GUIDELINES FOR BIODIVERSITY GREEN ROOFS

THE UNIVERSITY OF MELBOURNE

CITY OF MELBOURNE

Acknowledgement of Traditional Owners

The City of Melbourne respectfully acknowledges the Traditional Owners of the land we govern, the Wurundjeri Woi-Wurrung and Bunurong Boon Wurrung peoples of the Eastern Kulin and pays respect to their Elders past, present and emerging.

We acknowledge and honour the unbroken spiritual, cultural and political connection the Wurundjeri, Bunurong, Dja Dja Wurrung, Taungurung and Wadawurrung peoples of the Eastern Kulin have to this unique place for more than 2000 generations.

We are committed to our reconciliation journey, because at its heart, reconciliation is about strengthening relationships between Aboriginal and non-Aboriginal peoples, for the benefit of all Victorians.

TABLE OF CONTENTS

Julia Schiller, John P. Rayner and Nicholas S. G. Williams

School of Agriculture, Food and Ecosystem Sciences
University of Melbourne

Front cover image: Burnley Biodiversity Green Roof located at the University of Melbourne, Burnley Campus. Photo by Nicholas Williams.

Acknowledgements

The authors would like to thank the Parks and City Greening Branch at the City of Melbourne for their enthusiasm for the project and thorough review. The authors also thank Amy Hahs (University of Melbourne) for developing the process to select target fauna species outlined on page 26, Caragh Threlfall (Macquarie University) for advice on microbats, and Gary Simpson (Infinite Landscape) for his expertise and feedback during the peer review process for the list of plants suitable for biodiversity green roofs in Melbourne (see Urban Nature Planting Guide) which accompanies this guidelines document. The maintenance guidelines and sample schedule included in this document were originally developed as part of the project 'Researching the benefits of demonstration green roofs across Australia (GC16002)'. This was funded by the Hort Frontiers Green Cities Fund, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from the University of Melbourne, City of Melbourne, the Victorian Department of Environment, Land, Water and Planning, and contributions from the Australian government. We thank them for permission to use the material.

These guidelines were written by the University of Melbourne and supported by the City of Melbourne.

Please cite this document as:

Schiller, J., Rayner, J.P. and Williams, N.S.G. (2023) Guidelines for Biodiversity Green Roofs. Report for the City of Melbourne.

INTRODUCTION

Australia is one of the most urbanised countries in the world, and our major cities are experiencing rapid population growth and increasing densification. It is estimated that by 2056 about 80% of Victoria's population will live in Greater Melbourne[1]. Urbanisation increases the cover of impervious surfaces (i.e. buildings, streets) at the cost of native vegetation and green spaces. This is concerning due to the resulting loss of biodiversity and associated ecosystem services. Urban nature is also essential for human health and well-being. Positive and more frequent people-nature experiences can help increase awareness of and affinity for biodiversity conservation issues, both within the city and outside urban areas[2-5]. Green roofs are a novel engineered ecosystem that can help to address this need.

Green roofs can have many benefits: stormwater retention, building cooling, building energy savings, improved microclimate with potential to mitigate the urban heat island (UHI) effect, well-being, and biodiversity benefits[6,7]. In regions with seasonally hot and dry climates, such as much of southern Australia, maintaining a successful green roof can be challenging due to harsh climatic conditions during summer months.

In the last decade, researchers and the green roof industry have developed green roof substrates, designs and plant palettes that successfully withstand the Australian climate[8]. This foundation now allows green roofs to be designed to perform specific functions such as cooling, maximising stormwater retention or improving urban biodiversity. However, the interactions with biodiversity and green roofs in Australia is not well known and very few Australian green roofs are designed specifically to improve urban biodiversity habitat. In Melbourne, most of the green roofs built to date have been accessible green roofs designed to provide amenity spaces for apartments, office buildings or hospitals[8].

What is a green roof?

A green roof consists of a waterproof layer, a root barrier, a drainage layer, filter fabric and a lightweight growing substrate covered by plants. Green roofs with shallower substrate depths and low growing plants (e.g. succulents, herbaceous plants) selected for their lower water use requirements, are traditionally categorised as 'extensive green roofs'. Whereas 'intensive green roofs' usually have deeper substrates that support a greater variety of plant types such as lawn, shrubs and even small trees, but need more irrigation and maintenance.

Recently, this categorisation has become less distinct with many green roofs possessing characteristics of both types. A more useful typology recently proposed is naming green roofs according to their function and vegetation[9]. For example, a 'biodiversity native grassland green roof' or 'passive recreation native shrub green roof'. This typology also helps to clearly articulate the objective of the green roof, which influences flow on decisions about species selection, maintenance, among other key design considerations.

Residential
Biodiversity Green Roof
Hawke and King Apartments,
West Melbourne

Photo: Ben Nicholson, The Urban Greener

Local policy context

Increasing biodiversity within the urban environment is a goal of the City of Melbourne. This is articulated in strategies, policies and Council motions[10,11], including City of Melbourne's Nature in the City Strategy and Green our City Strategic Action Plan. But there are limited opportunities within the city to do so because of the constraints imposed by the high density of buildings and heritage listed parks and gardens.

City of Melbourne declared a Climate and Biodiversity Emergency in 2019 – a local and international movement recognising that climate change and mass species extinction poses serious risks to the people of Melbourne and Australia. The Victorian State Government has also recognised the importance of green infrastructure in the context of climate change and continued rapid increases in population through its Plan Melbourne 2017-2050 framework which specifically highlights a role for green roofs.

City of Melbourne has been progressing local environmentally sustainable design and green infrastructure policy through **Planning Scheme Amendment C376 Sustainable Building Design ('Amendment C376').** Amendment C376 will introduce new best-practice standards into the planning scheme to ensure that new buildings, alterations and additions in the municipality respond to the Climate Change and Biodiversity Emergency.

The **Green Factor Tool** (part of Amendment C376) was developed by the City of Melbourne with the University of Melbourne to support developers to optimise the design of green infrastructure on new developments. It is underpinned by an extensive and growing evidence-base and is intended to provide a consistent assessment methodology for greening on buildings for applicants, planners and referral experts. This Tool is City of Melbourne's preferred mechanism for demonstrating urban ecology outcomes on eligible developments requiring a minimum Green Factor score of 0.55 as proposed under the Urban Ecology standard in Amendment C376.

Amendment C376 and the Green Factor Tool are intended to stimulate the incorporation of green roofs, green facades and green walls into new developments and buildings within the City of Melbourne[12]. However, due to building design constraints not all green roofs can be accessible to people. Accessible green roofs can also be considerably more expensive due to additional weight loading, fall safety requirements (i.e. balustrades) and fire regulations. Consequently, developers may choose to implement inaccessible green roof designs that are lower cost but can still provide multiple ecosystem services and environmental benefits.

Green roofs specifically designed for biodiversity may therefore be a desirable way to meet the aspirations of the City of Melbourne's Green Factor Tool approach, simultaneously addressing government policy and corporate sustainability goals. However, landscape architects and other green roof designers typically have limited ecological knowledge, and there are risks that new green roofs may not fulfil their potential. More concerning, these sites could act as ecological traps that are detrimental to biodiversity. While large, complex green roof projects should include ecologists in the project team, not all projects will have the resources to do this.

For more information on Amendment C376 and the Green Factor Tool:

www.participate.melbourne.vic.gov.au/amendment-c376

www.greenfactor.com.au

Purpose of guidelines

The 'Guidelines for Biodiversity Green Roofs' has been developed to provide advice to building owners, landscape architects, landscape construction contractors and horticulturalists wanting to design and build a green roof that has a primary purpose as **provision of habitat for biodiversity.**

In this document, we explain the characteristics of green roofs known to influence their biodiversity habitat value, provide an evidenced-based overview of the fauna taxa known to live on and utilise green roofs, detail green roof design elements known to be important for fauna and suggest some Victorian habitat templates and plant traits to guide green roof plant selection. To guide the design of future biodiversity green roofs in Melbourne, we have compiled a list of suitable plants, comprising mostly native plant species known to grow successfully on green roofs, the biodiversity resources they can provide and fauna taxa recorded using them.

The infographic on the following page (Figure 1) provides a summary of the key considerations when designing green roofs for biodiversity. These considerations are explored throughout the document.

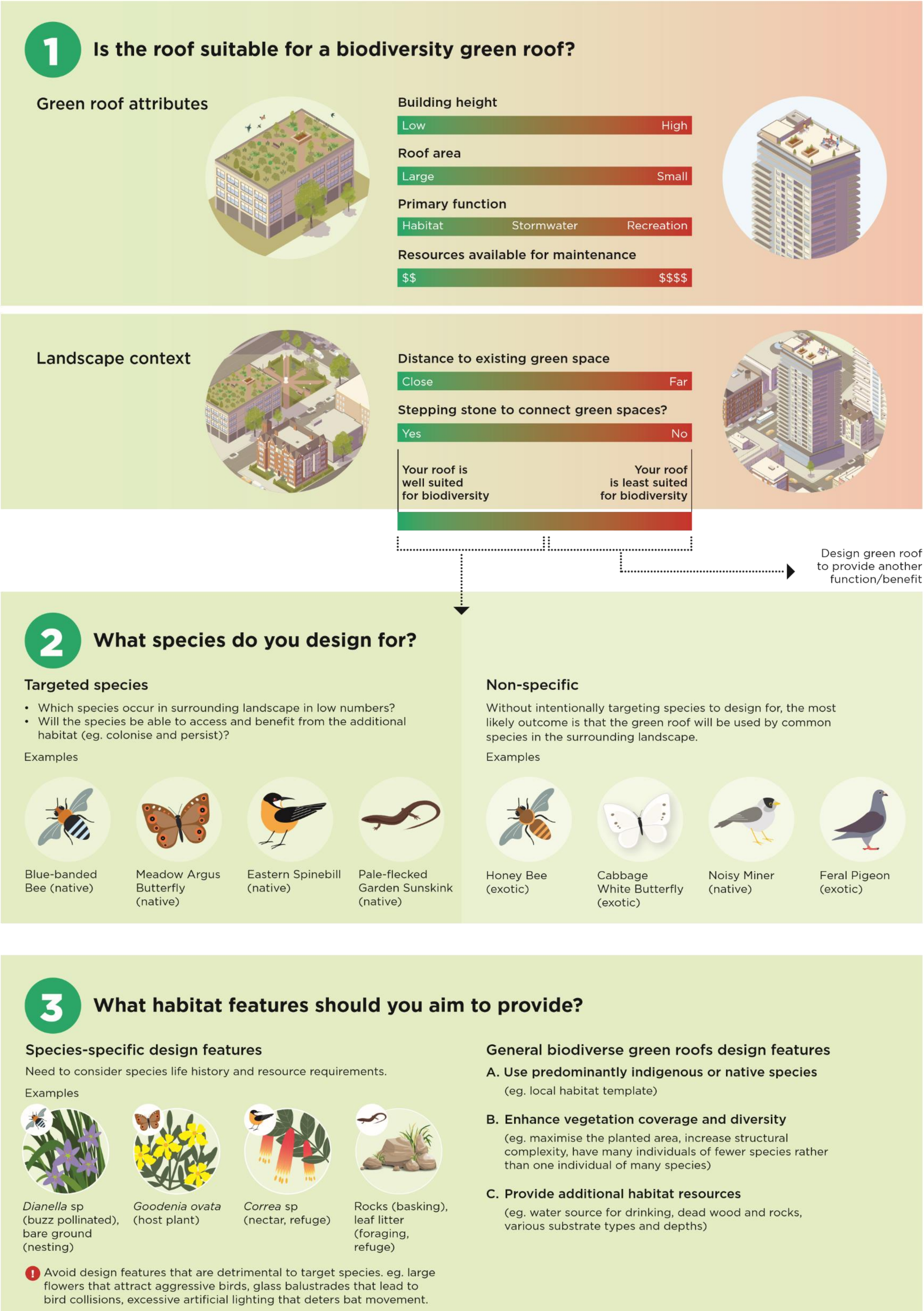


Figure 1. Summary of the key considerations when designing green roofs for biodiversity.

Why green roofs may be useful for biodiversity

There are many reasons to consider designing and constructing a green roof for biodiversity habitat. Roofs comprise a large proportion of the surface area of most cities, particularly in higher density central business districts, suburban activity centres and the inner suburbs where ground-level habitat is limited.

Although conventional roofs can be colonised by vegetation (particularly if wind-blown dust and soil is allowed to accumulate), deliberately adding substrate and vegetation to a formerly bare, impervious surface will provide stormwater retention benefits, urban cooling and create additional biodiversity habitat in cities[13,14]. Green roofs will therefore nearly always support greater faunal biodiversity than conventional roofs. Furthermore, if a green roof is planted with a diversity of indigenous plant species, local evidence from ground-level research suggests that it will support higher invertebrate abundance and diversity which in turn benefits insectivorous birds and bats[15,16].

Ground-level urban habitat patches can be subject to frequent disturbances associated with human access and use including mowing, trampling and exposure to a predation by domestic pets. Consequently, green roofs can provide urban habitat isolated from ground-level which can potentially act as biodiversity refuges for species sensitive to urban stressors.

A green roof's location within the landscape can also play an important role for animal movement and plant dispersal. Green roofs can be used as habitat stepping-stones by a variety of mobile fauna, such as birds, bats, bees, carabid beetles, spiders and weevils[17] to move through the urban landscape. They can improve the ecological connectivity of cities, providing links between large, urban green spaces of greater biodiversity value (i.e. parks, gardens, cemeteries, wetlands). Moreover, green roofs with a native planting palette have the potential to seed species into adjacent areas allowing them to colonise parts of the city where native vegetation has become scarce.

Biodiversity Green Roof
Minifie Park Early Childhood Centre,
Balwyn, Melbourne

Photo: Jacinda Drumgold

GREEN ROOFS DESIGNED FOR BIODIVERSITY

While most green roofs are not specifically designed for biodiversity, they can be improved by retrofitting elements that will provide resources to support fauna. Green roofs can also be designed with biodiversity habitat as their main purpose. These biodiverse green roofs are much more likely to support diverse faunal assemblages which is why some municipalities in Europe and North America have developed detailed biodiversity design guidelines for green roofs, often including planting palettes[18,19,20]. Best practice guides have also been developed to promote specific taxa on a green roof, such as design interventions to attract invertebrates[21] or insectivorous bats[22].

Recreating ground-level habitat on a rooftop to attract a locally rare target species is a complex task which requires detailed knowledge about the species' life history and resource requirements. A number of international projects have attempted this by developing green roof designs targeting one specific species of interest. Examples include the Black Redstart project in the United Kingdom where green roofs have been installed to provide nesting habitat for a rare bird species that is negatively affected by urban renewal projects and redevelopment of brownfield sites[23]. Similar projects have been established for rare ground-nesting birds in Switzerland[24] and an endangered butterfly in the San Francisco Bay area (although this project did not properly consider the ecology and dispersal ability of the species)[14].

Potential drawbacks

It is important to acknowledge the limitations of using green roofs for urban biodiversity habitat. Green roofs can provide supplementary novel habitat for existing urban biodiversity that already occurs in the local area – however, they should not be considered as replacement habitat for ground-level green space or remnant vegetation, as their ability to replicate ecological communities is unproven[14]. Green roof policies should reflect this, while those designing and building green roofs for biodiversity need to acknowledge their limitations and incorporate available ecological knowledge in an effort to provide good quality habitats.

This is important because green roofs that appear to provide suitable habitat for a species but do not offer the essential resources for survival and reproduction, can potentially be an 'ecological trap'. Ecological traps occur when animals prefer or select habitats that reduce their ecological fitness by causing mortality or reducing reproductive output. For example, in Switzerland green roofs were specifically designed as nesting habitat for ground-breeding birds that lost their natural breeding grounds due to agricultural intensification. Initial monitoring indicated very high chick mortality rates due to some design flaws, thereby creating an ecological trap[26,27]. However, chick survival significantly increased after some minor design modifications to the green roof. This included installation of a balustrade to prevent fatal falls from the roof's edge and increased availability of water and food in the temporary pond[24].

What characteristics of green roofs influence their biodiversity and why?

The diversity, composition and abundance of green roof faunal communities will be influenced by:

- characteristics of the green roof,
- characteristics of the landscape or neighbourhood in which it is found,
- potential interactions between them.

Many of these factors also drive ground-level urban biodiversity patterns but some are unique to the green roof context. Roof characteristics found to influence biodiversity include green roof age, height, area, substrate depth, plant cover and diversity, habitat diversity, management regime and connectivity.

Knapp et al. (2019)[13] provide a useful review and summary of the various green roof characteristics influencing species richness, abundance and functional diversity. This is summarised in Table 1. We elaborate and explain some of these characteristics in this section.

Table 1: Summary of the response of biodiversity to roof characteristics adapted from Knapp et al. (2019)[13]. ↑ = increase in biodiversity outcome, ↓ = decrease in biodiversity outcome.

ROOF CHARACTERISTICS	BIODIVERSITY OUTCOME
Conventional vs green roof	Conventional roof = ↓ species richness and abundance compared to a green roof
Roof habitat vs ground-level habitat	Roof habitat = ↓ species richness and abundance compared to ground-level habitat
Age	Mixed evidence
Area	↑ size of the green roof (area) = ↑ species richness and abundance
Connectivity	↑ connectivity = ↑ species richness and abundance
Height	↑ roof height = ↓ species richness and abundance
Substrate depth	↑ substrate depth = ↑ species richness and abundance
Irrigation	Irrigation installation = ↑ species richness and abundance
Plant cover	↑ plant cover = ↑ species richness
Plant diversity	↑ plant diversity = ↑ species richness and abundance
Microclimate diversity	↑ microclimate diversity = ↑ species richness and abundance
Structural complexity	↑ structural complexity = ↑ species richness and abundance

Vegetation

Recent local research suggests that increasing the amount of structurally complex native vegetation can increase biodiversity significantly in ground-level urban green spaces[15,16]. While any vegetation has a positive effect on biodiversity compared to a conventional unplanted roof[28-30], the most important determinant of green roof biodiversity is the vegetation that is planted on them.

This vegetation strongly depends on, and varies with substrate depth[31] as it determines the type of plants that can survive. Taller vegetation of greater structural complexity such as small trees and shrubs can only grow in deeper substrates (i.e. > 30 cm) while shallow substrates can only support simpler vegetation types such as succulents, low biomass grasses and geophytes. Vegetation structure, cover, diversity and origin are all important aspects of the green roof planting palette to consider and will be discussed later in the guide.

Age

While the green roof industry is relatively young in Australia, it has a long history in some European countries. Limited studies have investigated the effect of green roof age on fauna[13,34]. One study found that the abundance of soil organisms decreased after the initial planting of a green roof in London, United Kingdom[32], whereas no effect was found in *Collembola* (Springtail) abundance when compared between young and old green roofs in Hanover, Germany[33]. In many cases, it is likely that changes in green roof fauna over time will be related to the dynamics of green roof vegetation. For example, increases in vegetation diversity and structure due to spontaneous plant colonisation is likely to increase fauna resources whereas widespread death and simplification of planted green roof vegetation could decrease faunal diversity.

Biodiversity green roof located on Hawke and King Apartments, West Melbourne. This green roof was planted with *Lomandra longifolia*, *Poa labillardieri* and *Themedia triandra* in early 2018. It includes two perching logs, eight large volcanic stones and a small ephemeral pond, for shelter and a semi-reliable water source. Photo: Ben Nicholson, The Urban Greener.

Area

The area that a green roof covers is another variable found to affect biodiversity. By applying the Island biogeography theory[35] to dense urban areas, this predicts that larger green roofs should support greater species abundance and richness than smaller ones due to an increased variety of resources available to fauna. This has been shown to be true for arthropods[17,29,36-38], snails[39], birds[40,41] and microbats[42].

Height

Green roofs are different to ground-level urban habitats because they can be both horizontally and vertically isolated. The ability of most taxa to colonise green roofs has been found to be negatively correlated with roof height. This includes beetles[43], bees, wasps[44], bats[42], birds and butterflies[28,41]. It is likely that functional traits that correlate with movement ability such as body size for invertebrates are important for a species' ability to colonise those elevated habitats[45,46].

While the location and height of a green roof are both important determinants of green roof biodiversity, it is their interaction that really shapes the species community. A green roof may need to be physically connected to ground-level habitat for taxa that cannot fly or easily climb vertical surfaces to access it. Increasing this type of connectivity is also likely to increase the richness and abundance of fauna using a green roof.

Substrate

The substrate type and depth are key indicators of which vegetation can survive on a green roof. Therefore, it is expected that the substrate will also positively correlate with faunal diversity[31]. However, more detailed assessments have concluded that heterogeneity in both substrate depth and component materials shapes arthropod communities which are the basis of complex trophic structures. Although plant cover strongly influences the biodiversity on green roofs, it is as important to establish areas of bare soil of different granule sizes[47]. This is essential for many solitary bee species and other insects that burrow their nests into the ground[31,47] as well as for some ground-nesting birds[24,48].

Accessibility

Most of Melbourne's green roofs are designed for passive recreation which often results in a smaller area dedicated for vegetation – only 36% of the area of a typical green roof in Metropolitan Melbourne is planted, with about 64% of the area designed for social gatherings and activities (Schiller et al. unpublished). This appears to be contrary to practice in European countries, particularly Switzerland and the United Kingdom, where vegetation covers a much higher proportion of most green roofs, and they are only accessible for maintenance. Green roofs that are inaccessible to people could be more attractive for biodiversity, particularly for species intolerant of disturbance. However, more research is needed in this area. To date, there has only been one study assessing how human use affects biodiversity on green roofs, and no significant relationship was found between human presence and bird or butterfly abundance and richness[41].

Location and connectivity

The location of a green roof and how well it is connected to other suitable habitat is an important determinant of the biodiversity that can colonise or use it. Ecological connectivity depends on the amount and quality of habitat available within a target species' movement range and barriers to the species movement. These barriers could be physical (i.e. a road, building height) or related to the species themselves (i.e. ability to fly). If a green roof or a network of them are installed at strategic locations, they might be able to serve as part of a connectivity corridor enabling different fauna to move through the city.

Numerous studies have found that the amount of vegetation cover in neighbourhoods surrounding the green roof had strong positive effects on species richness[17,36,42,44,49-52]. This suggests that green roofs closer to ground-level habitats will have more diverse fauna assemblages. In an important study, Braaker et al. (2017) [53] assessed how a green roof's location affected arthropod diversity, and found that it increased with increasing connectivity to ground-level habitat as well as to nearby green roofs.

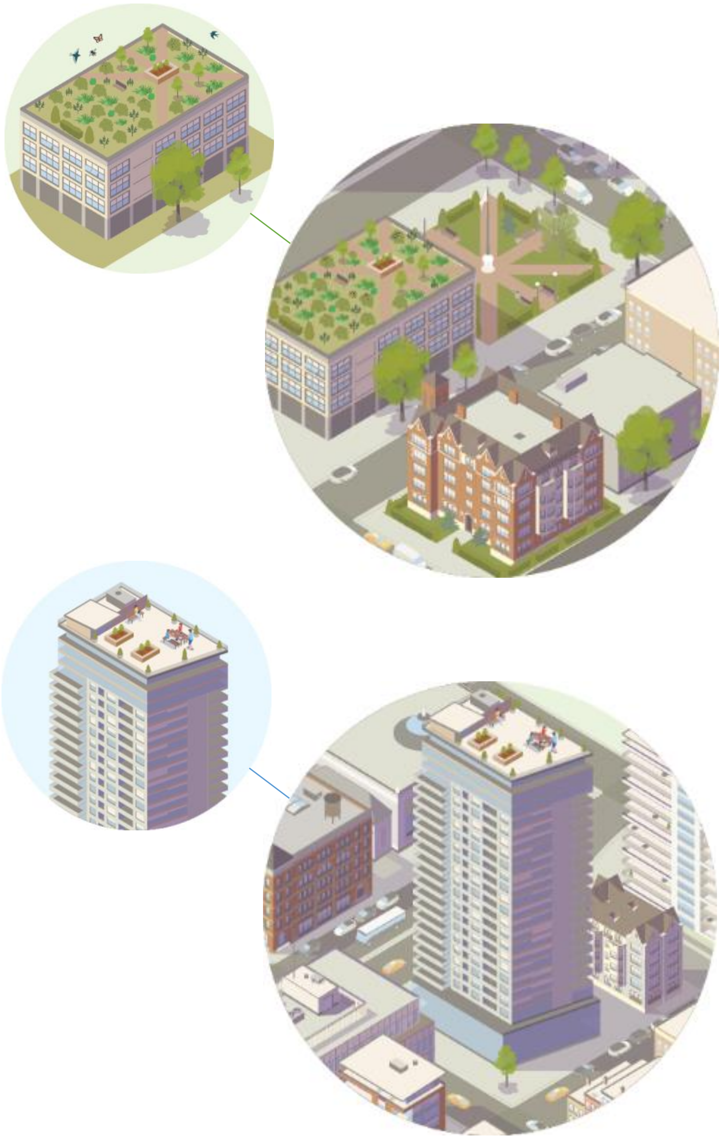


Illustration of a roof well suited for biodiversity (top) vs a green roof less suited for biodiversity (bottom), based on green roof attribues and landscape context.

OVERVIEW OF FAUNA TAXA LIKELY TO USE GREEN ROOFS

General patterns

Reviews of the scientific literature reveal a diverse range of fauna has been recorded using green roofs. Arthropods followed by birds are the most studied taxa on green roofs, but bat use has also received research attention[13]. Green roofs support greater bird[28,13,54] and arthropod[29] species richness than conventional roofs as they provide foraging and breeding opportunities that are otherwise absent[14]. However, the species richness of bird[40,55,], bee[45,53,56,57] and other arthropod communities[53,58] on green roofs is generally lower than those in similar nearby ground-level habitats.

Invertebrates

A wide range of invertebrates are known to use green roofs in Melbourne (Figure 2). While there has only been limited local research, the invertebrate fauna of green roofs is well studied internationally. The following section reviews this research and outlines the habitat and resource requirements of specific taxa groups.

Bees and wasps

Bee communities using green roofs are relatively well studied. They are a subset of ground-level communities and tend to be generalist species[57,59]. This is filtered by their ability to reach the roof[44] which may be related to body size[53,129]. A number of studies have reported ground-nesting bees to be more common on green roofs than species with other nesting requirements[53,57,59,60]. This indicates that green roof substrates may be attractive to this group, particularly if they are finely textured[45]. However, characteristics of the substrates (i.e. type of mineral component, particle size distribution, amount of bare substrate) need to be considered.

In Melbourne, European Honey Bees are the most common bee species found foraging on green roofs, and are known to visit both native and exotic plants. For larger native bees of the genus *Megachile* or *Amegilla*, these are known to consistently visit lower green roofs in Melbourne (J. Schiller pers. obs.). For instance, Blue-banded Bees (*Amegilla* sp.) and their kleptoparasite the Chequered Cuckoo Bee (*Thyreus caeruleopunctatus*), which lays eggs in their nests, are regularly observed on the Burnley Demonstration Green Roof at the Univeristy of Melbourne's Burnley Campus (J. Schiller pers. obs.).

Wasps frequently occupy holes in human-made infrastructure, such as cracks and crevices, in addition to nesting sites in coarse substrates which can make green roofs attractive habitat[44]. However, wasp diversity has been found to decline as building height increases and amount of green space in the surrounding area decreases[44,130] which suggests that inadequate connectivity is of concern for this taxon. Since solitary wasps often forage on pest insects which is a desirable ecosystem service, their presence on green roofs should be supported. Native wasps have been recorded on lower green roofs in Melbourne with an interesting trend – European Wasps (*Vespula germanica*) were often found on lawns whereas a green roof with larger areas of gravel and sand supported high numbers of native Sand Wasps (Sphecidae). The adult Sand Wasp was observed feeding on nectar plants but also hunting for prey (J. Schiller pers. obs.).

Although introduced European Wasps and bees are known to sting, Australian native wasps and bees rarely do so – in fact, some are even stingless[131,132]. Generally, this means that they are much safer to be around but should still be left alone by humans to avoid potential conflict.

Based on research findings:

- When considering bees, green roofs tend to be used by generalist ground-nesting bee communities.
- Consider substrate characteristics, including particle size and leaving bare areas of substrate to provide nesting sites for wasps and ground-nesting bees.
- Wasp diversity will reduce with increased green roof height and decreased surrounding green space.
- Native wasps and bees are useful for pest management and in most cases, are harmless to humans.

Butterflies and moths

Butterflies and moths are highly mobile insects. They are regularly caught as part of broader arthropod surveys on green roofs, although generally in low abundances[29,30,49]. Because they pass through a distinct egg, larval, pupal and adult stage (known as 'holometabolous metamorphosis'), butterflies and moths have different habitat requirements depending on their life stage. Consequently, it is important that plants which support both the larvae (caterpillars) and the adult butterfly or moth should be included in a green roof's planting palette. For further details on appropriate plant species for local butterflies please refer to the Urban Nature Planting Guide **www.melbourne.vic.gov.au/plantingguide**.

To date, only one study[41] has specifically surveyed butterflies on green roofs, with their study of rooftop gardens in Singapore. Butterflies most commonly seen using green roofs in Metropolitan Melbourne include:

- Common Grass Blue (*Zizina labradus*),
- Common Dart (*Ocybadistes flavovittatus*),
- introduced Cabbage White (*Pieris rapae*).

Australian Painted Lady (*Vanessa kershawi*) and Meadow Argus (*Junonia villida*) can also be seen occasionally (J. Schiller pers. obs.).

To our knowledge, no study has specifically assessed green roofs as habitat for moths which can be an important component of a microbat's diet. However, their presence has been recorded anecdotally in Melbourne. Various unidentified moths have been observed resting on temporary plantings of Matted Flax-lily (*Dianella amoena*) during the day on roofs varying in height that were normally unvegetated (J. Schiller pers. obs.). In addition, a high abundance of the Rose Anthelid (*Chenuala heliaspis*) caterpillar was found on a green roof located 18.5 metres above ground (J. Schiller pers. obs.).

Based on research findings:

- Butterflies and moths have distinct life stages which require different habitat requirements.
- Where possible, integrate plants which support both the larvae (caterpillars) and the adult butterfly or moth.

Other invertebrates

A variety of invertebrates using green roofs have been recorded in studies mostly located in the Northern Hemisphere: beetles (Coleoptera), flies (Diptera), true bugs (Hemiptera), wasps and ants (Hymenoptera), and spiders (Araneae) among others.

One of the more extensively studied taxa are beetles (Coleoptera) which have shown higher diversity on biodiverse green roofs compared to stormwater roofs and urban ground-level sites[61]. Their abundance and richness is positively affected by vegetation cover, particularly forbs and grasses, and negatively affected by roof height and age[43,50]. While green roofs are mostly colonised by mobile species adapted to open dry-habitats[50], some can also support rare or uncommon species. This was the case for rare beetle species found in Switzerland[62] and the United Kingdom[43].

While flies are commonly found on green roofs, only some of them provide important ecosystem services such as pollination and pest control. Hoverflies (Syrphidae) are highly mobile species which are considered crucial pollinators[63], particularly in Australian winters when native bees are scarce due to the lower temperatures[25]. Additionally, adult hoverflies lay their eggs into aphid colonies and when the larvae hatches, it feeds on the aphids, providing important pest control[64]. Hoverflies were seen foraging on flowers in Geneva, Switzerland[59] as well as mating on green roofs of different heights in Melbourne (J. Schiller pers. obs.). Another predatory fly seen resting on leaves on several low-level green roofs in Melbourne are the Green Long-legged Flies (Sciapodinae) (J. Schiller pers. obs.) that feed on aphids, thrips, mites, and other small insects[65].

Spiders are another invertebrate taxa typically found in high numbers on green roofs[17,66,67]. Based on current research, habitat preferences seem to be variable. Spider abundance and richness were negatively correlated with plant cover in Switzerland[67]. However, in Helsinki, spider abundance was positively associated with dead plant material, total vegetation cover and roof height[68]. In Zürich, the proportion of forbs and bare ground on green roofs and roof age significantly explained spider community composition[17]. Most spider species found on green roofs disperse via ballooning juveniles, with roof height acting as a filtering mechanism[66,68].

For some invertebrate taxa found on green roofs such as snails and collembola, it is not clear if they actively move to green roofs or if they are introduced as ‘hitchhikers’ with the substrate, plants or vegetated mats[32,39,69,70]. Hygiene measures such as inspection of plant material for slugs and snails, and disposal of the surface layer of soil of potted plants should be implemented to minimise species invasion.

Based on research findings:

- Green roofs may also attract other invertebrates such as beetles, spiders and hoverflies.
- Attracting predatory flies can be pest control measures.
- Minimise risk of introducing unwanted invertebrates to a green roof by undertaking hygiene measures.

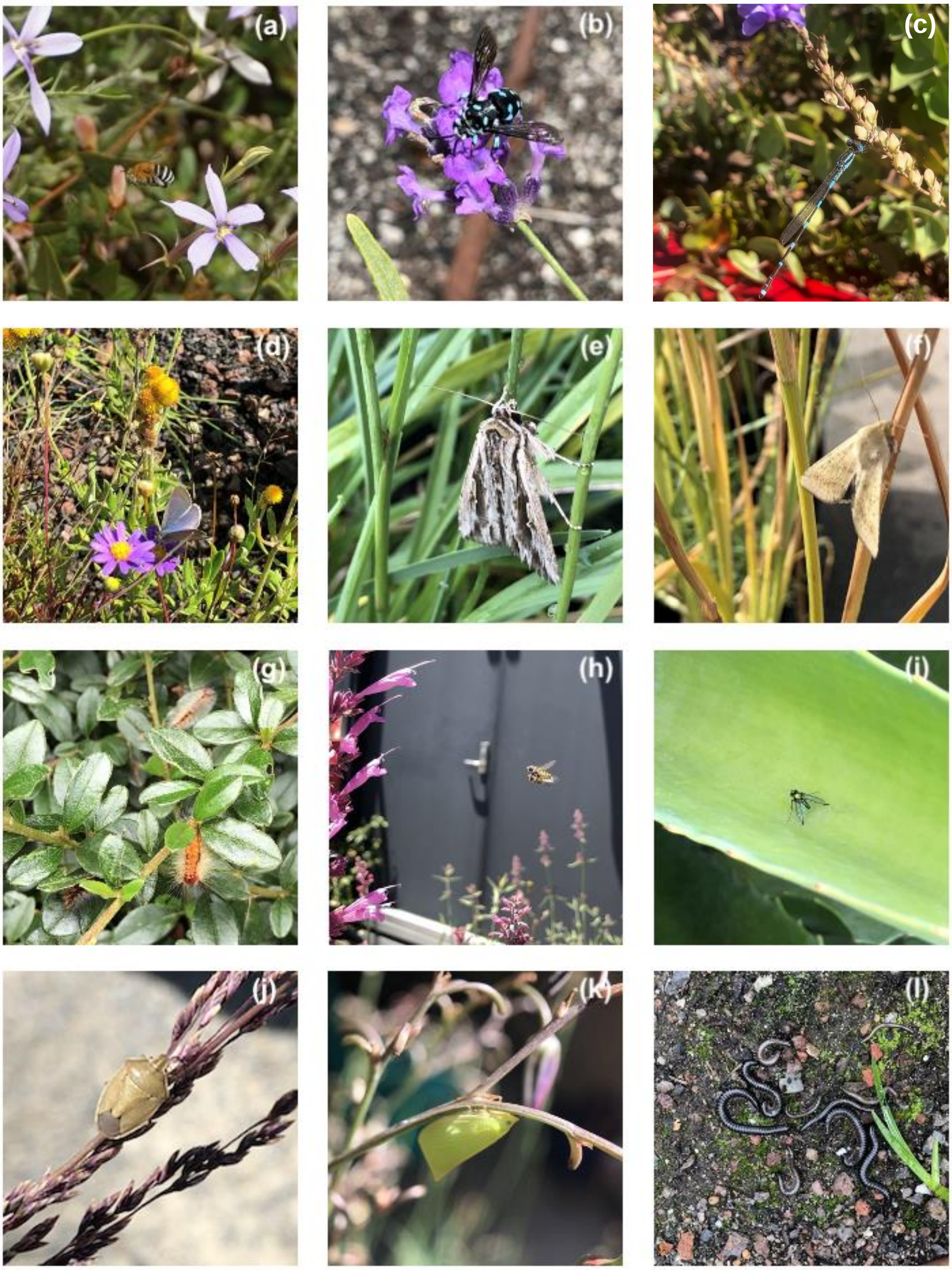


Figure 2. Examples of invertebrate fauna observed on established and temporary green roofs in Melbourne (J. Schiller pers. comm. and photo credit): **(a)** Native Blue-banded Bee (*Amegilla* sp.) foraging on native Rock Isotome (*Isotoma axillaris*), Burnley Demonstration Green Roof; **(b)** native Chequered Cuckoo Bee (*Thyreus caeruleopunctatus),* a nest parasite of the *Amegilla* genus, foraging on lavender flowers, Burnley Demonstration Green Roof; **(c)** native Wandering Ringtail (*Austrolestes leda*) foraging on native Digger's Speedwell (*Veronica perfoliata*), Burnley Demonstration Green Roof; **(d)** Common Grass Blue (*Zizina labradus*) butterfly foraging on native Cut-leaved Daisy (*Brachyscome multifida*) flowers on a residential green roof, Camberwell; **(e-f)** moths found using temporarily installed native Matted Flax-lily (*Dianella amoena*) plants for resting during the day on normally unvegetated roofs; **(g)** caterpillars of the Rose Anthelid (*Chenuala heliaspis*) moth found on a green roof located 18.5 meters above ground, Parkville; **(h)** hoverflies (Syrphidae) recorded both foraging on aphids as well as mating on a green roof located 25 metres above ground, Parkville**; (i)** predatory Green Long-Legged Fly (Sciapodinae) on residential green roof, Coburg; **(j)** true bug (Heteroptera) on residential green roof, St Kilda East; **(k)** Green Planthoppers (*Siphanta acuta*) found using temporarily installed native Matted Flax-lily (*D. amoena*) plants on normally unvegetated roofs, Parkville; **(l)** introduced Portuguese Millipedes (*Ommatoiulus moreleti*) under temporarily installed pollinator trap on a green roof located 18.5 metres above ground, Parkville.

Mammals

Despite the abundance of small mammals in urban areas, there have been very few records and fewer studies of mammals using green roofs. Pest control and building management companies in North America warn of the dangers of rats and mice on green roofs suggesting these ubiquitous urban species frequently use them. Brushtail (*Trichosurus vulpecula*) and Ringtail Possums (*Pseudocheirus peregrinus*) have been observed feeding on plants growing on green roofs in Melbourne, in some cases doing considerable damage to flowers and foliage (i.e. *Sedum pachyphyllum*, *S. rubotinctum*, *Allium* sp., *Verbena bonariensis*) (J. Rayner pers. obs; R. Bathgate pers. comm.). Brushtail Possums, which readily use artificial structures as den sites, have also been recorded nesting in the downpipe feeder boxes on the Demonstration Green Roof at the University of Melbourne's Burnley Campus (N. Williams pers. obs.).

As green roofs become more common in Australian cities, a better understanding of their use by small mammals will be desirable. This will be particularly important outside of the densely populated central business districts where there is more potential for conflict between possums and green roof owners.

Microbats are the one mammal group that has been studied on green roofs. Bat activity has been found to be higher over green roofs than conventional roofs. In New York City three of five bat species detected had higher activity over green roofs[54], with the activity of the most commonly recorded species Eastern Red Bat (*Lasiurus borealis*) positively correlated with moth abundance[51]. However, in London only biodiverse green roofs planted with, or colonised by a variety of wildflowers herbs, sedums, mosses and grasses had higher total and feeding bat activity. There was no difference between conventional roofs and green roofs dominated by *Sedum* species[42].

Based on research findings:

- There are very limited records and studies of mammals using green roofs.
- In Melbourne, there is potential for possums and microbats to use green roofs.

Brushtail Possum (*Trichosurus vulpecula*) nesting in the downpipe feeder boxes on the Burnley Demonstration Green Roof. Photo: Nicholas Williams.

Birds

Green roofs are known to be used by both resident and migratory bird species[30,41,71]. Most bird species recorded using green roofs are either insectivores or omnivores[30,41,71,72]. However, similar to ground-level habitats green roof bird communities appear to respond to the resources provided directly or indirectly by the available plant species. For example, in tropical Singapore, many green roofs are more garden-like with deeper substrates and more complex vegetation structure. A study found that species richness increased with the number of shrub species, and the bird most commonly found on green roofs was the long beaked nectarivore Olive-backed Sunbird[28]. This bird was observed feeding on shrub species with colourful tubular flowers. There are also many examples of specialised bird species such as Hummingbirds utilising native plant species[73].

Green roofs with low open vegetation and inorganic substrates (i.e. extensive *Sedum* dominated green roofs) in temperate climates appear to be suitable breeding habitat for several wading and water birds. Eurasian Oystercatchers (*Haematopus ostralegus*) have adapted their behaviour to breed on roofs in a number of countries including Scotland and Norway[74]. In addition, Kildeer (*Charadrius vociferus*), Canada Geese (*Branta canadensis*) and Mallard (*Anas platyrhynchos*) have commonly been recorded breeding on green roofs in Midwestern USA[40,55,75].

Kangan Tafe in Melbourne's Docklands had issues with Silver Gulls (*Chroicocephalus novaehollandiae*) nesting, living and dying on and around their green roof (Phillip Dixon, Manager Capital Development Kangan Tafe pers. comm.). This is ecologically novel as Silver Gulls are only known to breed on offshore islands[76] and an example of how unconventional habitats can provide important resources for urban biodiversity[77]. However, it also illustrates the potential human-wildlife conflicts associated with green roofs that need to be considered and designed for.

Northern Lapwing (*Vanellus vanellus*) and Little Ringed Plover (*Charadrius dubius*), are both listed as endangered, and have been recorded using green roofs close to natural habitats in Switzerland. Initially, breeding attempts were unsuccessful[27] but after the installation of a balustrade and permanent water source, successful breeding occurred[24]. Similar behaviour has been observed in Melbourne. Masked Lapwings (*Vanellus miles*) were found nesting unsuccessfully (chicks hatched but died) over several years in a pebble layer on the City of Monash council chambers roof in Glen Waverly. When a green roof was subsequently installed on the building, it was constructed to avoid breeding season (R. Mitchell pers. comm.). Many of these species' nest in scrapes they make in the ground and the coarse mineral substrates used on most green roofs mimic, in some cases deliberately, the material found in their natural habitats.

Figure 3 provides examples of birds using green roofs in Melbourne and internationally. While there have been no systematic surveys, native birds observed feeding on green roofs in Melbourne include (N. Williams pers. obs):

- Eastern Rosella (*Platycercus eximius*) eating seeds of *Senecio quadridentatus.*
- Australian Magpies (*Cracticus tibicen*), Little Ravens (*Corvus mellori*) and Noisy Miners (*Manorina melanocephala*) foraging for insects on green roofs.
- Rainbow Lorikeets (*Trichoglossus moluccanus*) have also been observed bathing in the pond on the Burnley Biodiversity Green Roof.

Based on research findings:

- Most birds recorded using green roofs are either insectivores or omnivores.
- Green roof bird communities appear to respond to the resources provided by the planted species. These resources may be linked to food or habitat structure (refuge, nesting material).
- It is important to consider the breeding cycle and life history traits of birds when designing for this taxa group. This includes design features to avoid (e.g. glass balustrades).

Figure 3. Examples of avifauna observed using green roofs in Melbourne and internationally: (a) Australian Magpies (*Cracticus tibicen*) foraging on the Burnley Demonstration Green Roof, University of Melbourne Burnley Campus (photo: Julia Schiller); (b) Rock pigeon (*Columba livia*) nest on the Sky Park green roof, Melbourne (photo: Stephanie Sirianni); (c) Herring Gull (*Larus argentatus*) and chicks on Javits Convention Centre green roof, New York (photo: greenroofs.com); (d) Little Ravens (*Corvus mellori*) foraging on a green roof planted with native grassland species in Northcote (photo: Nicholas Williams); (e) Eastern Rosella (*Platycercus eximius*) eating seeds of Cottony Fireweed (*Senecio quadridentatus*) on the Burnley Biodiversity Green Roof, University of Melbourne Burnley Campus (photos: Nicholas Williams); (f) Masked Lapwing (*Vanellus miles*) nest on City of Monash council chambers, Glen Waverley (photo: Robyn Mitchell).

Reptiles and amphibians

Although the relatively hot and dry environment of green roofs is potentially suitable for reptiles, there are few records and no scientific studies of them using the habitat. However, this could be due to the relatively recent uptake of green roofs by cities in warmer climates where reptile diversity and abundance is higher. Observations include:

- “Blue tail lizards” (which could be one of many species of skink native to the American southwest) on the green roof of New Mexico Court of Appeals in Albuquerque[78],
- Pale-flecked Garden Sunskink (*Lampropholis guichenotia*) on the Burnley Biodiversity Green Roof at the University of Melbourne’s Burnley Campus (N. Williams pers. obs.),
- Common Wall Lizards (*Podarcis muralis*) on the station platform green roofs at Zürich Central Station[79].

Although many reptiles have climbing ability, they are unlikely to spontaneously colonise green roofs that are not deliberately connected to suitable ground-level habitat. A variety of design techniques could be used to achieve the required connectivity by providing protection from predators and continuous suitable habitat. For example the building walls immediately below the Burnley Biodiversity Green Roof are covered in Virginia Creeper (*Parthenocissus quinquefolia*) that may have helped facilitate movement of the Pale-flecked Garden Sunskink, while the Zürich Central Station has specifically designed stone filled gabions that successfully act as “lizard ladders”.

Because of the lack of permanent water on most green roofs, they are unlikely to provide suitable habitat for amphibians. Their vertical isolation would also limit access of green roofs to frogs with the ability to climb such as tree frogs.

Based on research findings:

- Currently, there is limited records and studies of reptile use on green roofs.
- Consider incorporating elements of reptile ground-level habitat into green roof design (e.g. basking sites).
- For successful reptile colonisation, there needs to be continuous connection from the green roof to the ground-level habitat.
- Amphibians are unlikely to inhabit green roofs due to lack of permanent water and the vertical isolation.

Pale-flecked Garden Sunskink (*Lampropholis guichenoti*) sheltering under roof-tile habitat on the Burnley Biodiversity Green Roof. Photo: Nicholas Williams.

SELECTING TARGET FAUNA FOR BIODIVERSITY GREEN ROOFS

Most species of fauna observed using green roofs tend to be mobile urban generalists that are common in the surrounding urban landscape. However, the presence of some uncommon or locally rare species on a limited number of green roofs suggests that green roofs can be designed and managed to provide additional habitat for target species if they are present in the surrounding landscape.

> Selecting target fauna species needs to be done in a realistic way that considers both their presence in the local landscape and their ability to colonise and persist on a green roof. Failure to do so may lead to unnecessary expense and unrealistic expectations from green roof owners, building visitors and regulatory authorities.

An example is the green roof on the California Academy of Sciences in San Francisco which was promoted as providing habitat for the endangered Bay Checker-spot Butterfly. However, this was unsuccessful because the closest population of the species to the roof was well beyond its dispersal range[14].

Examining databases such as the Atlas of Living Australia (ala.org.au) or iNaturalist (inaturalist.org) can help identify species occurring in the urban landscape around the green roof (i.e. up to 5 km depending on mobility) that could potentially access it. Candidate target species would be a subset of these records that have enough recent occurrences to be reasonably likely to persist in the urban landscape but are not so ubiquitous and advantaged by urbanisation that providing additional habitat resources will make no or minimal difference (i.e. between 10-100 records). Whether a green roof can be designed to provide a species habitat and life history requirements is also critical and will limit target species to those from particular habitats.

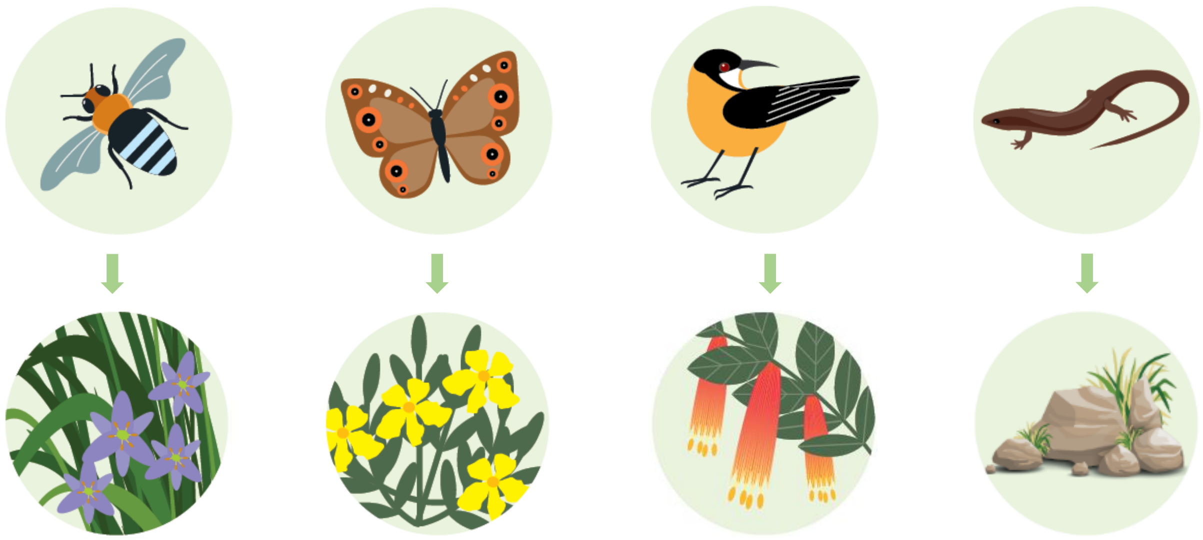
DESIGN CONSIDERATIONS FOR BIODIVERSITY GREEN ROOFS

When planning a biodiversity-friendly green roof, there are design considerations we recommend that will increase the habitat suitability for multiple fauna species. In addition to the plant palette, these include different textured substrate types, rocks, deadwood, water sources and artificial nests. However, even if specifically designed for biodiversity, not all green roofs will be suitable. This is due to landscape scale factors such as building height, excessive artificial light and lack of connectivity which will exclude groups of species based on their behaviour, characteristics and habitat preferences.

Plants listed in the Urban Nature Planting Guide include information about the biodiversity attributes and likely fauna that the plant will attract. This information will help guide you to develop a suitable green roof planting palette for your chosen target faunal group or species that you are designing for. Visit:

melbourne.vic.gov.au/plantingguide

Examples of target fauna and species-specific design considerations:



Blue-banded Bee

Plant *Dianella* species (buzz pollinated) and leave patches of bare ground (for nesting).

Meadow Argus Butterfly

Plant *Goodenia ovata* (host plant, larval food plant and butterfly nectar / pollen source).

Eastern Spinebill

Plant *Correa* species (high nectar food source and dense foliage provides refuge).

Pale-flecked Garden Sunskink

Plant native grasses and add leaf litter (foraging sites, habitat refuge) and rocks (basking sites).

Water

Water is essential for life. Highly mobile species can find a water source nearby but for those less mobile, the presence or absence of water on a green roof may determine whether it is suitable habitat or an ecological trap. For example, in Zürich green roofs that were specifically designed as nesting sites for endangered ground-nesting birds acted as ecological traps, with no chicks initially surviving the hot summer temperatures. However, the addition of a water source during the breeding season resulted in a large increase of chick survival[24]. Water can either be provided as a permanent feature, such as a pond or birdbath plumbed into the building, or a temporary one such as an ephemeral stream or pond that captures rain water. Ideally, clever building design that demonstrates integrated water management principles should be pursued so stormwater is captured and used for biodiversity, and urban cooling while reducing runoff.

Varying substrate characteristics

Using different substrate types can increase the diversity of fauna using green roofs. Different materials have varying thermal properties and therefore absorb and retain heat at differing rates. By doing so, this creates diverse thermal environments for species to regulate their temperature. This is particularly important for insects and reptiles that need to bask in the sun to warm up their bodies since they are cold-blooded. It can be achieved by including patches of materials such as river stones, broken bricks or gravel within the substrate matrix, while keeping in mind the weight loading of the roof as these materials are often heavier than the substrate. These areas should be kept largely vegetation-free for insects and lizards that need those heat-absorbing areas for basking. They may also act as hunting grounds for predatory species, such as carabid beetles and jumping spiders.

Varying substrate particle sizes is also important to maximise insect nesting potential. Many species of native bees and wasps nest in the ground as do certain spider species. Patches of fine textured substrates such as sand and clay soils are therefore important if these taxa are to breed on green roofs[45].

Dead wood and rocks

Incorporating dead wood into the green roof design benefits birds, microbats and insects alike. Decaying wood, in the form of logs can be colonised by mosses, lichen, fungi, carabid beetles and flies[80] which attracts their predators. However, this design features may need to be secured to prevent them blowing off the roof. The addition of rocks, roof tiles and other similar features can offer shelter from the harsh conditions found on roofs for smaller animals. Rocks and other elevated structures such as deadwood can encourage perching behaviour for various birds[30]. The placement of dead wood and rocks on a green roof should comply with any requirements for safety and access.

Example of rock habitat. Photo: Nicholas Williams.

Artificial nests

Artificial nests can be used to attract insect and bat species that struggle to find natural nesting sites due to land use change, urban densification, or modernisation of human-made structures that formerly offered nesting opportunities. Animals that use hollows and cavities for nesting may benefit from artificial nests which will be out of reach of most ground-level predators when installed on green roofs. Artificial nests (e.g. nest boxes, bee hotels) can also provide nature connection and education opportunities on green roofs.

Cavity-nesting native bees may use the holes in artificial traps nests (also known as bee or insect hotels) to lay their eggs. These can either be standing or hanging structures, constructed with natural products, such as bundles of reeds, plant stems or bamboo or alternatively wood with drilled holes. Bricks of rammed earth can also be made for ground-nesting bees. Unpublished data (Williams, Threlfall and Baumann) from bee hotel studies in Melbourne suggests holes should be less than 1 cm diameter because our relatively small native bees are unlikely to colonise the large holes often found in bee hotels sold commercially. It may also be important to have the front of the hotels facing north to receive sufficient heat for successful egg development and hatching. However, this will depend on the exposure of the green roof. Tips for installing bee hotels can be found at **www.aussiebee.com.au/bee-hotel-building-tips.html**

Installing bat roost boxes on green roofs can also provide habitat opportunities for common microbat species in the city[81,82]. Gunnell et al. (2012)[22] recommends that bat boxes are directly built into the building's structure because this makes them less affected by external disturbances and therefore, are more likely to be colonised. However, if this is not possible wooden boxes designed specifically for bats can be installed on poles or walls near the roof. Bats use multiple roost boxes and change roosting sites regularly in response to temperatures, parasites or to avoid predators. Therefore, it is important that roost boxes on green roofs are part of a network of roost boxes within a short distance (i.e. 50 m) of each other, close to water or parks, and of different orientation so they provide different thermal conditions[82]. More information on bat roost boxes can be found at **www.ausbats.org.au/bat-fact-sheets.html**

A patch of substrate made from broken bricks and an insect hotel on the Burnley Biodiversity Green Roof. Photo: Nicholas Williams.

Green roof design features to avoid

Balustrades

Balustrades create a physical barrier that has the potential to harm wildlife or inhibit their access to a green roof. These structures need to be carefully considered into the green roof design. For green roofs that are designed solely for biodiversity and are not routinely accessible to people, balustrades may not be required if maintenance can be performed via attachment to individual fall protection systems. However, if balustrades are required for human access, it is important that they are not made of glass as this can make them invisible to birds and increase the risk of fatal collisions similar to those involving windows[83-85]. Non-reflective, opaque balustrades should be installed instead.

Artificial light

Artificial night lighting should generally be avoided since it can act as barrier for bat movement. If it cannot be avoided, artificial light should be minimised to the level needed for safety and not diffuse upwards. For further technical details on bat-friendly lighting, see page 28 of Landscape and urban design for bats and biodiversity: **www.bats.org.uk/our-work/landscapes-for-bats/landscape-and-urban-design**

PLANTS FOR BIODIVERSITY GREEN ROOFS

Recent ground-level research in Melbourne's parks and gardens has demonstrated that planting a high proportion of locally indigenous species and maintaining structurally complex vegetation promotes native insect abundance and diversity[15,16]. This in turn benefits species up the food chain that feed on them such as birds and microbats[16].

Numerous studies have shown that increased plant cover and structural complexity in green roof vegetation leads to higher abundance and richness of various taxa of arthropods and birds[34,36,40,43,86,87]. This is likely due to the creation of more niches and diverse microclimates by installing a mix of plant growth forms in an otherwise hot and dry green roof landscape. For instance, this was observed by Nagase and Nomura (2014)[88] where highest invertebrate abundance was found in shaded areas of structurally diverse plantings like shrubs.

Globally, monocultures of the low-maintenance, succulent *Sedum* species are probably the most common vegetation type on green roofs[89,90] although they are rare in south-eastern Australia. This type of green roofs supports less abundant and diverse faunal communities compared to green roofs with more diverse plantings such as mixed herbaceous or grassland species[34,42,52,60,86]. While there are a few studies that contradict this notion[31,49], these unexpected results could be due to other underlying factors, such as young green roof age[49] or comparing bee abundances on a more diverse green roof during non-flowering periods to a monoculture in its main flowering season[31].

More diverse plant palettes will likely offer greater availability of floral resources than monocultures. Green roofs covered with a diversity of plants can create an extended flowering period which is highly beneficial for pollinators[45,91]. Increasing plant genera diversity is likely to increase diversity of floral structures, and broadly increase biodiversity (Berthon unpublished).

While plant diversity is important for increasing biodiversity, it is important to note that for successful plant coverage planting many individuals of fewer species should be prioritised over planting one individual of many species within the same area. This will ensure species can establish, persist and not be outcompeted. Plant diversity and vegetation success can be achieved by grouping plants with comparable growth habits and vigour together.

There are a variety of reasons beyond habitat provision as to why native plants should be specified for use on green roofs. This includes aesthetics, the desire for a green roof to fit with its surroundings, a perception that native plant species may be better adapted for the green roof environment, and attempting to minimise the use of invasive species[92]. However, green roofs are novel environments and not all native plant species are adapted to these conditions.

Residential
Biodiversity Green Roof
Cremorne, Melbourne

Photo: Phil Edwards, Coolth.Inc

Selecting native plant species for green roofs: habitat template and plant trait approaches

The **habitat template** approach[93] is often used to select plant species for green roofs. This technique tries to match the physical and chemical environment found on the green roof with a similar natural environment using the assumption that the plants that perform well in the natural habitat should be successful in a similar constructed environment.

Refer to pages 34–38 for more information.

The **plant trait approach** uses the characteristics of plants which confer stress tolerance to select plants for green roofs[94,95].

Refer to page 39 for more information.

Habitat templates useful for Metropolitan Melbourne

Natural systems commonly used as habitat templates include rock outcrops, coastal dunes, coastal barrens, grasslands, cliffs and roadside edges[96-101]. However, not all plants selected from a suitable template will be appropriate for green roofs. For example, in dryland ecosystems there are many different ways plants can tolerate drought stress but some of these strategies will not ensure survival on green roofs[97]. This is particularly the case for plants which avoid drought stress through deep root systems.

Potential habitat template communities for Melbourne green roofs designed to support biodiversity are described in this section. Further information on Melbourne's plant communities and the species that comprise them can be found in books such as Plants of Melbourne's Western Plains[102], Flora of Melbourne[103] and Indigenous Plants of the Sandbelt[104].

Rock Outcrops

Due to their shallow profile green roof substrates (soils) are likely to be wet and potentially water-logged during periods of high rainfall in winter and early spring, but dry, hot and subject to large amounts of solar radiation in summer. These conditions are analogous to those found in rock outcrops and rocky escarpments that have areas of shallow soils which are exposed to high temperatures and low water availability.

Victorian granite outcrops have been used as a habitat template for green roof research and the species growing on them assessed for survival in glasshouse experiments and on green roofs. Although there are small areas of relatively low granite outcrops on the northern outskirts of Melbourne (i.e. Woodlands Historic Park), those occurring in northern Victoria are more extensive and generally have more intact native vegetation. The relevant Ecological Vegetation Classes (EVCs) are:

- Granitic Hills Woodland (EVC 72),
- Rocky Outcrop Shrubland (EVC 28),
- Rocky Outcrop Herbland (EVC 193).

Unpublished University of Melbourne student projects have surveyed the flora of granite outcrops at Terrick Terrick National Park and Mt Korong and identified candidate green roof species with different lifeforms for further study.

Rock outcrop species found to be most successful on green roofs include:

- *Arthropodium milleflorum* (Pale Vanilla-lily),
- *Dianella admixta* (Spreading Flax-lily),
- *Lomandra longifolia* (Spiny-headed Mat-rush),
- *Stypandra glauca* (Nodding Blue Lily),
- *Isotoma axillaris* (Rock Isotome).

Note – All these species have been found to hold high water status in drought conditions and (with the exception of *Isotoma axillaris*) are high water users when water is abundant, which is important for the stormwater abatement function of green roofs[97].

Other rock outcrop species likely to do well on green roofs include:

- *Calytrix tetragona* (Common Fringe-myrtle)[105],
- *Hibbertia obtusifolia* (Grey Guinea-flower)[106],
- *Geranium solanderi* (Austral Crane's-bill),
- *Gonocarpus tetragynus* (Common Raspwort),
- *Gonocarpus elatus* (Tall Raspwort).

Other shrubs found to do well on green roofs with deficit irrigation include *Eutaxia microphylla* (Small-leaved Eutaxia), *Grevillea rosmarinifolia* (Latrobe's Grevillea) and *Dillwynia sericea* (Showy Parrot-pea).

Rock outcrop at Terrick Terrick National Park illustrating the zonation of vegetation communities across soils of different depth. Photo: Claire Brownridge.

Rocky Escarpments and Stony Knolls

Rocky habitats more commonly occurring in the Melbourne area include Stony Knoll Shrubland (EVC 649) and Escarpment Shrubland (EVC 895). While the trees and medium-large shrubs of these communities are unsuitable for green roofs, many of the ground layer plant species grow in shallow soils and have traits that allow persistence during hot dry periods. Species common in the EVCs that have performed well on green roofs include:

- *Austrostipa bigeniculata* (Tall Spear-grass),
- *Arthropodium minus* (Small Vanilla-lily),
- *Dichondra repens* (Kidney Weed),
- *Wahlenbergia* spp (Bluebells),
- *Chloris truncata* (Windmill Grass),
- *Dianella admixta* (Spreading Flax-lily),
- *Senecio quadridentatus* (Cottony Fireweed),
- *Rumex brownii* (Slender Dock),
- *Gonocarpus tetragynus* (Common Raspwort),
- *Goodenia ovata* (Hop Goodenia),
- *Lomandra filliformis* (Wattle Mat-rush),
- *Lomandra longifolia* (Spiny-headed Mat-rush),
- *Pelargonium rodneyanum* (Magenta Stork's-bill).

These EVCs also contain several species of fern that grow in sheltered locations; *Adiantum aethiopicum* (Maidenhair Fern), *Asplenium flabellifolium* (Necklace Fern), *Cheilanthes austrotenuifolia* (Green Rock-fern) and *Pleurosorus rutifolius* s.l. (Blanket Fern). Due to their ability to grow in shallow soil and survive dry periods by desiccating their leaves and quickly reshooting after rain, many of these resurrection ferns are potentially suitable for shaded areas of green roofs, particularly if their rhizomes can be protected from extreme heat (i.e. under rocks or pavers). *C. austrotenuifolia* has been growing successfully on the Burnley Biodiversity Green Roof for many years.

Stony Knoll, Diggers Rest
Copyright Michael Longmore

Escarpment Shrubland, Thomastown
Copyright Michael Longmore

Scoria Cone Woodland

Most of the green roofs built in Melbourne use scoria-based substrates. Because of this, the vegetation communities that grow on the volcanoes to the north and west of Melbourne where the scoria is quarried are potential habitat templates. The most common EVC of the volcanoes is Scoria Cone Woodland (EVC 894) which had an overstorey of *Allocasuarina verticillata* (Drooping She-oak), *Banksia marginata* (Silver Banksia - tree form) or *Eucalyptus viminalis* (Manna Gum).

Unfortunately, due to extensive clearing for agriculture the understorey of most scoria cones are greatly degraded and is relatively poorly known. Species thought to occur in the community that are potentially suitable for green roofs include:

- *Acaena echinata* (Sheep's Burr),
- *Ajuga australis* (Austral Bugle),
- *Rytidosperma geniculatum* (Kneed Wallaby-grass),
- *Rytidosperma pilosum* (Velvet Wallaby-grass),
- *Dichondra repens* (Kidney Weed),
- *Dianella admixta* (Spreading Flax-lily),
- *Lomandra filliformis* (Wattle Mat-rush),
- *Geranium potentilloides* (Soft Crane's-bill).
- *Note – Ptridium esculentum* (Austral Bracken) is characteristic of the community and could be worth further evaluation on shaded green roofs in areas with deeper substrate.

Mt Noorat Scoria Cone Woodland. Photo: Steve Sinclair.

Native Grasslands and Grassy Woodlands

The native grassland and grassy woodland communities of south-eastern Australia are a suitable habitat template for planting green roofs. Compared to many other vegetation communities in the region, they occur in areas of lower rainfall and on soils that are hot and dry in summer but can be waterlogged after heavy rains.

The ground storey component of some grassy woodland communities are similar. Many of the plant species growing in these grassy ecosystems have adaptations, or traits, that allow them to persist through hot and dry periods that also make them good candidate species for green roofs. The leaves of many grass species die off in late summer and lose most photosynthetic capacity with new leaves reshooting from tussock bases. Most grassland herb species die back to dormant buds when soil moisture is low and temperatures high. Orchids, many lilies (i.e. *Arthropodium* sp.), some daisies (*Microseris*, *Podolepis* sp.) and other herb genera (i.e. *Geranium*, *Convolvulus*) have fleshy underground tubers that store water and carbohydrates that allow them to resprout after periods of water stress. Other herb species have small leaves that minimise water loss. *Dianella* species and other species that spread vegetatively often have succulent rhizomes that confer drought resistance.

There are many reasons beyond potential suitability of plant species for attempting to create native grassland communities on green roofs. Native grasslands were formerly common in western and northern Melbourne. They are now highly fragmented due to intensive agriculture and urban development and have suffered a massive decline of 98.8% leading to their listing as critically endangered under Australia's Environment Protection and Biodiversity Conservation Act[107]. Planting species from native grassland communities on green roofs is a form of ex-situ plant conservation as many of the potential species are regionally rare. However, it must be stressed that planting native grassland species on green roofs cannot be considered ecological restoration due to its unique context and should not be used as an offset or part of other ecological compensation mechanisms.

Native Grassland at Woorndoo Common. Photo: Nicholas Willliams.

Plant traits useful for Metropolitan Melbourne

The most common plants used on green roofs are the non-native *Sedum* (Stonecrop) spp. which are highly succulent[6]. This genus has been shown to be very successful in surviving in shallow substrates where water is limited during summer months[108]. However, their suitability varies depending on climate, with species with greater leaf succulence (i.e. more water storage) being more suitable in hot and dry climates than smaller leaved species[109].

Our research has shown that in species generally considered non-succulent, other plant tissues such as roots and stems can also have succulence and this is an important indicator of drought tolerance on Australian green roofs[109]. For example, many Australian geophytes have fleshy tubers which allow them to sacrifice their above-ground leaves and survive hot and dry periods beneath the soil and then resprout when conditions improve[110]. Other traits likely to enable plants to survive the hot dry environment of green roofs include:

- **Low biomass:** Species with low biomass have been demonstrated to have lower water use and hence greater survival on green roofs[97,105]. This trait will also be important when selecting tussock grass species for green roofs as large amounts of dead leaves i.e. *Themeda triandra* (Kangaroo Grass) may be perceived as a fire risk.

- **Small leaves:** Plants with small thick leaves i.e. lower specific leaf area (SLA) can often regulate water loss well.

- **Vegetative spread:** Vegetative spread via rhizomes or adventitious roots will allow species to persist if other parts of the plant die and will also facilitate colonisation of other areas of a green roof if plant parts become detached.

- **Resurrection plants:** This refers to plants with foliage that revives after dehydration to air-dryness[111]. This group includes ferns that occur in dry environments such as *Cheilanthes* sp, *Pleurosorus rutifolius* (Blanket Fern), *Pellaea falcata* (Sickle Fern) and the rare grass *Tripogonella loliiformis* (Rye Beetle-grass) which occurs in native grasslands and on rock outcrops.

- **Annual species**: Annual species can persist in hot and dry environments by surviving adverse conditions as seed, germinating when there is sufficient moisture.

In practice, when selecting plants for green roofs designed to improve local biodiversity it is often useful to combine the habitat template approach with the plant trait approach. This allows the further refinement of a regional species pool occurring in habitats analogous to green roofs on the basis of traits that may further enhance survival. Other important plant selection criteria include the resources they provide for target fauna (i.e. nectar, larval food plants) and maintenance requirements.

Plant species suitable for biodiversity green roofs in Melbourne

These guidelines include a list of over 90 suitable plant species (mostly native) known to grow successfully on green roofs, with information on the biodiversity resources they can provide and fauna taxa recorded using them (Table 2). Their inclusion is supported by experimental data from our green roof research, observational data from the green roofs being maintained and monitored, and reasoned assumptions based on expert knowledge of their natural occurrence and performance of closely related species on green roofs.

These plants have been classified based on their suitability into six nested classes:

- unirrigated < 10 cm in depth,
- irrigated < 10 cm in depth,
- unirrigated 10-20 cm in depth,
- irrigated 10-20 cm in depth,
- unirrigated > 20 cm in depth,
- irrigated > 20 cm in depth.

If a species is listed as suitable for an unirrigated depth, it is by definition suitable for an irrigated roof of the same depth and deeper green roofs.

The irrigation class assigned to each plant is based on 'post-establishment' requirements.

All plants regardless of the irrigation class provided, may require emergency or 'back-up' irrigation during extended periods of extreme hot and dry weather that Melbourne can experience. See *Irrigation* page 45 for more information.

For detailed information about the plant species, growing tolerances and green roof suitability, and the biodiversity resources they provide, visit the Urban Nature Planting Guide at

melbourne.vic.gov.au/plantingguide

Table 2: Plant species suitable for biodiversity green roofs in Melbourne. For detailed plant information head to City of Melbourne's Urban Nature Planting Guide (melbourne.vic.gov.au/plantingguide).

COMMON NAME	SCIENTIFIC NAME	UNIRRIGATED <10 cm	IRRIGATED <10 cm	UNIRRIGATED 10-20 cm	IRRIGATED 10-20 cm	UNIRRIGATED > 20 cm	IRRIGATED > 20 cm
Austral Crane's Bill	*Geranium solanderi* var. *solanderi*	✓	✓	✓	✓	✓	✓
Austral Storksbill	*Pelargonium australe*				✓		✓
Australian Harebell, Rock Isotome, Showy Isotome	*Isotoma axillaris*				✓		✓
Black-anther; Spreading Flax-lily	*Dianella admixta*	✓	✓	✓	✓	✓	✓
Blanket Fern	*Asplenium subglandulosum*		✓	✓	✓	✓	✓
Blue Marguerite; Kingfisher Daisy	*Felicia amelloides*						✓
Bristly Wallaby Grass	*Rytidosperma setaceum*				✓		✓
Chamomile Sunray	*Rhodanthe anthemoides*				✓		✓
Chocolate Lily	*Arthropodium strictum*		✓	✓	✓	✓	✓
Clustered Everlasting; Yellow Buttons	*Chrysocephalum semipapposum*						✓
Coast Flax-lily; Small-flower Flax-lily	*Dianella brevicaulis*		✓		✓		✓
Coast Saltbush; Grey Saltbush	*Atriplex cinerea*				✓		✓
Coast Spear-grass	*Austrostipa flavescens*				✓	✓	✓
Coastal Daisybush; Wild Rosemary	*Olearia axillaris*						✓
Coastal Fan-flower; Dune Fan-flower	*Scaevola calendulacea*						✓
Coastal Tussock-grass; Blue Tussock-grass	*Poa poiformis*				✓	✓	✓
Common New Holland Daisy; Fuzzy New Holland Daisy	*Vittadinia cuneata*				✓		✓
Common Everlasting; Yellow Buttons	*Chrysocephalum apiculatum*				✓		✓
Common Flat-pea	*Platylobium obtusangulum*						✓
Common Rice-flower	*Pimelea humilis*				✓		✓
Common Trigger Plant	*Stylidium armeria*				✓		✓
Cottony Fireweed	*Senecio quadridentatus*	✓	✓	✓	✓	✓	✓
Creeping Boobialla	*Myoporum parvifolium*				✓		✓
Creeping Bossiaea	*Bossiaea prostrata*				✓		✓
Cushion Bush	*Leucophyta brownii*						✓
Cut-leaf Daisy	*Brachyscome multifida*				✓		✓
Digger's Speedwell	*Veronica perfoliata*						✓
Drumsticks	*Pycnosorus globosus*						✓

COMMON NAME	SCIENTIFIC NAME	UNIRRIGATED <10 cm	IRRIGATED <10 cm	UNIRRIGATED 10-20 cm	IRRIGATED 10-20 cm	UNIRRIGATED > 20 cm	IRRIGATED > 20 cm
English Lavender	*Lavandula angustifolia*						✓
False Sarsaparilla; Purple Coral Pea	*Hardenbergia violacea*						✓
Feather Spear-grass; Elegant Spear-grass; Spider Grass	*Austrostipa elegantissima*				✓	✓	✓
Finger Rush	*Juncus subsecundus*						✓
Fringe Myrtle	*Calytrix tetragona*						✓
Golden Billy Buttons	*Pycnosorus chrysanthes*						✓
Golden Everlasting; Straw Flower	*Xerochrysum bracteatum*						✓
Grassland Crane's-bill	*Geranium retrorsum*	✓	✓	✓	✓	✓	✓
Green Rock-fern	*Cheilanthes austrotenuifolia*		✓	✓	✓	✓	✓
Grevillea	*Grevillea* x *'Coconut Ice'*						✓
Hop Goodenia	*Goodenia ovata*				✓		✓
Ivy-leaved Violet	*Viola hederacea*		✓		✓		✓
Kangaroo Grass	*Themeda triandra*				✓		✓
Kangaroo Paw	*Anigozanthos* cultivars		✓		✓	✓	✓
Kidney Weed	*Dichondra repens*	✓	✓	✓	✓	✓	✓
Knobby Club-rush	*Ficinia nodosa*	✓	✓	✓	✓	✓	✓
Lemon Beauty-heads	*Calocephalus citreus*		✓	✓	✓	✓	✓
Long-hair Plume Grass	*Dichelachne crinita*	✓	✓	✓	✓	✓	✓
Long-leaved Guinea-flower	*Hibbertia obtusifolia*						✓
Magenta Stork's-bill	*Pelargonium rodneyanum*	✓	✓	✓	✓	✓	✓
Maidenhair Fern	*Adiantum aethiopicum*		✓	✓	✓	✓	✓
Matted Flax Lily	*Dianella amoena*	✓	✓	✓	✓	✓	✓
Milky Beauty-heads	*Calocephalus lacteus*		✓	✓	✓	✓	✓
Narrow-leaf New Holland Daisy	*Vittadinia muelleri*			✓	✓	✓	✓
Narrow-leaf Plantain	*Plantago gaudichaudii*	✓	✓	✓	✓	✓	✓
Native Flax	*Linum marginale*		✓	✓	✓	✓	✓
Native Fuchsia; Common Correa	*Correa reflexa*						✓
Necklace Fern	*Asplenium flabellifolium*		✓	✓	✓	✓	✓
Nodding Blue Lily	*Stypandra glauca*				✓		✓
Pale Rush	*Juncus pallidus*						✓
Pale Vanilla-lily	*Arthropodium milleflorum*				✓	✓	✓
Prickly Spear Grass; Coast Spear Grass	*Austrostipa stipoides*				✓	✓	✓
Pigface; Angular Pigface	*Carpobrotus glaucescens*		✓	✓	✓	✓	✓
Red Leg Grass	*Bothriochloa macra*		✓	✓	✓	✓	✓

COMMON NAME	SCIENTIFIC NAME	UNIRRIGATED <10 cm	IRRIGATED <10 cm	UNIRRIGATED 10-20 cm	IRRIGATED 10-20 cm	UNIRRIGATED > 20 cm	IRRIGATED > 20 cm
Ringed Wallaby Grass; Common Wallaby Grass	*Rytidosperma caespitosum*				✓		✓
Rock Correa; Smooth Correa	*Correa glabra*						✓
Rock Thryptomene	*Thryptomene saxicola*						✓
Rosemary	*Rosmarinus officinalis*				✓	✓	✓
Ross' Noonflower; Karkalla	*Carpobrotus rossii*		✓		✓		✓
Rough Spear-grass	*Austrostipa scabra ssp. falcata*				✓	✓	✓
Round-leaf Pigface; Rounded Noon Flower	*Disphyma crassifolium ssp. clavellatum*		✓		✓		✓
Running Postman; Scarlet Coral Pea	*Kennedia prostrata*						✓
Sage	*Salvia officinalis*				✓	✓	✓
Showy Copper Wire Daisy	*Podolepis jaceoides*		✓	✓	✓	✓	✓
Slender Speedwell	*Veronica gracilis*				✓	✓	✓
Small Crowea	*Crowea exalata*						✓
Small St John's Wort	*Hypericum gramineum*	✓	✓	✓	✓	✓	✓
Small-leaved Eutaxia	*Eutaxia microphylla* (prostrate form)				✓		✓
Smooth Rice-flower	*Pimelea glauca*				✓		✓
Snake Vine	*Hibbertia scandens*						✓
Spiny-headed Mat-rush	*Lomandra longifolia*				✓		✓
Sticky Everlasting	*Xerochrysum viscosum*						✓
Sword Rush; Coastal Sword-sedge	*Lepidosperma concavum*				✓		✓
Tall Bluebell	*Wahlenbergia stricta*		✓		✓		✓
Tasman Flax-lily	*Dianella tasmanica*		✓	✓	✓	✓	✓
Tufted Bluebell	*Wahlenbergia communis*		✓		✓		✓
Variable Daisy	*Brachyscome ciliaris*				✓		✓
Variable Groundsel	*Senecio pinnatifolius*				✓		✓
Velvet Tussock-grass	*Poa morrisii*				✓		✓
Wallaby Grass	*Rytidosperma racemosum*				✓		✓
Wattle Mat-rush	*Lomandra filiformis*				✓		✓
Western Golden-tip; Clover-leaved Poison	*Goodia medicaginea*						✓
Windmill Grass; Umbrella Grass	*Chloris truncata*	✓	✓	✓	✓	✓	✓

Note – If a species is listed as suitable for an unirrigated depth it is by definition suitable for an irrigated roof of the same depth and deeper.

Cut-leaf Daisy
Brachyscome multifida
Planted on a biodiversity green roof
St Kilda East, Melbourne

Photo: Julia Schiller

MAINTENANCE REQUIREMENTS OF BIODIVERSITY GREEN ROOFS

Maintenance is crucially important in sustaining green roof design and function. Maintenance should be driven by objectives, formed during the design phase of the project, and then delivered through a maintenance plan specific to the green roof. Determining maintenance for a biodiversity green roof can be particularly complex and specialist advice will generally be needed. This includes specifying the maintenance of vegetation and any roof features that provide biodiversity outcomes. While ideally the maintenance needs are low (particularly resource needs), they need to be identified, planned for, and then budgeted as part of the maintenance plan.

Planning maintenance is influenced by the design and layout of the green roof, but also by the site conditions such as the building topography, orientation, aspect and microclimate. Planning also needs to consider roof access for maintenance activities, including access for specific tasks, personnel, and training requirements (such as 'Working at heights') materials and equipment. Ease of access will also determine how maintenance is delivered and influence the likely ongoing costs for this.

Maintenance tends to be classified into two lifecycle phases in a landscape, the establishment phase and the post-establishment phase[112].

Establishment maintenance
includes initial maintenance following construction and any treatments or interventions to sustain the design outcomes. During establishment, green roof plantings have high water and nutrition requirements[113] and as in any landscape, the horticultural inputs can be quite high to ensure successful plant growth outcomes[114,115]. Establishment maintenance can be as short as a few months and up to two years post-completion.

Post-establishment maintenance
is referred to as recurrent or routine maintenance and includes the regular activities and tasks undertaken to ensure the green roof is functional, safe and meets the broad design outcomes. Some of this maintenance will be based around seasonal or annual tasks, both for vegetation but also for the hard landscape and infrastructure (e.g. functional checks to ensure drainage points are not blocked by roots).

The most common vegetation maintenance tasks on green roofs includes fertilising, irrigation, pruning and weeding[7,116-118]. While these may be undertaken differently on a biodiversity green roof to a standard green roof, they do need to be planned for.

Irrigation

Irrigation needs to be planned for when designing biodiverse green roofs in Melbourne. Most biodiversity green roofs require a period of 12 months of irrigation during establishment to assist with plant growth and coverage. Note that irrigation for many green roofs, particularly during establishment, can be significant; with some high demand species requiring 6.3 litres of water per square metre per day[119]. Post-establishment irrigation is more complex and application rates (i.e. quantity and frequency) should be based on the vegetation community, substrate depth, season, location and the substrate physical properties.

Most green roofs in dry climates need some form of irrigation to be successful[101]. Even where drought-tolerant plants have been used, irrigation on green roofs has been shown to assist plant survival[120], improve plant growth rates[117] and increase plant diversity[119]. Planning irrigation on green roofs is best completed by a specialist as many factors, particularly climate and microclimate, substrate depth and properties, vegetation design and maintenance, will influence irrigation design. Efficient irrigation systems, such as microsprays, driplines (surface and subsurface) and hand watering are all used widely on green roofs[117,119]. Best practice design should explore incorporating aspects of integrated water management to maximise passive irrigation and stormwater re-use where possible to reduce potable water use.

The plants we have selected as suitable for biodiversisty green roofs in Melbourne (Table 2), grow naturally in seasonally hot and dry environments and therefore can survive periods of water stress once established. For many species we have also demonstrated this experimentally[97,105,121,122]. However, research and green roof growing experience has demonstrated that almost no native plants growing on shallow green roofs (< 12.5 cm) can survive the extreme summer heatwaves that Melbourne can experience[109]. Consequently, emergency irrigation, typically with a hose and with rose or sprinkler attachment, needs to be applied during extended periods of hot, dry weather when evaporative demand is high on all green roofs in Melbourne including biodiversity roofs. Emergency irrigation is also used to support diverse flora on 150 mm deep Mediterranean green roofs[96].

Fertilising

Fertilisers needs to be applied carefully on green roofs and are closely linked to the vegetation community. Fertiliser practice should be based around providing sufficient nutrients to support vegetation, whilst minimising nutrient run off[123]. Green roof design and substrate properties also play a role here, particularly in the storage and recycling of nutrients[124]. Most fertilisers used are either synthetic, controlled-release fertilisers (CRF) or organic, slow-release fertilisers with application rates generally lower than that of ground-level landscapes. The elevated temperatures of green roofs can lead to excessive fertiliser release rates, particularly when coupled with increased moisture or rainfall events. Ideally fertiliser application is based on the nutritional needs of the green roof, through a biannual or annual analysis of substrate pH and electrical conductivity (EC). Biodiversity green roofs in south-eastern Australia will typically have low fertiliser requirements (i.e. CRF rates can be one quarter to one-eighth of the recommended rates).

Weed control

Weed control has been identified as the most problematic and important of maintenance tasks on green roofs[113,117]. Tree seedlings can be particularly serious weeds[113] and spontaneous annual or perennial weeds can be extremely difficult to manage long-term[125]. Gravel mulches can be used effectively to reduce weeds on roofs where weight loading allows[126], but the most effective means of weed control on green roofs is maintaining high plant density and cover[125,126] and balancing substrate nutrition[125]. Many species planted can themselves become a source of future weeds[126] so plant selection for biodiversity green roofs is of particular importance. Maintenance interventions to control weeds should be undertaken early in the life of a green roof by staff who have skills in weed identification[119] and understand weed lifecycles and flowering times so maintenance can be targeted to remove weeds before they set seed[126]. Most weed control on green roofs involves hand tools, but contact herbicides may also be useful, provided they are applied carefully.

Any runoff from a green roof via stormwater will enter the broader city environment, therefore chemical use on green roofs should be minimal. Good hygiene practices during maintenance, such as cleaning footwear, tools and equipment prior to access, and the careful removal of any weed seeds and propagules off site (e.g. stolons, seeds, bulbs, etc.) can minimise weed spread. Care is always needed in the use of hand tools on green roofs, to reduce the risk of damage to underlying layers; and during removal of any woody or stoloniferous weeds, to that ensure lower layers of the profile (i.e. filter fabric or drainage layer) are not damaged.

The remaining maintenance tasks important to biodiversity green roofs relate to vegetation maintenance. While for most green roofs of this type, it will be beneficial to have some decaying plant materials for habitat value, in some cases it may be necessary to include periodic pruning and biomass removal in the maintenance plan. This is particularly relevant for vegetation around access and drainage infrastructure locations and to reduce any potential fire hazard. For some species such as native grasses, pruning is also required to maintain their vigour and to prevent them out competing and eliminating other lower growing species[127].

Pests such as possums or rodents are best controlled by physical controls, such as removing access to the roof, rather than the use of poisonous baits that may harm other fauna. Plant replacement will also be needed over time. This should be approached through careful plant selection and timed to maximise post-planting success on the roof. Specialist horticultural or ecological advice may be needed to assist with some aspects of biodiversity green roofs maintenance.

Example of a maintenance schedule for a biodiversity green roof

Details on maintenance of a biodiversity green roof in south-east Australia is provided below in Table 3, extracted from Rayner et al. (2022)[128]. This was developed as part of the Hort Innovation project *Researching the benefits of demonstration green roofs across Australia (GC16002).*

Table 3. Biodiversity green roof maintenance requirements.

MAINTENANCE CONSIDERATION	DESCRIPTION
Design and function	A green roof designed primarily to enhance biodiversity using a largely indigenous plant palette and a range of features to create habitat and resources for invertebrates, birds and other wildlife.
Maintenance objective	Plants and other habitat features provide ecological resources – primarily habitat and food – for a range of biota, including target species where appropriate. Biodiversity on the roof increases ensuring connectivity with ground-level populations. Plants are healthy and weeds do not negatively impact plants, habitat features or biota. Species diversity is maintained to 80% of original plant list in routine maintenance.
Maintenance inputs	Low maintenance: bimonthly or quarterly schedule
Substrate depth	200 mm with some variation in topography (+/- 100 mm) to allow for habitat features
Accessibility	Access for maintenance purposes only, use of a fall-arrest system
Vegetation type	A mixture of largely native/indigenous herbaceous plants, mainly grasses and forbs.
Irrigation system	Yes – low pressure microspray system.
Infrastructure and hard landscape elements	• Drains, gutters and flashings • Safety harness attachment points • Non-vegetated zones • Retaining edges • Structures/elements for habitat provision such as logs and old wood, piles of sticks, native bee/insect hotels, bird/bat boxes, rocks, water provision e.g. ephemeral pond/other water feature

Maintenance schedule summary

Table 4 shows maintenance tasks and a suggested frequency per year. Biodiverse areas should be disturbed as little as possible during maintenance so as not to upset any microhabitats that might be colonised.

Table 4: Example of routine maintenance schedule for biodiversity green roofs.

TASK	ESTABLISHMENT (visits/yr)	ROUTINE (visits/yr)
Safe work practices		
Safety procedures (3.1.1)	Every visit	Every visit
Maintain safety systems	2	2 and as required
Staff training	1	1 and as required
Monitoring		
Visual inspection	Every visit	Every visit
Maintenance report	Every visit	Every visit
Review maintenance plan	1	1
Horticulture		
Weed control	Every visit	Every visit
Pruning	1 and as required	1 and as required
Fertilisation	1	1
Plant health	Every visit	Every visit
Mulching	1	1 and as required
Biomass removal	2	2
Replanting	2	1 and as required
Check substrate depth	1	1
Infrastructure and hard landscape		
Irrigation maintenance	Every visit	1
Drains, gutters and flashings maintenance	4	4
Surface cleaning	1	1
Maintaining hard landscape elements	1	1
Check habitat provision (e.g. bee hotel, water feature)	1	1

CONCLUSION

Green roofs support greater biodiversity than conventional unvegetated roofs. Research has found they provide habitat for a wide range of fauna including many invertebrate taxa, birds and bats. However, the number of species using them is lower than comparable ground-level habitats. Consequently, green roofs need to be considered as an additional novel urban habitat providing biodiversity resources rather than compensatory habitat for the removal of ground-level green space. Given the low number of green roofs specifically designed for biodiversity in Melbourne and other cities, urban planners in Australia need to continue to develop and implement policy that helps to promote the uptake of extensive green rooftops for biodiversity benefits.

Synthesis of international studies examining the drivers of biodiversity on green roofs suggests:

- the most **important** determinant of green roof biodiversity is the **vegetation** that is planted on them. Roofs with more vegetation cover, higher plant species richness and greater vegetation structural complexity have higher fauna diversity;
- the **location and connectivity** of green roofs is **important**. Many studies have found that the amount of vegetation cover in neighbourhoods surrounding the green roof had strong positive effects on species richness;
- green roofs on **taller buildings** will support comparatively **fewer species** than those on lower buildings.

Because different fauna species require different resources it is important to explicitly choose target species to attract and design the green roof for them. Target species should not be ubiquitous in the landscape as they would likely to find and use the green roof anyway and the additional habitat value would be marginal. Conversely, there is little point choosing target species that do not occur in the surrounding urban landscape as they will be unlikely to encounter the roof.

Planting native or indigenous plant species known to be used by the target species for food, shelter or nesting should increase their likelihood of using the green roof. However, not all plant species are able to grow in the often shallow substrates and harsh climatic conditions found on greens roofs. Plant palettes should be selected with reference to both the plant trait and habitat template approaches. Numerous native species have been demonstrated to grow successfully on green roofs of different depths and there are many more potentially suitable species from a variety of local habitats that can be trailled.

Key recommendations for designing green roofs for biodiversity:

- Consider site context and feasibility for a biodiversity green roof. If appropriate, design for specific target fauna or groups present in the area that are likely to both access the green roof and benefit from additional habitat.

- Focus on planting native and indigenous plants with consideration of:

    - whether the plant species will be used by the target faunal group;

    - whether the plants will survive in the growing conditions on the green roof i.e. substrate depth, solar radiation, irrigation requirements;

    - plant palette selection with reference to both the plant trait and habitat template approaches.

- Refer to the **Urban Nature Planting Guide** for more information (melbourne.vic.gov.au/plantingguide).

- Increase both plant diversity and vegetation structural complexity where possible.

- Explore opportunities to safely integrate other habitat structures such as dead wood, rocks and importantly water on to the green roof.

- Determining maintenance (establishment and post-establishment) for a biodiversity green roof can be complex due the need to manage resources for target fauna species while potentially balancing aesthetic and public perception considerations. Specialist advice may be needed to ensure long-term success.

Small-leaved Eutaxia
Eutaxia microphylla
Planted on a biodiversity green roof
Northcote, Melbourne

Photo: Nicholas Williams

REFERENCES

1. The State of Victoria Department of Environment, Land, Water and Planning, 2019. Victoria in Future 2019: Population Projections 2016 to 2056, Victoria, p. 16.
2. Aerts, R., Honnay, O. and Van Nieuwenhuyse, A., 2018. Biodiversity and human health: mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British medical bulletin*, 127(1), 5-22. https://doi.org/10.1093/bmb/ldy021
3. Kondo, M.C., Fluehr, J.M., McKeon, T. and Branas, C.C., 2018. Urban green space and its impact on human health. *International journal of environmental research and public health*, 15(3), 445. https://doi.org/10.3390/ijerph15030445
4. Shanahan, D.F., Astell–Burt, T., Barber, E.A., Brymer, E., Cox, D.T., Dean, J., ... and Gaston, K.J., 2019. Nature–based interventions for improving health and wellbeing: The purpose, the people and the outcomes. *Sports*, 7(6), 141. https://doi.org/10.3390/sports7060141
5. Gianfredi, V., Buffoli, M., Rebecchi, A., Croci, R., Oradini-Alacreu, A., Stirparo, G., Marino, A., Odone, A., Capolongo, S. and Signorelli, C., 2021. Association between urban greenspace and health: a systematic review of literature. *International Journal of Environmental Research and Public Health,* 18(10), 5137. https://doi.org/10.3390/ijerph18105137
6. Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R.R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K.K.Y. and Rowe, B., 2007. Green roofs as urban ecosystems: ecological structures, functions, and services. *BioScience*, 57(10), 823-833. https://doi.org/10.1641/B571005
7. Shafique, M., Kim, R. and Rafiq, M., 2018. Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews*, 90, 757-773. https://doi.org/10.1016/j.rser.2018.04.006
8. Williams, N.S.G., Bathgate, R.S., Farrell, C., Lee, K.E., Szota, C., Bush, J., Johnson, K.A., Miller, R.E., Pianella, A., Sargent, L.D., Schiller, J., Williams, K.J.H. and Rayner, J.P., 2021. Ten years of greening a wide brown land: A synthesis of Australian green roof research and roadmap forward. *Urban Forestry & Urban Greening*, 62, 127179. https://doi.org/10.1016/j.ufug.2021.127179
9. Kotze, D.J., Kuoppamäki, K., Niemikapee, J., Mesimäki, M., Vaurola, V. and Lehvävirta, S., 2020. A revised terminology for vegetated rooftops based on function and vegetation. *Urban Forestry & Urban Greening*, 49, 126644. https://doi.org/10.1016/j.ufug.2020.126644
10. City of Melbourne, 2017a. Green our City Strategic Action Plan 2017-2021. Vertical and rooftop greening in Melbourne, City of Melbourne, Melbourne, p. 40.
11. City of Melbourne, 2017b. Nature in the City: thriving biodiveristy and healthy ecosystems, City of Melbourne, Melbourne, p. 60.
12. Bush, J., Ashley, G., Foster, B. and Hall, G., 2021. Integrating green infrastructure into urban planning: Developing Melbourne's green factor tool. *Urban Planning*, 6(1), 20-31. https://doi.org/10.17645/up.v6i1.3515
13. Knapp, S., Schmauck, S. and Zehnsdorf, A., 2019. Biodiversity impact of green roofs and constructed wetlands as progressive eco-technologies in urban areas. *Sustainability*, 11(20), 5846. https://doi.org/10.3390/su11205846
14. Williams, N.S.G., Lundholm, J. and MacIvor, J.S., 2014. Do green roofs help urban biodiversity conservation? *Journal of Applied Ecology,* 51(6), 1643-1649. https://doi.org/10.1111/1365-2664.12333
15. Mata, L., Andersen, A.N., Morán-Ordóñez, A., Hahs, A.K., Backstrom, A., Ives, C.D., Bickel, D., Duncan, D., Palma, E., Thomas, F., Cranney, K., Walker, K., Shears, I., Semeraro, L., Malipatil, M., Moir, M.L., Plein, M., Porch, N., Vesk, P.A., Smith, T.R. and Lynch, Y., 2021. Indigenous plants promote insect biodiversity in urban greenspaces. *Ecological Applications*, 31(4), e02309. https://doi.org/10.1002/eap.2309
16. Threlfall, C.G., Mata, L., Mackie, J.A., Hahs, A.K., Stork, N.E., Williams, N.S.G. and Livesley, S.J., 2017. Increasing biodiversity in urban green spaces through simple vegetation interventions. *Journal of Applied Ecology*, 54(6), 1874-1883. https://doi.org/10.1111/1365-2664.12876
17. Braaker, S., Ghazoul, J., Obrist, M.K. and Moretti, M., 2014. Habitat connectivity shapes urban arthropod communities: the key role of green roofs. *Ecology,* 95(4), 1010-1021. https://doi.org/10.1890/13-0705.1
18. Currie, B.A., Bass, B., 2010. Using Green Roofs to Enhance Biodiversity in the City of Toronto. Toronto, p. 47.
19. Engel, S., 2017. Artenvielfalt fördern auf dem Gründach. Landeshaupstadt Munchen, Munchen, p. 31.
20. Torrance, S., Bass, B., MacIvor, J.S., McGlade, T., 2013. City of Toronto guidelines for biodiverse green roofs. City of Toronto, p. 37.
21. Gedge, D., Grant, G., Kadas, G. and Dinham, C., 2012. Creating green roofs for invertebrates–a best practice guide. Buglife - The invertebrate conservation trust, Peterborough., p. 29.
22. Gunnell, K., Grant, G., Williams, C., 2012. Landscape and urban design for bats and biodiversity. Bat Conservation Trust, p. 40.
23. Grant, G., 2006. Extensive green roofs in London. *Urban Habitats,* 4(1), 51-65. https://www.urbanhabitats.org/v04n01/london_pdf.pdf
24. Brenneisen, S., Baumann, N. and Tausenpfund, D., 2010. Ökologischer Ausgleich auf dem Dach: Vegetation und bodenbrütende Vögel. Zürcher Hochschule für Angewandte Wissenschaften, p. 40.

25. Lequerica Tamara, M. E., 2023. The ecology and behaviour of hover flies in urban ecosystems, PhD thesis. The University of Sydney, Sydney.

26. Baumann, N. and Kasten, F., 2010. Green roofs-urban habitats for ground-nesting birds and plants, in: Muller, N., Werner, P. and Kelcy, J.G. (Eds.), *Urban biodiversity and design*. John Wiley and Sons, Chichester, pp. 348-362.

27. Brenneisen, S., 2006. Space for urban wildlife: designing green roofs as habitats in Switzerland. *Urban Habitats*, 4(1), 27-36.

28. Belcher, R.N., Sadanandan, K.R., Goh, E.R., Chan, J.Y., Menz, S. and Schroepfer, T., 2019. Vegetation on and around large-scale buildings positively influences native tropical bird abundance and bird species richness. *Urban Ecosystems,* 22, 213-225. https://doi.org/10.1007/s11252-018-0808-0

29. Berthon, K., Nipperess, D., Davies, P. and Bulbert, M., 2015. Confirmed at last: green roofs add invertebrate diversity.in: *7th State of Australian Cities Conference*, 9-11.

30. Partridge, D.R. and Clark, J.A., 2018. Urban green roofs provide habitat for migrating and breeding birds and their arthropod prey. *PLoS One*, 13(8), e0202298. https://doi.org/10.1371/journal.pone.0202298

31. Dusza, Y., Kraepiel, Y., Abbadie, L., Barot, S., Carmignac, D., Dajoz, I., Gendreau, E., Lata, J.C., Meriguet, J., Motard, E. and Raynaud, X., 2020. Plant-pollinator interactions on green roofs are mediated by substrate characteristics and plant community composition. *Acta oecologica*, 105, 103559. https://doi.org/10.1016/j.actao.2020.103559

32. Rumble, H., Finch, P. and Gange, A.C., 2018. Green roof soil organisms: Anthropogenic assemblages or natural communities? *Applied Soil Ecology*, 126, 11-20. https://doi.org/10.1016/j.apsoil.2018.01.010

33. Schrader, S. and Böning, M., 2006. Soil formation on green roofs and its contribution to urban biodiversity with emphasis on Collembolans. *Pedobiologia*, 50 (4), 347-356. https://doi.org/10.1016/j.pedobi.2006.06.003

34. Ksiazek-Mikenas, K., Herrmann, J., Menke, S.B. and Köhler, M., 2018. If you build it, will they come? plant and arthropod diversity on urban green roofs over time. *Urban Naturalist*, 1, 52-72.

35. MacArthur, R.H. and Wilson, E.O., 2001. The theory of island biogeography. *Princeton University Press*.

36. Fabián, D., González, E., Domínguez, M.V.S., Salvo, A. and Fenoglio, M.S., 2021. Towards the design of biodiverse green roofs in Argentina: assessing key elements for different functional groups of arthropods. *Urban Forestry & Urban Greening*, 61, 127107. https://doi.org/10.1016/j.ufug.2021.127107

37. Domínguez, M.V.S., González, E., Fabián, D., Salvo, A. and Fenoglio, M.S., 2020. Arthropod diversity and ecological processes on green roofs in a semi-rural area of Argentina: similarity to neighbor ground habitats and landscape effects. *Landscape and Urban Planning*, 199, 103816. https://doi.org/10.1016/j.landurbplan.2020.103816

38. Schindler, B.Y., Griffith, A.B. and Jones, K.N., 2011. Factors influencing arthropod diversity on green roofs. *Cities and the Environment*, 4(1), 5.

39. McKinney, M.L., Gladstone, N.S., Lentz, J.G. and Jackson, F.A., 2019. Land snail dispersal, abundance and diversity on green roofs. *PLoS One*, 14(11), e0221135. https://doi.org/10.1371/journal.pone.0221135

40. Eakin, C.J., Campa III, H., Linden, D.W., Roloff, G.J., Rowe, D.B. and Westphal, J., 2015. Avian response to green roofs in urban landscapes in the Midwestern USA. *Wildlife Society Bulletin*, 39(3), 574-582. https://doi.org/10.1002/wsb.566

41. Wang, J.W., Poh, C.H., Tan, C.Y.T., Lee, V.N., Jain, A. and Webb, E.L., 2017. Building biodiversity: drivers of bird and butterfly diversity on tropical urban roof gardens. *Ecosphere*, 8(9), e01905. https://doi.org/10.1002/ecs2.1905

42. Pearce, H. and Walters, C.L., 2012. Do green roofs provide habitat for bats in urban areas?. *Acta Chiropterologica*, 14(2), 469-478. https://doi.org/10.3161/150811012X661774

43. Mills, W.P. and Rott, A., 2020. Vertical life: impact of roof height on beetle diversity and abundance on wildflower green roofs. *Journal of Urban Ecology*, 6(1), juaa017. https://doi.org/10.1093/jue/juaa017

44. MacIvor, J.S., 2016. Building height matters: nesting activity of bees and wasps on vegetated roofs. *Israel Journal of Ecology and Evolution*, 62(1-2), 88-96.

45. Kratschmer, S., Kriechbaum, M. and Pachinger, B., 2018. Buzzing on top: Linking wild bee diversity, abundance and traits with green roof qualities. *Urban Ecosystems*, 21, 429-446. https://doi.org/10.1007/s11252-017-0726-6

46. Quispe, I. and Fenoglio, M.S., 2015. Host-parasitoid interactions on urban roofs: an experimental evaluation to determine plant patch colonisation and resource exploitation. *Insect Conservation and Diversity*, 8(5), 474-483. https://doi.org/10.1111/icad.12127

47. MacIvor, J.S. and Ksiazek, K., 2015. Invertebrates on green roofs, in: Sutton, R.K. (Ed.), *Green Roof Ecosystems*. Springer, Cham, pp. 333-355.

48. Baumann, N., 2006. Ground-nesting birds on green roofs in Switzerland: preliminary observations. *Urban habitats*, 4(1), 37-50.

49. Dromgold, J.R., Threlfall, C.G., Norton, B.A. and Williams, N.S.G., 2020. Green roof and ground-level invertebrate communities are similar and are driven by building height and landscape context. *Journal of Urban Ecology*, 6(1), juz024. https://doi.org/10.1093/jue/juz024

50. Kyrö, K., Brenneisen, S., Kotze, D.J., Szallies, A., Gerner, M. and Lehvävirta, S., 2018. Local habitat characteristics have a stronger effect than the surrounding urban landscape on beetle communities on green roofs. *Urban Forestry & Urban Greening* 29, 122-130. https://doi.org/10.1016/j.ufug.2017.11.009

51. Parkins, K.L. and Clark, J.A., 2015. Green roofs provide habitat for urban bats. *Global Ecology and Conservation*, 4, 349-357. https://doi.org/10.1016/j.gecco.2015.07.011

52. Tonietto, R., Fant, J., Ascher, J., Ellis, K. and Larkin, D., 2011. A comparison of bee communities of Chicago green roofs, parks and prairies. *Landscape and Urban Planning*, 103(1), 102-108. https://doi.org/10.1016/j.landurbplan.2011.07.004

53. Braaker, S., Obrist, M.K., Ghazoul, J. and Moretti, M., 2017. Habitat connectivity and local conditions shape taxonomic and functional diversity of arthropods on green roofs. *Journal of Animal Ecology*, 86(3), 521-531. https://doi.org/10.1111/1365-2656.12648

54. Partridge, D.R., Parkins, K.L., Elbin, S.B. and Clark, J.A., 2020. Bat activity correlates with moth abundance on an urban green roof. *Northeastern Naturalist*, 27(1), 77-89. https://doi.org/10.1656/045.027.0107

55. Washburn, B.E., Swearingin, R.M., Pullins, C.K. and Rice, M.E., 2016. Composition and diversity of avian communities using a new urban habitat: Green roofs. *Environmental management*, 57, 1230-1239. https://doi.org/10.1007/s00267-016-0687-1

56. Colla, S.R., Willis, E. and Packer, L., 2009. Can green roofs provide habitat for urban bees (Hymenoptera: Apidae)?. *Cities and the Environment,* 2(1), 4. https://digitalcommons.lmu.edu/cate/vol2/iss1/4

57. Tonietto, R., Fant, J., Ascher, J., Ellis, K. and Larkin, D., 2011. A comparison of bee communities of Chicago green roofs, parks and prairies. *Landscape and Urban Planning,* 103(1), 102-108. https://doi.org/10.1016/j.landurbplan.2011.07.004

58. MacIvor, J.S. and Lundholm, J., 2011. Insect species composition and diversity on intensive green roofs and adjacent level-ground habitats. *Urban Ecosystems,* 14, 225-241. https://doi.org/10.1007/s11252-010-0149-0

59. Passaseo, A., Petremand, G., Rochefort and S., Castella, E., 2020. Pollinator emerging from extensive green roofs: wild bees (Hymenoptera, Antophila) and hoverflies (Diptera, Syrphidae) in Geneva (Switzerland). *Urban Ecosystems*, 23, 1079-1086. https://doi.org/10.1007/s11252-020-00973-9

60. Brenneisen, S., 2005. The Natural Roof (NADA): Research Project Report on the Use of Extensive Green Roofs by Wild Bees. University of Wädenswil, Wädenswil, p. 21.

61. Gonsalves, S., Starry, O., Szallies, A. and Brenneisen, S., 2022. The effect of urban green roof design on beetle biodiversity. *Urban Ecosystems*, 25(1), 205-219. https://doi.org/10.1007/s11252-021-01145-z

62. Pétremand, G., Chittaro, Y., Braaker, S., Brenneisen, S., Gerner, M., Obrist, M.K., Rochefort, S., Szallies, A. and Moretti, M., 2018. Ground beetle (Coleoptera: Carabidae) communities on green roofs in Switzerland: synthesis and perspectives. *Urban Ecosystems*, 21, 119-132. https://doi.org/10.1007/s11252-017-0697-7

63. Larson, B.M.H., Kevan, P.G. and Inouye, D.W., 2001. Flies and flowers: taxonomic diversity of anthophiles and pollinators. *The Canadian Entomologist*, 133(4), 439-465. https://doi.org/10.4039/Ent133439-4

64. Dunn, L., Lequerica, M., Reid, C.R. and Latty, T. 2020. Dual ecosystem services of syrphid flies (Diptera: Syrphidae): pollinators and biological control agents. *Pest management science*, 76(6), 1973-1979. https://doi.org/10.1002/ps.5807

65. Bickel, D.J., 1994. The Australian Sciapodinae (Diptera: Dolichopodidae), with a review of the Oriental and Australasian faunas, and a world conspectus of the subfamily. *Records of the Australian Museum*, 21(S1), 1-394.

66. Bergeron, J.A.C., Pinzon, J. and Spence, J.R., 2018. Carabid and spider population dynamics on urban green roofs. Zoosymposia, 12, 69-89. https://doi.org/10.11646/zoosymposia.12.1.8

67. Brenneisen, S. and Hänggi, A., 2006. Begrünte Dächer–ökofaunistische Charakterisierung eines neuen Habitattyps in Siedlungsgebieten anhand eines Vergleichs der Spinnenfauna von Dachbegrünungen mit naturschutzrelevanten Bahnarealen in Basel (Schweiz). *Mitteilungen der Naturforschenden Gesellschaften beider Basel*, 9, 99-122.

68. Kyrö, K., Kotze, D.J., Müllner, M.A., Hakala, S., Kondorosy, E., Pajunen, T., Vilisics, F. and Lehvävirta, S., 2020. Vegetated roofs in boreal climate support mobile open habitat arthropods, with differentiation between meadow and succulent roofs. *Urban Ecosystems*, 23(6), 1239-1252. https://doi.org/10.1007/s11252-020-00978-4

69. Joimel, S., Grard, B., Auclerc, A., Hedde, M., Le Doaré, N., Salmon, S. and Chenu, C., 2018. Are Collembola “flying” onto green roofs? *Ecological Engineering*, 111, 117-124. https://doi.org/10.1016/j.ecoleng.2017.12.002

70. Kadas, G., 2006. Rare invertebrates colonizing green roofs in London. *Urban Hhabitats*, 4(1), 66-86.

71. Deng, H. and Jim, C.Y., 2017. Spontaneous plant colonization and bird visits of tropical extensive green roof. *Urban Ecosystems*, 20(2), 337-352. https://doi.org/10.1007/s11252-016-0596-3

72. Brenneisen, S., 2003. The benefits of biodiversity from green roofs – key design consequences. Conference Proceedings of Greening Rooftops for Sustainable Communities, Chicago.

73. Dvorak, B., 2021. Ecoregional green roofs: theory and application in the western USA and Canada. *Springer*.

74. Duncan, A., Duncan, R., Rae, Rebecca, G.W. and Stewart, B.J., 2001. Roof and ground nesting Eurasian Oystercatchers in Aberdeen. *Scottish Birds*, 22(1), 1-8.

75. Coffman, R.R. and Waite, T., 2011. Vegetated roofs as reconciled habitats: rapid assays beyond mere species counts. *Urban Habitats*, 6(1), 1-10.

76. Pizzey, G., Knight, F and, Menkhorst, P., 2007. The field guide to the birds of Australia. *HarperCollins Publishers Australia*.

77. Soanes, K., Sievers, M., Chee, Y.E., Williams, N.S.G., Bhardwaj, M., Marshall, A.J. and Parris, K.M., 2019. Correcting common misconceptions to inspire conservation action in urban environments. *Conservation Biology*, 33 (2), 300-306. https://doi.org/10.1111/cobi.13193

78. Dvorak, B. and Bousselot, J., 2021. Green Roofs in Shortgrass Prairie Ecoregions, in: Dvorak, B. (Ed.), *Ecoregional green roofs: theory and application in the western USA and Canada*. Springer, Cham, pp. 143-200.

79. Earth Pledge, 2005. Green roofs: ecological design and construction. *Schiffer Publishing*.

80. Müller, J., Ulyshen, M., Seibold, S., Cadotte, M., Chao, A., Bässler, C., Vogel, S., Hagge, J., Weiß, I., Baldrian, P., Tláskal, V. and Thorn, S., 2020. Primary determinants of communities in deadwood vary among taxa but are regionally consistent. *Oikos*, 129(10), 1579-1588. https://doi.org/10.1111/oik.07335

81. Griffiths, S.R., Bender, R., Godinho, L.N., Lentini, P.E., Lumsden, L.F. and Robert, K.A., 2017. Bat boxes are not a silver bullet conservation tool. *Mammal Review*, 47(4), 261-265. https://doi.org/10.1111/mam.12097

82. Rhodes, M. and Jones, D., 2011. The use of bat boxes by insectivorous bats and other fauna in the greater Brisbane region. *Australian Zoologist*, 35, 424-442. https://doi.org/10.7882/FS.2011.043

83. Machtans, C.S., Wedeles, C.H.R., Bayne, E.M., 2013. A first estimate for Canada of the number of birds killed by colliding with building windows. *Avian Conservation and Ecology*, 8(2). http://dx.doi.org/10.5751/ACE-00568-080206

84. Ocampo-Peñuela, N., Peñuela-Recio, L. and Ocampo-Durán, Á., 2016. Decals prevent bird-window collisions at residences: a successful case study from Colombia. *Ornitología Colombiana*, 15, 94-101.

85. Veltri, C.J. and Klem, D., 2005. Comparison of fatal bird injuries from collisions with towers and windows. *Journal of Field Ornithology*, 76(2), pp.127-133. https://doi.org/10.1648/0273-8570-76.2.127

86. Madre, F., Vergnes, A., Machon, N. and Clergeau, P., 2013. A comparison of 3 types of green roof as habitats for arthropods. *Ecological Engineering*, 57, 109-117. https://doi.org/10.1016/j.ecoleng.2013.04.029

87. Salman, I.N.A. and Blaustein, L., 2018. Vegetation cover drives arthropod communities in Mediterranean/subtropical green roof habitats. *Sustainability*,10(11), 4209. https://doi.org/10.3390/su10114209

88. Nagase, A. and Nomura, M., 2014. An evaluation of one example of biotope roof in Japan: Plant development and invertebrate colonisation after 8 years. *Urban forestry & urban greening*, 13(4), 714-724. https://doi.org/10.1016/j.ufug.2014.07.004

89. Dunnett, N. and Kingsbury, N., 2004. Planting green roofs and living walls. *Timber Press*.

90. Snodgrass, E.C. and McIntyre, L., 2010. The green roof manual: a professional guide to design, installation and maintenance. *Timber Press*.

91. Benvenuti, S., 2014. Wildflower green roofs for urban landscaping, ecological sustainability and biodiversity. *Landscape and Urban Planning*, 124, 151-161. https://doi.org/10.1016/j.landurbplan.2014.01.004

92. Butler, C., Butler, E. and Orians, C.M., 2012. Native plant enthusiasm reaches new heights: Perceptions, evidence, and the future of green roofs. *Urban forestry & urban greening*,. 11(1), 1-10. https://doi.org/10.1016/j.ufug.2011.11.002

93. Lundholm, J., 2006. Green roofs and facades: a habitat template approach. *Urban Habitats*, 4(1), 87-101.

94. Lundholm, J., Heim, A., Tran, S. and Smith, T., 2014. Leaf and life history traits predict plant growth in a green roof ecosystem. *PLoS One*, 9(6), e101395. https://doi.org/10.1371/journal.pone.0101395

95. Lundholm, J. and Williams, N.S.G., 2015. Effects of vegetation on green roof ecosystem services, in: Sutton, R.K. (Ed.), *Green Roof Ecosystems*. Springer, Cham, pp. 211-232.

96. Benvenuti, S. and Bacci, D., 2010. Initial agronomic performances of Mediterranean xerophytes in simulated dry green roofs. *Urban Ecosystems*, 13, 349-363. https://doi.org/10.1007/s11252-010-0124-9

97. Farrell, C., Szota, C., Williams, N.S.G. and Arndt, S.K., 2013. High water users can be drought tolerant: using physiological traits for green roof plant selection. *Plant and soil*, 372, 177-193. https://doi.org/10.1007/s11104-013-1725-x

98. MacIvor, J.S. and Lundholm, J., 2011. Performance evaluation of native plants suited to extensive green roof conditions in a maritime climate. *Ecological engineering*, 37(3), 407-417. https://doi.org/10.1016/j.ecoleng.2010.10.004

99. Nagase, A. and Tashiro-Ishii, Y., 2018. Habitat template approach for green roofs using a native rocky sea coast plant community in Japan. *Journal of environmental management*, 206, 255-265. https://doi.org/10.1016/j.jenvman.2017.10.001

100. Sutton, R.K., Harrington, J.A., Skabelund, L., MacDonagh, P., Coffman, R.R. and Koch, G., 2012. Prairie-based green roofs: literature, templates, and analogs. *Journal of Green Building*, 7(1), 143-172. https://doi.org/10.3992/jgb.7.1.143

101. Van Mechelen, C., Dutoit, T. and Hermy, M., 2014. Mediterranean open habitat vegetation offers great potential for extensive green roof design. *Landscape and Urban Planning*, 121, 81-91. https://doi.org/10.1016/j.landurbplan.2013.09.010

102. Society for Growing Australian Plants. Keilor Plains Group, 1995. Plants of Melbourne's western plains: a gardener's guide to the original flora. *Society for Growing Australian Plants*.

103. Bull, M., 2014. Flora of Melbourne: a guide to the indigenous plants of the greater Melbourne area. *Hyland House Publishing*.

104. Scott, R., Blake, N., Campbell, J., Evans, D. and Williams, N.S.G., 2002. Indigenous plants of the sandbelt: a gardening guide for South-eastern Melbourne. *Earthcare St Kilda*.

105. Du, P., Arndt, S.K. and Farrell, C., 2018. Relationships between plant drought response, traits, and climate of origin for green roof plant selection. *Ecological Applications*, 28(7), 1752-1761. https://doi.org/10.1002/eap.1782

106. Szota, C., Farrell, C., Williams, N.S.G., Arndt, S.K. and Fletcher, T.D., 2017. Drought-avoiding plants with low water use can achieve high rainfall retention without jeopardising survival on green roofs. *Science of the Total Environment*, 603, 340-351. https://doi.org/10.1016/j.scitotenv.2017.06.061

107. Williams, N.S.G. and Morgan, J.W., 2015. The native temperate grasslands of south-eastern Australia, in: Williams, N.S.G., Marshall, A. and Morgan, J.W. (Eds.), *Land of sweeping plains: managing and restoring the native grasslands of South-eastern Australia*. CSIRO Publishing, Melbourne, pp. 27-60.

108. Rowe, B., Monterusso, M. and Rugh, C., 2005. Evaluation of sedum species and Michigan native taxa for green roof applications. Canada.

109. Rayner, J.P., Farrell, C., Raynor, K.J., Murphy, S.M. and Williams, N.S.G., 2016. Plant establishment on a green roof under extreme hot and dry conditions: The importance of leaf succulence in plant selection. *Urban forestry & urban greening*, 15, 6-14. https://doi.org/10.1016/j.ufug.2015.11.004

110. Parsons, R.F., 2000. Monocotyledonous geophytes: comparison of California with Victoria, Australia. *Australian Journal of Botany*, 48(1), 39-43. https://doi.org/10.1071/BT98056

111. Gaff, D.F. and Latz, P.K., 1978. The occurence of resurrection plants in the Australian flora. *Australian Journal of Botany*, 26(4), 485-492. https://doi.org/10.1071/BT9780485

112. Hitchmough, J.D., 1994. Urban Landscape Management. *Inkata Press*.

113. Luckett, K., 2009. Green roof construction and maintenance. *McGraw Hill LLC*.

114. Sorvig, K. and Thompson, J.W., 2018. Sustainable landscape construction: a guide to green building outdoors. *Island Press*.

115. Thoday, P.R., 2016. Plants and planting on landscape sites: selection and supervision. *CABI*.

116. Bull, J. and Wright, M., 2019. Elevating the botanical. *Landscape Architecture Australia*, 162, 26-35.

117. Sherk, J.T., Fu, W. and Neal, J.C., 2020. Site conditions, maintenance costs, and plant performance of 10 extensive green roofs in the research triangle area of Central North Carolina. *HortTechnology*, 30(6), 761-769. https://doi.org/10.21273/HORTTECH04565-20

118. Silva, C.M., Flores-Colen, I. and Coelho, A., 2015. Green roofs in Mediterranean areas - Survey and maintenance planning. *Building and Environment*, 94, 131-143. https://doi.org/10.1016/j.buildenv.2015.07.029

119. Nektarios, P.A., 2018. Green roofs: Irrigation and maintenance, in: Perez, G. and Perini, K. (Eds.), *Nature Based Strategies for Urban and Building Sustainability*. Butterworth-Heinemann, pp. 75-84.

120. Price, J.G., Watts, S.A., Wright, A.N., Peters, R.W. and Kirby, J.T., 2011. Irrigation lowers substrate temperature and enhances survival of plants on green roofs in the southeastern United States. *HortTechnology*, 21(5), 586-592. https://doi.org/10.21273/HORTTECH.21.5.586

121. Du, P.Z., Arndt, S.K. and Farrell, C., 2019. Is plant survival on green roofs related to their drought response, water use or climate of origin? *Science of the Total Environment*, 667, 25-32. https://doi.org/10.1016/j.scitotenv.2019.02.349

122. Williams, N.S.G., Hughes, R.E., Jones, N.M., Bradbury, D.A. and Rayner, J.P., 2010. The performance of native and exotic species for extensive green roofs in Melbourne, Australia. *Acta Horticulturae*, 881, 689-696.

123. Kuoppamäki, K. and Lehvävirta, S., 2016. Mitigating nutrient leaching from green roofs with biochar. *Landscape and Urban Planning*, 152, 39-48. https://doi.org/10.1016/j.landurbplan.2016.04.006

124. Buffam, I. and Mitchell, M., 2015. Nutrient cycling in green roof ecosystems, in: Sutton, R.K. (Ed.), *Green Roof Ecosystems*. Springer, Cham, pp. 107-137.

125. Vanstockem, J., Somers, B. and Hermy, M., 2019. Weeds and gaps on extensive green roofs: Ecological insights and recommendations for design and maintenance. *Urban Forestry & Urban Greening*, 46, 126484. https://doi.org/10.1016/j.ufug.2019.126484

126. Nagase, A., Dunnett, N. and Choi, M.S., 2013. Investigation of weed phenology in an establishing semi-extensive green roof. *Ecological engineering*, 58, 156-164. https://doi.org/10.1016/j.ecoleng.2013.06.007

127. Morgan, J.W. and Williams, N.S.G., 2015. The ecology and dynamics of temperate native grasslands in South-eastern Australia, in: Williams, N.S.G., Marshall, A. and Morgan, J.W. (Eds.), *Land of sweeping plains: managing and restoring the native grasslands of South-eastern Australia*. CSIRO Publishing, Melbourne, pp. 61-86.

128. Rayner, J., Lumsden, E. and Bathgate, R.S., 2022. Maintenance guidelines for Australian green roofs. University of Melbourne, Melbourne, p. 44.

129. MacIvor, J.S., Ruttan, A. and Salehi, B., 2015. Exotics on exotics: Pollen analysis of urban bees visiting Sedum on a green roof. *Urban Ecosystems*, 18, 419-430. https://doi.org/10.1007/s11252-014-0408-6

130. MacIvor, J.S. and Packer, L., 2016. The bees among us: Modelling occupancy of solitary bees. *PLoS One*, 11(12), e0164764. https://doi.org/10.1371/journal.pone.0164764

131. Houston, T., 2011. Native bees. Western Australian Museum. https://museum.wa.gov.au/research/collections/terrestrial-zoology/entomology-insect-collection/entomology-factsheets/native-bees

132. CSIRO, 2022. What's So Wonderful About Australian Native Wasps? CSIRO Publishing. https://blog.publish.csiro.au/wonderful-australian-native-wasps/

How to contact us

Online:
melbourne.vic.gov.au

In person:
Melbourne Town Hall - Administration Building
120 Swanston Street, Melbourne
Business hours, Monday to Friday
(Public holidays excluded)

Telephone:
03 9658 9658
Business hours, Monday to Friday
(Public holidays excluded)

Fax:
03 9654 4854

In writing:
City of Melbourne
GPO Box 1603
Melbourne VIC 3001
Australia

Interpreter services
We cater for people of all backgrounds
Please call 03 9280 0726

03 9280 0717	廣東話
03 9280 0719	Bahasa Indonesia
03 9280 0720	Italiano
03 9280 0721	普通话
03 9280 0722	Soomaali
03 9280 0723	Español
03 9280 0725	Việt Ngữ
03 9280 0726	عربي
03 9280 0726	한국어
03 9280 0726	हिंदी
03 9280 0726	All other languages

National Relay Service:
If you are deaf, hearing impaired or speech-impaired, call us via the National Relay Service: Teletypewriter (TTY) users phone 1300 555 727 then ask for 03 9658 9658
9am to 5pm, Monday to Friday (Public holidays excluded)

melbourne.vic.gov.au

CITY OF MELBOURNE