollution in environmentally sensitive areas through the use of narrow-spectrum bulbs, down lights, shields, embedded lights and motion-activated lighting	Design and engage	Design outcomes must also consider and may need to amend CPTED principles
47	Encourage the introduction of parklets with a minimum 75% vegetation area	Create	Temporary structures such as parklets may provide important local biodiversity outcomes and will add to the local aesthetics of local parks and town centres

## 9 REFERENCES

- Abraham, A., Sommerhalder, K., & Abel, T. (2010). Landscape and well-being: a scoping study on the health-promoting impact of outdoor environments. *International Journal of Public Health, 55*(1), 59-69. doi:10.1007/s00038-009-0069-z
- Andersson, E., Barthel, S., Borgstrom, S., Colding, J., Elmqvist, T., Folke, C., & Gren, A. (2014). Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services. *Ambio, 43*(4), 445-453. doi:10.1007/s13280-014-0506-y
- Angold, P. G., Sadler, J. P., Hill, M. O., Pullin, A., Rushton, S., Austin, K., Small, E., Wood, B., Wadsworth, R., Sanderson, R., & Thompson, K. (2006). Biodiversity in urban habitat patches. *Science of The Total Environment, 360*(1-3), 196-204. doi:10.1016/j.scitotenv.2005.08.035
- Barth, B. J., FitzGibbon, S. I., & Wilson, R. S. (2015). New urban developments that retain more remnant trees have greater bird diversity. *Landscape and Urban Planning, 136*, 122-129. doi:10.1016/j.landurbplan.2014.11.003
- Beninde, J., Veith, M., & Hochkirch, A. (2015). Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters, 18*(6), 581-592. doi:10.1111/ele.12427
- Borgström, S. T., Elmqvist, T., Angelstam, P., & Alfsen-Norodom, C. (2006). Scale mismatches in management of urban landscapes. *Ecology and Society, 11*(2), 16.
- Bowen, K. J., & Parry, M. (2015). *The evidence base for linkages between green infrastructure, public health and economic benefit*. Available at <https://www.vu.edu.au/sites/default/files/cs/es/pdfs/gi-econ-health-paper.pdf>
- Bradsen, J. (1992). Biodiversity legislation: species, vegetation, habitats. *Environmental and Planning Law Journal, 9*, 175.
- Buizer, M., Elands, B., Mattijssen, T., van der Jagt, A., Ambrose, B., Geróházi, É., Santos, A., & Steen Møller, M. (2015). *The Governance of Urban Green Spaces in Selected EU-Cities: policies, practices, actors, topics*. GREEN SURGE. Available at [http://greensurge.eu/working-packages/wp6/files/Buizer\\_et\\_al\\_2015\\_D6.1\\_GREEN\\_SURGE\\_The\\_governance\\_of\\_urban\\_green\\_spaces\\_in\\_selected\\_EU\\_cities.pdf](http://greensurge.eu/working-packages/wp6/files/Buizer_et_al_2015_D6.1_GREEN_SURGE_The_governance_of_urban_green_spaces_in_selected_EU_cities.pdf)
- Byron, N., Craik, W., Keniry, J., & Possingham, H. (2014). *A Review of Biodiversity Legislation in New South Wales: final report*. Independent Biodiversity Legislation Review Panel, NSW Office of Environment and Heritage. Available at <http://www.environment.nsw.gov.au/resources/biodiversity/BiodivLawReview.pdf>
- Cadenasso, M. L., Pickett, S. T. A., & Grove, M. J. (2006). Integrative approaches to investigating human-natural systems: The Baltimore ecosystem study. *Natures Sciences Societes, 14*(1), 4-14. doi:10.1051/nss:2006002
- Choi, L., & McIlrath, B. (2016). *New South Wales' Planning Framework for Water Sensitive Urban Design*. Cooperative Research Centre for Water Sensitive Cities. Available at <https://watersensitivecities.org.au/content/new-south-wales-planning-framework-water-sensitive-urban-design/>
- Cilliers, E. J., Timmermans, W., van den Goorbergh, F., & Slijkhuis, J. S. A. (2015). Designing public spaces through the lively planning integrative perspective. *Environment, Development and Sustainability, 17*, 1367-1380.

- Cincotta, R. P., Wisnewski, J., & Engelman, R. (2000). Human population in the biodiversity hotspots. *Nature*, 404(6781), 990-992. doi:10.1038/35010105
- City of Melbourne (2016). *Draft Urban Ecology and Biodiversity Strategy*. Available at [http://participate.melbourne.vic.gov.au/application/files/4214/6524/9371/Draft\\_Urban\\_Ecology\\_and\\_Biodiversity\\_Strategy.pdf](http://participate.melbourne.vic.gov.au/application/files/4214/6524/9371/Draft_Urban_Ecology_and_Biodiversity_Strategy.pdf)
- Clark, W. R. (2010). Principles of Landscape Ecology. *Nature Education Knowledge*, 3(10), 34. Available at <http://www.nature.com/scitable/knowledge/library/principles-of-landscape-ecology-13260702>.
- Clean Air and Urban Landscapes Hub (CAUL) (2015). Research Summary: Developed under the National Environmental Science Programme. Available at <http://www.nespurban.edu.au/>.
- Colding, J. (2011). The role of ecosystem services in contemporary urban planning. In J. Niemelä, J. Breuste, T. Elmqvist, G. Guntenspergen, P. P. James, & N. E. McIntyre (Eds.), *Urban Ecology - Patterns, Processes, and Applications* (pp. 228-237). Oxford: Oxford University Press.
- Collins, J. P., Kinzig, A., & Grimm, N. B. (2000). A new urban ecology. *American Scientist*, 88(5), 416-425.
- Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change-Human and Policy Dimensions*, 26, 152-158. doi:10.1016/j.gloenvcha.2014.04.002
- Davies, P. J., Ives, C. D., Findlay, S. J., & Taylor, M. P. (2011). Urban rivers and riparian systems - directions and recommendations for legislators, policy makers, developers and community users. *Environmental and Planning Law Journal*, 28(5), 313-331.
- Davies, P. J., Wright, I. A., Findlay, S. J., Jonasson, O. J., & Burgin, S. (2010). Impact of urban development on aquatic macroinvertebrates in south eastern Australia: degradation of in-stream habitats and comparison with non-urban streams. *Aquatic Ecology*, 44(4), 685-700. doi:10.1007/s10452-009-9307-y
- Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A., Mittal, N., Feliu, E., & Faehnle, M. (2014). Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management*, 146, 107-115.
- Design WA (2016). *Draft Apartment Design Policy*. Available at [https://www.planning.wa.gov.au/dop\\_pub\\_pdf/WAPC\\_Apartment\\_Design\\_Policy\\_DRAFT\\_.pdf](https://www.planning.wa.gov.au/dop_pub_pdf/WAPC_Apartment_Design_Policy_DRAFT_.pdf)
- Dijkstra, L., & Poelman, H. (2014). A harmonised definition of cities and rural areas: The new degree of urbanisation. *Working Papers 01/2014*. Available at [http://ec.europa.eu/regional\\_policy/sources/docgener/work/2014\\_01\\_new\\_urban.pdf](http://ec.europa.eu/regional_policy/sources/docgener/work/2014_01_new_urban.pdf)
- Drinnan, I. N. (2005). The search for fragmentation thresholds in a Southern Sydney Suburb. *Biological Conservation*, 124(3), 339-349. doi:10.1016/j.biocon.2005.01.040
- Eigenbrod, F., Bell, V. A., Davies, H. N., Heinemeyer, A., Armsworth, P. R., & Gaston, K. J. (2011). The impact of projected increases in urbanization on ecosystem services. *Proceedings of the Royal Society B-Biological Sciences*, 278, 3201-3208.
- Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C., & Wilkinson, C. (2013).

*Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities.*  
Dordrecht: Springer.

- Elmqvist, T., Setälä, H., Handel, S. N., van der Ploeg, S., Aronson, J., Blignaut, J. N., Gómez-Baggethun, E., Nowak, D. J., Kronenberg, J., & de Groot, R. (2015). Benefits of restoring ecosystem services in urban areas. *Current Opinion in Environmental Sustainability*, 14, 101-108. doi:<http://dx.doi.org/10.1016/j.cosust.2015.05.001>
- Ely, E., & Pitman, S. D. (2014). Green Infrastructure: Life Support for Humans *The compelling evidence for incorporating nature into urban environments*. South Australia: Botanic Gardens of South Australia
- Escobedo, F. J., Kroeger, T., & Wagner, J. E. (2011). Urban forests and pollution mitigation: analyzing ecosystem services and disservices. *Environmental Pollution*, 159(8–9), 2078-2087. doi:<http://dx.doi.org/10.1016/j.envpol.2011.01.010>
- Faehnle, M., Söderman, T., Schulman, H., & Lehvävirta, S. (2015). Scale-sensitive integration of ecosystem services in urban planning. *GeoJournal*, 80(3), 411-425. doi:10.1007/s10708-014-9560-z
- Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology and Systematics*, 34, 487-515. doi:10.1146/annurev.ecolsys.34.011802.132419
- Fauth, J. E., Bernardo, J., Camara, M., W. J. Resetarits, J., Buskirk, J. V., & McCollum, S. A. (1996). Simplifying the Jargon of Community Ecology: A Conceptual Approach. *The American Naturalist*, 147(2), 282-286. doi:doi:10.1086/285850
- Floyd, J., Iaquinto, B. L., Ison, R., & Collins, K. (2014). Managing complexity in Australian urban water governance: transitioning Sydney to a water sensitive city. *Futures*, 61, 1-12. doi:<http://dx.doi.org/10.1016/j.futures.2014.04.002>
- Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, 30, 441-473.
- Forman, R. T. T. (2014). *Urban Ecology: Science of Cities*. New York: Cambridge University Press.
- Foster, J., Lowe, A., & Winkelmann, S. (2011). *The value of green infrastructure for urban climate adaptation*. Available at [http://www.amwa.net/galleries/climate-change/Green\\_Infrastructure\\_FINAL.pdf](http://www.amwa.net/galleries/climate-change/Green_Infrastructure_FINAL.pdf)
- Fragkias, M., Güneralp, B., Seto, K. C., & Goodness, J. (2013). *A Synthesis of Global Urbanization Projections*. Netherlands: Springer.
- Franklin, J. F. (1988). Structural and functional diversity in temperate forests. In E. O. Wilson (Ed.), *Biodiversity* (pp. 166-175). Washington, D.C.: National Academy Press.
- Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., & Gaston, K. J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biology Letters*, 3(4), 390-394. doi:10.1098/rsbl.2007.0149
- Gaston, K. J. (2010). *Urban Ecology* (318 pp.). Cambridge: Cambridge University Press.
- Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study. *Research Policy*, 31(8), 1257-1274.
- Geels, F. W. (2010). Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy*, 39(4), 495-510.
- Godefroid, S., & Koedam, N. (2007). Urban plant species patterns are highly driven by density and function of built-up areas. *Landscape Ecology*, 22(8), 1227-1239. doi:10.1007/s10980-007-9102-x

- Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, *86*, 235-245.  
doi:<http://dx.doi.org/10.1016/j.ecolecon.2012.08.019>
- Goodsell, P. J. (2009). Diversity in fragments of artificial and natural marine habitats. *Marine Ecology Progress Series*, *384*, 23-31. doi:10.3354/meps08037
- Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008a). Global change and the ecology of cities. *Science*, *319*(5864), 756-760.  
doi:10.1126/science.1150195
- Hahs, A. K., McDonnell, M. J., McCarthy, M. A., Vesk, P. A., Corlett, R. T., Norton, B. A., Clemants, S. E., Duncan, R. P., Thompson, K., Schwartz, M. W., & Williams, N. S. G. (2009). A global synthesis of plant extinction rates in urban areas. *Ecology Letters*, *12*(11), 1165-1173. doi:10.1111/j.1461-0248.2009.01372.x
- Hajer, M. (2003). A frame in the fields: policymaking and the reinvention of politics. In M. Hajer & H. Wagenaar (Eds.), *Deliverative policy analysis: understanding governance in the network society* (pp. 88-110). Cambridge: Cambridge University Press.
- Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity: Views from urban planning. *American Journal of Preventive Medicine*, *23*(2, Supplement 1), 64-73.  
doi:[http://dx.doi.org/10.1016/S0749-3797\(02\)00475-0](http://dx.doi.org/10.1016/S0749-3797(02)00475-0)
- Hanford, J. K., Crowther, M. S., & Dieter, F. H. (2016). Effectiveness of vegetation-based biodiversity offset metrics as surrogates for ants. *Conservation Biology*, *Early view*, doi: 10.1111/cobi.12794.
- Hansen, R., Rolf, W., Santos, A., Ana, C. L., Száraz, L., Tosics, I., Vierikko, K., Rall, E., Davies, C., & Pauleit, S. (2016). *Advanced Urban Green Infrastructure Planning and Implementation: innovative approaches and strategies from European cities*. Green Infrastructure Planning and Implementation. Available at [http://greensurge.eu/working-packages/wp5/files/D5\\_2\\_Hansen\\_et\\_al\\_2016\\_Advanced\\_UGI\\_Planning\\_and\\_Implementation\\_v3.pdf](http://greensurge.eu/working-packages/wp5/files/D5_2_Hansen_et_al_2016_Advanced_UGI_Planning_and_Implementation_v3.pdf)
- Ilhardt, B. L., Verry, E. S., & Palik, B. J. (2000). Defining Riparian Areas. In E. S. Verry, J. W. Hornbeck, & C. A. Dolloff (Eds.), *Riparian Management in Forests of the Continental Eastern United States* (pp. 23-42): Lewis Publishers.
- IPCC (Intergovernmental Panel on Climate Change) (n.d.). Working Group I: The Scientific Basis Appendix 1: Glossary. Available at <https://www.ipcc.ch/ipccreports/tar/wg1/518.htm>.
- Ives, C. D., Hose, G. C., Nipperess, D. A., & Taylor, M. P. (2011). The influence of riparian corridor width on ant and plant assemblages in northern Sydney, Australia. *Urban Ecosystems*, *14*(1), 1-16.
- Ives, C. D., & Kelly, A. H. (2016). The coexistence of amenity and biodiversity in urban landscapes. *Landscape Research*, *41*(5), 495-509.  
doi:10.1080/01426397.2015.1081161
- Ives, C. D., Lentini, P. E., Threlfall, C. G., Ikin, K., Shanahan, D. F., Garrard, G. E., Bekessy, S. A., Fuller, R. A., Mumaw, L., Rayner, L., Rowe, R., Valentine, L. E., & Kendal, D. (2016). Cities are hotspots for threatened species. *Global Ecology and Biogeography*, *25*(1), 117-126.

- Ives, C. D., Taylor, M. P., & Davies, P. J. (2013). A setback for river and riparian ecosystem: a response to the New South Wales office of water 2012 policy on riparian controls. *Environmental and Planning Law Journal*, 30, 122-131.
- Ives, C. D., Taylor, M. P., Nipperess, D., & Davies, P. (2010). New directions in urban biodiversity conservation: the role of science and its interaction with local environmental policy. *Environmental and Planning Law Journal*, 27, 249.
- Josh Byrne & Associates (2016). *The 202020 Vision Policy Guide: Rules & Regulations*. The 202020 Vision Policy Guides. Available at [http://202020vision.com.au/media/72573/jba\\_book2\\_fa-spreads.pdf](http://202020vision.com.au/media/72573/jba_book2_fa-spreads.pdf)
- Kang, W., Minor, E. S., Park, C. R., & Lee, D. (2015). Effects of habitat structure, human disturbance, and habitat connectivity on urban forest bird communities. *Urban Ecosystems*, 18(3), 857-870. doi:10.1007/s11252-014-0433-5
- Keeley, M., Koburger, A., Dolowitz, D. P., Medearis, D., Nickel, D., & Shuster, W. (2013). Perspectives on the use of Green Infrastructure for stormwater management in Cleveland and Milwaukee. *Environmental Management*, 51(6), 1093-1108. doi:10.1007/s00267-013-0032-x
- Kellert, S. (2016). Biophilic urbanism: the potential to transform. *Smart and Sustainable Built Environment*, 5(1), 4-8. doi:doi:10.1108/SASBE-10-2015-0035
- King, R. S., Barker, M. E., Whigham, D. F., Weller, D. E., Jordon, T. E., Kazyak, P. F., & Hurd, M. K. (2005). Spatial considerations for linking watershed land cover to ecological indicators in streams. *Ecological Applications*, 15, 137-153.
- Krebs, C. J. (1972). *Ecology, the Experimental Analysis of Distribution and Abundance*. New York: Harper & Row.
- Laurance, W. F. (2010). Habitat destruction: death by a thousand cuts. In N. S. Sodhi & P. R. Ehrlich (Eds.), *Conservation Biology for All*. Oxford: Oxford University Press.
- Lawlor, G., Currie, B., Doshi, H., & Wieditz, I. (2006). Green Roofs: A Resource Manual for Municipal Policy Makers. *Canada Mortgage and Housing Corporation*.
- Le Roux, D. S., Ikin, K., Lindenmayer, D. B., Manning, A. D., & Gibbons, P. (2014). The future of large old trees in urban landscapes. *PLoS ONE*, 9(6), e99403. doi:10.1371/journal.pone.0099403
- Lee, K. E., Williams, K. J. H., Sargent, L. D., Williams, N. S. G., & Johnson, K. A. (2015). 40-second green roof views sustain attention: the role of micro-breaks in attention restoration. *Journal of Environmental Psychology*, 42, 182-189. doi:http://dx.doi.org/10.1016/j.jenvp.2015.04.003
- Loram, A., Tratalos, J., Warren, P. H., & Gaston, K. J. (2007). Urban domestic gardens (X): the extent & structure of the resource in five major cities. *Landscape Ecology*, 22(4), 601-615. doi:10.1007/s10980-006-9051-9
- Luck, G. W. (2007). A review of the relationships between human population density and biodiversity. *Biological Reviews*, 82(4), 607-645. doi:10.1111/j.1469-185X.2007.00028.x
- Luck, G. W., Davidson, P., Boxall, D., & Smallbone, L. (2011). Relations between urban bird and plant communities and human well-being and connection to nature. *Conservation Biology*, 25, 816-818.
- Luck, M., & Wu, J. G. (2002). A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA. *Landscape Ecology*, 17, 327-339.

- Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., Panzer, L., Partelow, S., Rau, A.-L., Sasaki, R., Abson, D. J., Lang, D. J., Wamsler, C., & von Wehrden, H. (2015). A review of urban ecosystem services: six key challenges for future research. *Ecosystem Services*, *14*, 98-112.  
doi:<http://dx.doi.org/10.1016/j.ecoser.2015.05.001>
- Lyytimäki, J., Petersen, L. K., Normander, B., & Bezák, P. (2008). Nature as a nuisance? Ecosystem services and disservices to urban lifestyles. *Environmental Sciences*, *5*(3), 161-172.
- MacDonald, H. (2015). 'Fantasies of Consensus:' Planning Reform in Sydney, 2005-2013. *Planning Practice and Research*, *30*(2), 115-138.
- Madre, F., Clergeau, P., Machon, N., & Vergnes, A. (2015). Building biodiversity: Vegetated façades as habitats for spider and beetle assemblages. *Global Ecology and Conservation*, *3*, 222-233. doi:<http://dx.doi.org/10.1016/j.gecco.2014.11.016>
- Major, R. E., & Parsons, H. (2010). What do museum specimens tell us about the impact of urbanisation? A comparison of the recent and historical bird communities of Sydney. *Emu*, *110*(1), 92-103. doi:10.1071/mu09058
- Maron, M., Ives, C. D., Kujala, H., Bull, J. W., Maseyk, F. J., Bekessy, S., Gordon, A., Watson, J. E., Lentini, P. E., Gibbons, P., & Possingham, H. P. (2016). Taming a wicked problem: resolving controversies in biodiversity offsetting. *BioScience*, *66*(6), 489-498.
- Marzluff, J. M. (2005). Island biogeography for an urbanizing world: how extinction and colonization may determine biological diversity in human-dominated landscapes. *Urban Ecosystems*, *8*(2), 157-177. doi:10.1007/s11252-005-4378-6
- McCordle (2016). *Urban Living Index*. Available at <http://urbanlivingindex.com/>
- McDonald, T., Jonson, J., & Dixon, K. W. (2016). National standards for the practice of ecological restoration in Australia. *Restoration Ecology*, *24*(S1), S4-S32.
- McDonnell, M. J. (1997). A Paradigm Shift. *Urban Ecosystems*, *1*(2), 85-86.
- McDonnell, M. J., & Hahs, A. K. (2008). The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: current status and future directions. *Landscape Ecology*, *23*(10), 1143-1155. doi:10.1007/s10980-008-9253-4
- McDonnell, M. J., & Hahs, A. K. (2015). Adaptation and adaptedness of organisms to urban environments. In D. J. Futuyma (Ed.), *Annual Review of Ecology, Evolution, and Systematics*, Vol 46 (Vol. 46, pp. 261-280). Palo Alto: Annual Reviews.
- McIntyre, N. E., Knowles-Yáñez, K., & Hope, D. (2000). Urban ecology as an interdisciplinary field: differences in the use of "urban" between the social and natural sciences. *Urban Ecosystems*, *4*(1), 5-24. doi:10.1023/a:1009540018553
- McPhearson, T., Pickett, S. T. A., Grimm, N. B., Niemelä, J., Alberti, M., Elmqvist, T., Weber, C., Haase, D., Breuste, J., & Qureshi, S. (2016). Advancing urban ecology toward a science of cities. *BioScience*, *66*, 198-212.
- Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning*, *147*, 38-49.  
doi:<http://dx.doi.org/10.1016/j.landurbplan.2015.11.011>
- Meyer, J. L., Paul, M. J., & Taulbee, W. K. (2005). Stream ecosystem function in urbanizing landscapes. *Journal of the North American Benthological Society*, *24*(3), 602-612.  
doi:10.1899/0887-3593(2005)024[0602:SEFIUL]2.0.CO;2
- MEA (Millennium Ecosystem Assessment) (2005). *Ecosystems and Human Well-Being: Synthesis*. Washington, D.C., USA: Island Press.

- Moffatt, S., & Kohler, N. (2008). Conceptualizing the built environment as a social–ecological system. *Building Research & Information*, 36(3), 248-268.  
doi:10.1080/09613210801928131
- Moudon, A. V. (1997). Urban morphology as an emerging interdisciplinary field. *Urban Morphology*, 1(1), 3-10.
- Nassauer, J. I. (1995). Messy Landscapes Orderly Frames. *Landscape Journal*, 14(2), 161-169.
- Nearmap LTD (2017). Available at <http://www.nearmap.com.au/>.
- Norton, B., Bosomworth, K., Coutts, A., Williams, N., Livesley, S., Trundle, A., Harris, R., & McEvoy, D. (2013). *Planning for a cooler future: green infrastructure to reduce urban heat*. Available at <http://www.urbanaffairs.com.au/downloads/2014-2-12-3.pdf>
- Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: a framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, 134, 127-138. doi:<http://dx.doi.org/10.1016/j.landurbplan.2014.10.018>
- Noss, R. F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, 4(4), 355-364.
- NSW Department of Planning and Environment (2014). *A Plan for Growing Sydney*. Available at <http://www.planning.nsw.gov.au/~media/Files/DPE/Plans-and-policies/a-plan-for-growing-sydney-2014-12.ashx>
- NSW Department of Planning and Environment (2015a). *Apartment Design Guide: Tools for improving the design of residential apartment development*. Available at <http://www.planning.nsw.gov.au/~media/7ED8E40113064120AEE3432457390171.ashx>
- NSW Department of Planning and Environment (2015b). *Draft Hunter Regional Plan*. Available at <http://www.planning.nsw.gov.au/~media/Files/DPE/Plans-and-policies/draft-hunter-regional-plan-2015-11.ashx>
- NSW Department of Planning and Environment (2015c). *Illawarra-Shoalhaven Regional Plan; available at http://www.planning.nsw.gov.au/~media/Files/DPE/Plans-and-policies/illawarra-shoalhaven-regional-plan-2015-11.ashx*. Available at <http://www.planning.nsw.gov.au/~media/Files/DPE/Plans-and-policies/illawarra-shoalhaven-regional-plan-2015-11.ashx>
- NSW Department of Planning and Environment (2016). *Draft Medium Density Design Guide: Tools for improving the design of medium density residential development*. Available at <http://www.planning.nsw.gov.au/~media/Files/DPE/Manuals-and-guides/draft-medium-density-design-guide-2016-10.ashx>
- NSW Government, *Threatened Species Conservation Act 1995*. Available at <http://www.legislation.nsw.gov.au/#/view/act/1995/101>
- NSW Government (2015). *Rebuilding NSW State Infrastructure Strategy 2014*. Available at [https://www.nsw.gov.au/sites/default/files/state\\_infrastructure\\_strategy\\_2014\\_-\\_update.pdf](https://www.nsw.gov.au/sites/default/files/state_infrastructure_strategy_2014_-_update.pdf)
- NSW Government (2016). *Premier's Priorities in Action*. Available at <https://www.nsw.gov.au/premiers-priorities>.
- NSW OEH (NSW Office of Environment and Heritage) (2015). *Urban Green Cover in NSW - Technical Guidelines*. Available at <http://climatechange.environment.nsw.gov.au/~media/6AF91E36950E4E06BFC6188A1E7D6343.ashx>

- Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K. K. Y., & Rowe, B. (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. *BioScience*, *57*(10), 823-833. doi:10.1641/b571005
- Palmer, G. C., Fitzsimons, J. A., Antos, M. J., & White, J. G. (2008). Determinants of native avian richness in suburban remnant vegetation: implications for conservation planning. *Biological Conservation*, *141*(9), 2329-2341. doi:10.1016/j.biocon.2008.06.025
- Parris, K. M. (2016). *Ecology of Urban Environments*. Oxford: John Wiley and Sons.
- Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. *Annual Review of Ecology and Systematics*, *32*, 333-365. doi:10.1146/annurev.ecolsys.32.081501.114040
- Peirce, N. R., Johnson, C. W., & Peters, F. M. (2008). *Century of the City: No Time to Lose*. New York: The Rockefeller Foundation.
- Pickett, S., Cadenasso, M., Grove, J., Nilon, C., Pouyat, R., Zipperer, W., & Costanza, R. (2008). Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Urban Ecology*, 99-122.
- Pickett, S. T. A. (2012). Ecology of the City: A Perspective from Science. *Urban Design Ecologies* (pp. 160-169): John Wiley & Sons Ltd.
- Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Boone, C. G., Groffman, P. M., Irwin, E., Kaushal, S. S., Marshall, V., McGrath, B. P., Nilon, C. H., Pouyat, R. V., Szlavecz, K., Troy, A., & Warren, P. (2011). Urban ecological systems: Scientific foundations and a decade of progress. *Journal of Environmental Management*, *92*(3), 331-362. doi:10.1016/j.jenvman.2010.08.022
- Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., & Costanza, R. (2001). Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review Ecological Systems*(32), 127-157.
- Pitman, S. D., & Ely, M. E. (2015). Green infrastructure as life support: urban nature and climate change. *Transactions of the Royal Society of South Australia*, *139*(1), 97-112. doi:10.1080/03721426.2015.1035219
- Power, M. E., Tilman, D., Estes, J. A., Menge, B. A., Bond, W. J., Mills, L. S., Daily, G., Castilla, J. C., Lubchenco, J., & Paine, R. T. (Full publication date: Sep., 1996) (1996). Challenges in the Quest for Keystones. *BioScience*, *46*(8), 609-620. doi:10.2307/1312990
- Primack, R. B. (2010). *Essentials of Conservation Biology*. (2nd ed.). Sunderland, MA, USA: Sinauer Associates.
- Rees, W. E. (1997). Urban ecosystems: the human dimension. *Urban Ecosystems*, *1*, 63-75.
- Rip, A., & Kemp, R. (1998). Technological change. In S. Rayner & E. L. Malone (Eds.), *Human Choice and Climate Change. (Vol. II - Resources and Technology)* (pp. 327-399). Columbus, OH.: Battelle Press.
- Roberge, J.-M., & Angelstam, P. E. R. (2004). Usefulness of the Umbrella Species Concept as a Conservation Tool. Utilidad del Concepto de Especie Paraguas como Herramienta de Conservación. *Conservation Biology*, *18*(1), 76-85. doi:10.1111/j.1523-1739.2004.00450.x
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin (III), F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U.,

- Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., & Foley, J. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*, 14(2), 32. [online] URL: <http://www.ecologyandsociety.org/vol14/iss32/art32/>.
- Rosenzweig, C., Solecki, W., Hammer, S. A., & Mehrotra, S. (2010). Cities lead the way in climate-change action. *Nature*, 467, 909-911.
- Roy, S., Byrne, J., & Pickering, C. (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban Forestry & Urban Greening*, 11(4), 351-363. doi:<http://dx.doi.org/10.1016/j.ufug.2012.06.006>
- Ruming, K. J., & Davies, P. J. (2014). To what extent 'an entirely new approach to how planning is done'? Tracing planning system reform in New South Wales. *Australian Planner*, 51(2), 122-131.
- Scott, J. M., Heglund, P. J., Morrison, M., Haufler, J. B., Raphael, M. G., & Samson, F. B. (2002). *Predicting Species Occurrences: Issues of Scale and Accuracy*. Covello, CA, USA: Island Press.
- Sharifi, E., & Lehmann, S. (2014). Comparative analysis of surface urban heat island effect in central sydney. *Journal of Sustainable Development*, 7(3), 23-34. doi:10.5539/jsd.v7n3p23
- Soga, M., Yamaura, Y., Koike, S., & Gaston, K. J. (2014). Land sharing vs. land sparing: Does the compact city reconcile urban development and biodiversity conservation? *Journal of Applied Ecology*, 51(5), 1378-1386. doi:10.1111/1365-2664.12280
- Soulsbury, C. D., & White, P. C. L. (2015). Human-wildlife interactions in urban areas: a review of conflicts, benefits and opportunities. *Wildlife Research*, 42(7), 541-553. doi:10.1071/wr14229
- Stagoll, K., Lindenmayer, D. B., Knight, E., Fischer, J., & Manning, A. D. (2012). Large trees are keystone structures in urban parks. *Conservation Letters*, 5(2), 115-122. doi:10.1111/j.1755-263X.2011.00216.x
- Steffen, W., Crutzen, P. J., & McNeill, J. R. (2007). The anthropocene: Are humans now overwhelming the great forces of nature. *AMBIO: A Journal of the Human Environment*, 36(8), 614-621.
- Sukopp, H. (2008). On the early history of urban ecology in europe *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature* (pp. 79-97).
- Tait, C. J., Daniels, C. B., & Hill, R. S. (2005). Changes in species assemblages within the Adelaide Metropolitan Area, Australia, 1836-2002. *Ecological Applications*, 15(1), 346-359. doi:10.1890/04-0920
- Taylor, G. (2005). *Negotiated governance and public policy in Ireland*. Manchester: Manchester University Press.
- Taylor, L., & Hochuli, D. F. (2015). Creating better cities: how biodiversity and ecosystem functioning enhance urban residents' wellbeing. *Urban Ecosystems*, 18(3), 747-762. doi:10.1007/s11252-014-0427-3
- TEEB (The Economics of Ecosystems & Biodiversity) (2010). *Mainstreaming the economics of nature a synthesis of the approach, conclusions and recommendations of TEEB*. Available at <http://www.teebweb.org/publication/mainstreaming-the-economics-of-nature-a-synthesis-of-the-approach-conclusions-and-recommendations-of-teeb/>

- Tewksbury, J. J., Levey, D. J., Haddad, N. M., Sargent, S., Orrock, J. L., Weldon, A., Danielson, B. J., Brinkerhoff, J., Damschen, E. I., & Townsend, P. (2002). Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(20), 12923-12926. doi:10.1073/pnas.202242699
- Thompson, K., Austin, K. C., Smith, R. M., Warren, P. H., Angold, P. G., & Gaston, K. J. (2003). Urban domestic gardens (I): Putting small-scale plant diversity in context. *Journal of Vegetation Science*, *14*(1), 71-78. doi:10.1111/j.1654-1103.2003.tb02129.x
- Triguero-Mas, M., Dadvand, P., Cirach, M., Martínez, D., Medina, A., Mompert, A., Basagaña, X., Gražulevičienė, R., & Nieuwenhuijsen, M. J. (2015). Natural outdoor environments and mental and physical health: Relationships and mechanisms. *Environment International*, *77*, 35-41. doi:http://dx.doi.org/10.1016/j.envint.2015.01.012
- Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. *Landscape and Urban Planning*, *81*(3), 167-178. doi:10.1016/j.landurbplan.2007.02.001
- Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and Urban Planning*, *81*(3), 167-178. doi:http://dx.doi.org/10.1016/j.landurbplan.2007.02.001
- United Nations Department of Economic and Social Affairs (2014). *World urbanization prospects: the 2014 revision*. Population Division. Available at <https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf>
- US EPA (United States Environmental Protection Agency) (2008). R. Lukes, C. Kloss, & Low Impact Development Center. *Green streets* Available at [https://www.epa.gov/sites/production/files/2015-10/documents/gi\\_munichandbook\\_green\\_streets\\_0.pdf](https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_green_streets_0.pdf)
- van der Ree, R., & McCarthy, M. A. (2005). Inferring persistence of indigenous mammals in response to urbanisation. *Animal Conservation*, *8*, 309-319. doi:10.1017/s1367943005002258
- Vandermeulen, V., Verspecht, A., Vermeire, B., Van Huylenbroeck, G., & Gellynck, X. (2011). The use of economic valuation to create public support for green infrastructure investments in urban areas. *Landscape and Urban Planning*, *103*(2), 198-206.
- Vanhorne, B. (1983). Density as a misleading indicator of habitat quality. *Journal of Wildlife Management*, *47*(4), 893-901.
- Vitousek, P. M., Mooney, H. A., Lubchenko, J., & Mellilo, J. M. (1997). Human domination of Earth's ecosystems. *Science*, *227*, 494-499.
- von Döhren, P., & Haase, D. (2015). Ecosystem disservices research: A review of the state of the art with a focus on cities. *Ecological Indicators*, *52*, 490-497. doi:http://dx.doi.org/10.1016/j.ecolind.2014.12.027
- Vucetich, J. A., Bruskotter, J. T., & Nelson, M. P. (2015). Evaluating whether nature's intrinsic value is an axiom of or anathema to conservation. *Conservation Biology*, *29*(2), 321-332. doi:10.1111/cobi.12464
- Walsh, C. J., Fletcher, T. D., & Ladson, A. R. (2005). Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the

- stream. *Journal of the North American Benthological Society*, 24(3), 690-705.  
doi:10.1899/0887-3593(2005)024\{0690:sriuct\}2.0.co;2
- Washburn, B. E., Swearingin, R. M., Pullins, C. K., & Rice, M. E. (2016). Composition and Diversity of Avian Communities Using a New Urban Habitat: Green Roofs. *Environmental Management*, 57(6), 1230-1239. doi:10.1007/s00267-016-0687-1
- Western Australian Planning Commission (2010). *Directions 2031 and beyond - metropolitan planning beyond the horizon*. Available at [https://www.planning.wa.gov.au/dop\\_pub\\_pdf/plan\\_directions2031\\_Part1.pdf](https://www.planning.wa.gov.au/dop_pub_pdf/plan_directions2031_Part1.pdf)
- WHO (World Health Organisation) (2006). Constitution of the World Health Organisation. *Basic Documents, Supplement, October 2006* (Forty-fifth edition ed.). Available at [http://www.who.int/governance/eb/who\\_constitution\\_en.pdf](http://www.who.int/governance/eb/who_constitution_en.pdf)
- Wolman, A. (1965). The metabolism of cities. *Scientific American*, 213, 179-190.
- Wu, J. (2014). Urban ecology and sustainability: the state-of-the-science and future directions. *Landscape and Urban Planning*, 125, 209-221.
- Wu, J., He, C., Huang, G., & Yu, D. (2013). Urban landscape ecology: Past, present, and future *Landscape Ecology for Sustainable Environment and Culture* (pp. 37-53).
- Zari, M. P. (2014). Ecosystem services analysis in response to biodiversity loss caused by the built environment. *Surveys and Perspectives Integrating Environment and Society (S.A.P.I.E.N.S.)*, (7.1). Available at <http://sapiens.revues.org/1684>.

DRAFT

## 10 APPENDICES

### Appendix A: Environmental Planning Instruments

The Environmental Planning and Assessment Act enables the making of environmental planning instruments (EPIs). These instruments are made by the state government and are used as part of the plan making and development assessment process. There are a number of different types of EPIs

SEPPs are an adaptable EPI. They can be based on a specific site or apply to the whole of the state, can establish policy frameworks for environmental protection and sustainability affecting land and water, can relate to certain industries or activities, overcome land use conflicts or provide specific planning details. The NSW Department of Planning and Environment are currently reviewing the SEPPs as part of a reform to the planning process.<sup>42</sup>

Despite the name, SEPPs are statutory provisions that modify planning controls under LEPs and in the case of the now repealed Part 3A of the EP&A introduced under *SEPP (Major Development) 2005*, used in order to prevent major projects from being refused development approval. There are several subject matter and area-specific SEPPs which deal with UE principles, and we have examined a number of them here.

#### SEPP No 19 – Bushland in Urban Areas

SEPP No 19 has the general aim of protection and preservation of bushland within urban areas.<sup>43</sup> The specific aims of the policy are:

- (a) to protect the remnants of plant communities which were once characteristic of land now within an urban area,
- (b) to retain bushland in parcels of a size and configuration which will enable the existing plant and animal communities to survive in the long term,
- (c) to protect rare and endangered flora and fauna species,
- (d) to protect habitats for native flora and fauna,
- (e) to protect wildlife corridors and vegetation links with other nearby bushland,
- (f) to protect bushland as a natural stabiliser of the soil surface,
- (g) to protect bushland for its scenic values, and to retain the unique visual identity of the landscape,
- (h) to protect significant geological features,
- (i) to protect existing landforms, such as natural drainage lines, watercourses and foreshores,
- (j) to protect archaeological relics,
- (k) to protect the recreational potential of bushland,
- (l) to protect the educational potential of bushland,
- (m) to maintain bushland in locations which are readily accessible to the community, and
- (n) to promote the management of bushland in a manner which protects and enhances the quality of the bushland and facilitates public enjoyment of the bushland compatible with its conservation.

The operation of the SEPP prevents the disturbance of any bushland zoned or reserved for public open space

<sup>42</sup> Refer to <http://www.planning.nsw.gov.au/Policy-and-Legislation/State-Environmental-Planning-Policies-Review>. Accessed 25/07/16.

<sup>43</sup>State Environmental Planning Policy No 19 – Bushland in Urban Areas cl 2(1).

purposes (or adjoining land) without consent, and prevents a consent authority from approving any development unless an assessment on the need to protect and preserve bushland is undertaken.<sup>44</sup> In addition, the consent authority must be satisfied that the disturbance is essential for a purpose in the public interest and that no reasonable alternative is available.

Furthermore, where it is a public authority that proposes to carry out development, development shall not be carried out without taking into account the need to retain any bushland and the effect of the development on soils, siltation of streams and the spread of weeds and exotic plants within the bushland.<sup>45</sup>

Finally, the SEPP requires LEPs to have regard for its aims and to give priority to any bushland.<sup>46</sup> The SEPP does not apply to land under the *National Parks and Wildlife Act 1974*, State forest or Western Sydney Parklands (which is covered by its own SEPP).

#### SEPP No 65 – Design Quality of Residential Apartment Development

SEPP No 65 contains provisions regarding the design quality of residential apartment buildings. Its general aim “recognises [that] design quality ... is of significance for environmental planning for the State due to the economic, environmental, cultural and social benefits of high quality design”.<sup>47</sup> By improving the design quality of residential apartment developments, the SEPP aims to ensure that it contributes to the sustainable development of NSW by providing sustainable housing in social and environmental terms<sup>48</sup> and that it minimises the consumption of energy from non-renewable sources, conserves the environment and reduces greenhouse gas emissions.<sup>49</sup>

SEPP 65 prevails over all other EPIs with the exception of *SEPP (Building Sustainability Index: BASIX) 2004*,<sup>50</sup> and Development Control Plans (DCPs) cannot be inconsistent with the provision of the Apartment Design Guide.<sup>51</sup> In determining applications, consent authorities must consider advice from the design review panel, the Apartment Design Guide and the overall quality of development. These are standards to which s 79C(2) of the EP&A apply.<sup>52</sup>

The design quality principles set out in the SEPP indicate support for the protection of urban ecology and biodiversity. The guidelines in Principle 4: Sustainability advises protection of ecological zones, namely by:

- use of natural cross ventilation and sunlight for the amenity and liveability of residents and passive thermal design for ventilation, heating and cooling reducing reliance on technology and operation costs;
- recycling and reuse of materials and waste, use of sustainable materials and deep soil zones for groundwater recharge and vegetation;
- enhancing the development’s environmental performance by retaining positive natural features which contribute to the local context, co-ordinating water and soil management, solar access, micro-climate, tree canopy, habitat values and preserving green networks.

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<sup>44</sup> Ibid cls 6, 9.

<sup>45</sup> Ibid cl 9(2)(d).

<sup>46</sup> Ibid cl 10.

<sup>47</sup> State Environment Planning Policy No 65 – Design Quality of Resident Apartment Development cl 2.

<sup>48</sup> Ibid cl 3(a)(i).

<sup>49</sup> Ibid cl 3(e).

<sup>50</sup> Ibid cl 6.

<sup>51</sup> Ibid cl 6A. and NSW Department of Planning and Environment (2015) Apartment Design Guide, tools for improving the design of residential apartment development. July. Available at

<http://www.planning.nsw.gov.au/~media/7ED8E40113064120AEE3432457390171.ashx>. Accessed 26/07/16

<sup>52</sup> Ibid cl 30.

#### SEPP (State Significant Precincts) 2005

This SEPP relates to State Significant Precincts, defined as important urban, coastal and regional sites of economic, environmental or social significance to the State.<sup>53</sup> In the context of this review, a number of State Significant Precincts fall within the target area, including the Sydney Opera House and Luna Park. The SEPP outlines specific requirements for zoning and land use, as well as other requirements such as ecological buffers<sup>54</sup> and design excellence,<sup>55</sup> although these vary from project to project.

#### Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005

The Sydney Harbour Catchment REP is an example of a REP that has been taken to be a SEPP. It applies specifically to the Harbour catchment area, which encompasses land within the target area of this study. The planning principles for this area prescribe that:

- development is to protect and, where practicable, improve the hydrological, ecological and geomorphological processes on which the health of the catchment depends;<sup>56</sup>
- the natural assets of the catchment are to be maintained and, where feasible, restored for their scenic and cultural values and their biodiversity and geodiversity;<sup>57</sup>
- decisions with respect to the development of land are to take account of the cumulative environmental impact of development within the catchment;<sup>58</sup>
- development is to protect and, if practicable rehabilitate watercourses, wetlands, riparian corridors, remnant native vegetation and ecological connectivity within the catchment.<sup>59</sup>

With regard to development applications in the prescribed area, there are specific provisions on biodiversity, ecology and environment protection. These include whether the development protects and enhances terrestrial and aquatic species, populations and ecological communities, whether the land provides vegetative buffers to protect wetlands, and the cumulative impact of the development.<sup>60</sup>

#### SEPP No 59 – Central Western Sydney Regional Open Space and Residential

SEPP 59 applies to the areas of land zoned Regional Open Space and Residential in the Central Western Sydney area. It is intended to oversee the rezoning of certain land for urban development while providing for “*optimal environmental and planning outcomes for the land*”.<sup>61</sup> In doing so, the SEPP intends to:

- conserve those areas that have a high biodiversity or heritage, scenic or cultural value and, in particular, areas of remnant vegetation;
- help to achieve the goals set out in *Action for Air*, the New South Wales Government’s 25-year Air Quality Management Plan;
- implement the principles of good urban design; and
- ensure that extractive industries are carried out in an environmentally acceptable manner.

As a result, when making a consideration for a development application in the Central Western Sydney Region, consent authorities are required to consider, for example, whether the development:

<sup>53</sup>State Environmental Planning Policy (State Significant Precincts) 2005 cl 2(c).

<sup>54</sup>Ibid Sch 3 pt 6 cl 7.

<sup>55</sup>Ibid Sch 3 pt 5 cl 22.

<sup>56</sup>Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005 cl 13(a).

<sup>57</sup>Ibid cl 13(b).

<sup>58</sup>Ibid cl 13(c).

<sup>59</sup>Ibid cl 13(j).

<sup>60</sup>Ibid cl 21(b), (g)-(h).

<sup>61</sup>State Environmental Planning Policy No 59 – Central Western Sydney Regional Open Space and Residential cl 2(a),(g).

- conserves significant bushland and other natural features;
- ensures that the environmental and social quality of existing and future residential areas are safeguarded; and
- is designed and located to ensure the best possible urban design outcomes including landscape quality and visual character.

In the context of this study, this SEPP is an example of how area-specific EPIs could be used to enforce biodiversity in environmentally sensitive sites without impacting on other zoned areas.

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## Appendix B: The EPA's guideline to successful implementation of a green street program.

### Elements necessary for a successful green streets program:

- **Pilot projects are critical.** The most successful municipal green street programs to date all began with well documented and monitored pilot projects. These projects have often been at least partially grant funded and receive the participation of locally active watershed groups working with the city infrastructure programs. The pilot projects are necessary to demonstrate that green streets can work in the local environment, can be relied upon, and fit with existing infrastructure. Pilot projects will help to dispel myths and resolve concerns.
- **Leadership in sustainability from the top.** The cities with the strongest green streets programs are those with mayors and city councils that have fully bought into sustainable infrastructure. Council passed green policies and mayoral sustainability mandates or mission statements are needed to institutionalize green street approaches and bring it beyond the token green project.
- **Buy-in from all municipal infrastructure departments.** By their nature, green streets cross many municipal programs. Green street practices impact stormwater management, street design, underground utilities, public lighting, green space planning, public work maintenance, and budgeting. When developing green streets, all of the relevant agencies must be represented. Also, coordination between the agencies on project planning is important for keeping green infrastructure construction costs low. Superior green street design at less cost occurs when sewer and water line replacement projects can be done in tandem with street redevelopment. These types of coordination efforts must happen at the long-term planning stage.
- **Documentation.** Green street projects need to be documented on two levels, the design and construction level and on a citywide tracking level. Due to the different street types and siting conditions, green street designs will take on many variations. By documenting the costs, construction, and design, the costs of similar future projects can be minimized and construction or design problems can be avoided or addressed. Tracking green street practices across the city is crucial for managing maintenance and quantifying aggregate benefits.
- **Public outreach.** Traditional pollution prevention outreach goes hand in hand with green street programs. Properly disposing of litter, yard waste, and hazardous chemicals and appropriately applying yard chemicals will help prolong the life of green street practices. An information campaign should also give the public an understanding of how green infrastructure works and the benefits and trade offs. In many cases, remedial maintenance of green street practices will be performed by neighboring property owners; they need to know how to maintain the practices to keep them performing optimally.

Source: US EPA (2008)

## Appendix C: Journals from which articles have been sourced

1	Ambio
2	American Journal of Preventive Medicine
3	Annals of the New York Academy of Sciences
4	Annual Review of Ecology, Evolution, and Systematics
5	Applied Acoustics
6	Applied Energy
7	Arboriculture and Urban Forestry
8	Australian Geographer
9	Biological Conservation
10	Biology Letters
11	BioScience
12	Building and Environment
13	Building Research & Information
14	Chemical Engineering Journal
15	Climate Dynamics
16	Conservation Letters
17	Current Opinion in Environmental Sustainability
18	Ecological Applications
19	Ecological Economics
22	Ecological Engineering
23	Ecological Indicators
24	Ecological Monographs
25	Ecology Letters
26	Ecosystem Services
27	Energy and Buildings
28	Environment and Behavior
29	Environment International
30	Environmental Health Perspectives

31	Environmental Management
33	Environmental Pollution
34	Environmental Research Letters
35	Environmental Science & Policy
36	Environmental Science and Technology
37	Forests
38	Frontiers in Ecology and the Environment
39	Futures
40	GeoJournal
41	Global Ecology and Biogeography
42	Global Ecology and Conservation
43	Health and Place
45	International Journal of Environmental Research and Public Health
46	International Journal of Public Health
47	Journal of Affective Disorders
48	Journal of Animal and Veterinary Advances
49	Journal of Cleaner Production
51	Journal of Environmental Management
52	Journal of Environmental Planning and Management
53	Journal of Environmental Psychology
54	Journal of Environmental Quality
55	Journal of Epidemiology and Community Health
56	Journal of Hazardous Materials
57	Journal of Industrial Ecology
58	Journal of Sustainable Development
59	Landscape and Ecological Engineering
61	Landscape and Urban Planning
62	Landscape Ecology
64	Landscape Research

65	Natural Resources Journal
66	Nature
67	Natures Sciences Societes
68	Oikos
69	Pediatrics
70	Plant and Soil
71	PLoS ONE
72	Psychological Science
73	Renewable Energy
74	Science
76	Science of The Total Environment
77	Scientific American
78	Scientific Reports
79	Smart and Sustainable Built Environment
80	Social Indicators Research
81	Social Science & Medicine
82	Structural Survey
83	Sustainability
84	The Lancet
85	Transactions of the Royal Society of South Australia
86	Trends in Ecology & Evolution
88	Urban Ecosystems
89	Urban Forestry and Urban Greening
90	Water Science and Technology
91	Wildlife Research

## Appendix D: Built Environment – Literature review search terms

NUMBER	DATE	KEY WORD SEARCH	TIME FRAME	RESULTS	SEARCH ENGINE	COMMENTS
1	29/06/2016	urban ecology and ecosystem services and review	10 years	69	SCOPUS	not many relevant
2	29/06/2016	urban ecology and the built environment and review	10 years	15	SCOPUS	not many relevant
3	30/06/2016	urban ecology and resilience and review	10 years	23	SCOPUS	not many relevant
4	30/06/2016	urban ecology and resilience	10 years	166	SCOPUS	
5	30/06/2016	urban ecology and urban resilience	10 years	166	SCOPUS	
6	30/06/2016	green infrastructure AND urban resilience	10 years	69	SCOPUS	
7	pre May 2016	various			Google	Searches undertaken before UNSW log in given
8	1/07/2016	urban resilience and review	10 years	178	SCOPUS	not many relevant
9	4/07/2016	urban ecosystem services and stormwater	10 years	76	SCOPUS	mid review of results
10	5/07/2016	urban ecology and economic benefits	10 years	157	SCOPUS	not many relevant
11	6/07/2016	urban ecology and aesthetic benefits	10 years	17	SCOPUS	not many relevant
12	6/07/2016	urban ecology and visual benefits	10 years	13	SCOPUS	
13	6/07/2016	urban ecology and visual	10 years	115	SCOPUS	not many relevant
14	6/07/2016	urban ecosystem services	10 years	2060	SCOPUS	a lot of results
15	8/07/2016	built environment and ecology	10 years	1,670,000	Google Scholar	not many relevant
16	14/07/2016	green roofs and urban heat island	10 years	37000	Google Scholar	

17	21/07/2016	urban ecology and green wall	10 years	33	SCOPUS	
18	22/07/2016	urban ecology and blue infrastructure	10 years	3	SCOPUS	
19	4/08/2016	effects of green roofs			SCOPUS	

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## 11 ACRONYMS AND ABBREVIATIONS

AUD	Australian dollar
CPTED	Crime Prevention through Environmental Design
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	community strategic plan
DCP	development control plan
EPA	Environmental Protection Agency
EPI	environmental planning instrument
EU	European Union
EUR	euro
FMA	Fisheries Management Act 1994
GAK	General Urban Mitigation Plan (Berlin - Gesamtstädtische Ausgleichskonzeption)
GARP	Greened Acre Retrofit Program (Philadelphia)
GREEN SURGE	Green Infrastructure and Urban Biodiversity for Sustainable Urban Development and the Green Economy
GSC	Greater Sydney Commission
GSC Act	Greater Sydney Commission Act 2015
IGS	informal green space
ISC	Impervious surface cover
LaPro	Landscape Programme (Berlin)
LEED	Leadership in Energy and Environmental Design
LEP	local environment plan
LGA	local government area
LLSA	Local Land Services Act 1993
NABERS	National Australian Built Environment Rating System (AUS)
NatHERS	Nationwide House Energy Rating Scheme (AUS)
NCT	Nature Conservation Trust
NCTA	Nature Conservation Trust Act 2001
NSW	New South Wales

NVA	Native Vegetation Act 2003
OEH	Office of Environment and Heritage
RMS	Roads and Maritime Services
SEPP	state environment planning policy
SMIP	Stormwater Management Incentives Program (Philadelphia)
SOC	soil organic carbon
SSD	state-significant development
SSI	state-significant infrastructure
TEV	total economic value
UERI	Urban Ecology Renewal Investigation
UHI	urban heat island
UNSW	University of New South Wales
US	United States of America
USD	US dollar
USyd	The University of Sydney
WSUD	water-sensitive urban design

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