ECOSYSTEM SERVICES IN URBAN LANDSCAPES

BENEFITS OF TROPICAL URBAN VEGETATION

ACKNOWLEDGEMENTS

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Photo Credit: Future Cities Laboratory at the Singapore-ETH Centre, Carlina Teteris

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PREFACE

Singapore is justly proud of being a city immersed in greenery. Since it became an independent nation, Singapore has planted millions of trees and created hundreds of kilometres of green corridors while conserving tropical forests in nature reserves and nature parks, so that all citizens can enjoy the benefits of living in a green city. In the early years, the purpose of urban greenery was to make the city beautiful and pleasant and to provide places where people could enjoy exercise and recreation.

Over the years, however, it has become apparent that urban green spaces provide many other benefits, especially for people living in densely populated cities like Singapore. Large cities are prone to environmental problems such as poor air quality, high levels of noise, the urban heat island effect and the risk of flooding. As many recent studies have shown, green spaces can mitigate these problems, for example by cooling the air and retaining water after heavy storms. In this way, green spaces provide valuable benefits, which today are usually called 'ecosystem services'.

This booklet is about the relationships between vegetation and ecosystem services in Singapore. Unlike most books about vegetation, which highlight the importance of the natural and semi-natural habitats such as tropical forests, this one is concerned with the types of vegetation that are most easily accessible to urban residents and deliver valuable ecosystem services. From this perspective, the large areas of planted and managed vegetation such as lawns and street trees are also important contributors of ecosystem services and biodiversity.

Designing green spaces for specific ecosystem services raises new questions. What types of ecosystem services are most needed in particular urban settings? How do different types of vegetation differ in the services they provide? Which vegetation types would people like to have in the areas where they live? Why do people visit green spaces?

Based upon recent research at the Future Cities Laboratory and inputs from the Centre of Urban Greenery and Ecology (CUGE) of the National Parks Board (NParks), this booklet attempts to answer these and other questions. It describes the properties of different types of urban vegetation in Singapore and compares their capacity to provide ecosystem services. It also presents new information about how people in Singapore use urban vegetation and perceive the services and disservices it provides.

This booklet is intended not only for planners and designers. It is also for anyone interested in making Singapore a City in Nature, which will bring about benefits for all residents and make us more resilient in the face of climate change and increasing urbanisation. We hope it will contribute to a greater awareness of just how valuable green spaces are in a modern city and inspire the reader to make them even better. To that end, the booklet contains many recommendations about how urban vegetation can be designed and managed to provide the greatest benefits for all residents.

PART 1:
INTRODUCTION TO ECOSYSTEM SERVICES
What are Ecosystem Services and Disservices?

In cities like Singapore, urban residents obtain many benefits from both natural and managed ecosystems within the urban boundaries [1-3]. A growing field of research is dedicated to quantifying these benefits, which are now called 'ecosystem services' [4].

Ecosystem services are of various kinds. One kind is *provisioning services*, which means tangible products such as food, water and raw materials [3, 4]. While most of Singapore's food is imported, some is produced on agricultural land within the city's boundaries, and there are plans to increase proportion of food produced locally [5, 6]. Singapore's ecosystems are also very important for ensuring an adequate supply of water, with around 20% of the demand being met from local catchments [7].

A second kind of ecosystem service is *regulating services*, which are important for sustaining life and maintaining a balanced environment [3, 4]. Due to its tropical location and high population density, Singapore has to cope with urban warming and the risk of flooding [8]. In addition, episodes of poor air quality occur regularly due to cross-border haze events [9]. Regulating services provided by urban ecosystems can help reduce these environmental pressures in various ways. For example, urban vegetation can cool the air [10] and provide shade [11], making it more comfortable for people who are active outdoors [12, 13]. It can also retain water during a storm, thereby reducing pressure on the drainage systems [14, 15]. And by trapping fine particles, plant foliage helps in cleaning the air during a haze event [16, 17]. A third kind of ecosystem service is *supporting services*, which maintain the functioning of ecosystems. Examples include pollination and nutrient cycling.

Finally, urban ecosystems provide *cultural services*, which comprise a combination of benefits including mental and physical well-being, education, and cultural heritage [18, 19]. In Singapore, public parks are an important space for recreation and relaxation [20, 21], providing opportunities for numerous recreational activities [22]. Studies have shown that the use of green spaces brings significant health benefits [23, 24], and specific green spaces are now being designed to provide horticultural therapy to at-risk groups such as the elderly [25].

Around the world, city planners are embracing the concept of ecosystem services as a way to offset some of the negative environmental effects of urbanization. Singapore was one of the pioneers of urban greening [26], with the first initiatives being designed mainly to provide aesthetic, environmental and recreational benefits. More recent projects though have been planned with a much wider range of ecosystem services and biodiversity in mind. For example, the PUB's Active, Beautiful, Clean Waters (ABC Waters) Programme aims to slow down water runoff, as well as provide multifunctional blue-green infrastructure including bioretention swales and rain gardens [27, 28]. Singapore is also at the frontier of skyrise greening, with the Urban Redevelopment Authority (URA)'s Landscaping for Urban Spaces and High-Rises (L.U.S.H) Programme and NParks' Skyrise Greenery Incentive Scheme (SGIS) designed to enhance stormwater regulation, urban heat island mitigation and provide alternative green recreational and relaxation spaces [29]. Community gardening and allotment schemes have been recently introduced to further engage communities and society. These enable people to grow their own fruit and vegetables, connect with nature, and also contribute to the greening of Singapore [30].

Photo Credit: Zuzana Drillet

PART 1:
INTRODUCTION TO ECOSYSTEM SERVICES
What are Ecosystem Services and Disservices?

Some effects of urban nature may be undesirable, and these are referred to as 'ecosystem disservices' [31-33]. Examples worldwide include plants that are poisonous or cause allergies and harbour breeding grounds for mosquitoes and rats, which in turn may be carriers of diseases such as dengue. Urban planning and design must also consider the risk of increasing these disservices, and balance them against the benefits that urban nature can provide.

Singapore has made great progress in applying the ecosystem services concept to urban planning and design, but there is still more to do. Not all urban greenery is the same in providing ecosystem services, with some types of vegetation being more effective than others in delivering particular services. Further, soils deserve much more attention, since healthy soil is the basis for healthy vegetation and the ecosystem services it provides. Many factors influence which ecosystem services are most important in a particular context, including the type of development, its location, and the requirements of the users. To make good decisions, planners and designers need reliable information on the potential of different types of vegetation to deliver ecosystem services, and on how the vegetation and soil should be managed. This booklet aims to summarise the current state of knowledge on urban ecosystem services provided by common types of vegetation in Singapore's urban landscape, to guide design.

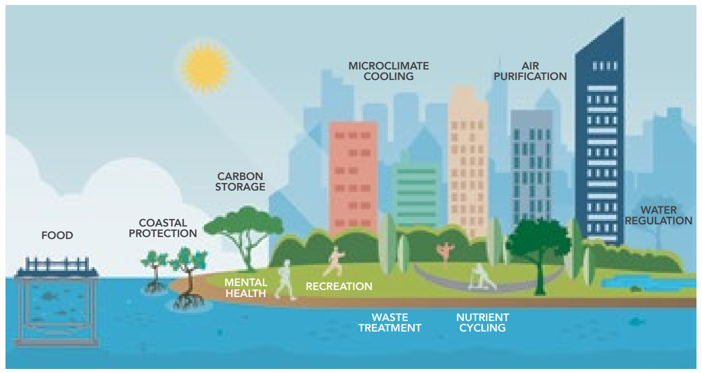

Fig. 1 Concept diagram of ecosystem services in urban landscapes.
Image Credit: Natural Capital Singapore

Photo Credit: Tze Kwan Fung

PART 2:
SINGAPORE'S URBAN VEGETATION
Recent History of Singapore's Vegetation

Before the British arrived in 1819, most of Singapore was covered by forest of various types [34, 35], including tropical lowland dipterocarp forest, freshwater swamp forest and mangrove forest. Lowland dipterocarp forest, so named because the dominant trees are members of the plant family Dipterocarpaceae, was the most common type and covered large parts of inland Singapore. Freshwater swamp forest was found along river and stream systems and in other low-lying inland areas prone to flooding. Mangrove forest was common in the areas of tidal influence, both around the coast and in estuaries.

Following colonisation, large areas of forest were cleared and the land was used for agriculture. Harvesting of timber for firewood and charcoal together with growing of crops such as gambier, pepper and pineapple, reduced the original biodiversity and degraded the soils. The gambier and pepper plantations had the greatest impact on the original vegetation, because the farmers not only cleared forest to grow these crops, but cleared a similar area of forest for firewood to process the gambier. When the soil was depleted of nutrients, which would have happened after about 15 or 20 years, the farmers abandoned the land and shifted their cultivation elsewhere [35, 36]. By 1900, less than 10% of Singapore's original forest cover remained [34]. Between 1900 and 1935, rubber became the most important natural product in Singapore, with rubber plantations covering as much as 40% of the total land area. After Singapore had achieved self-government in 1959, land use change was mostly driven by industrialisation and urbanisation [34, 35].

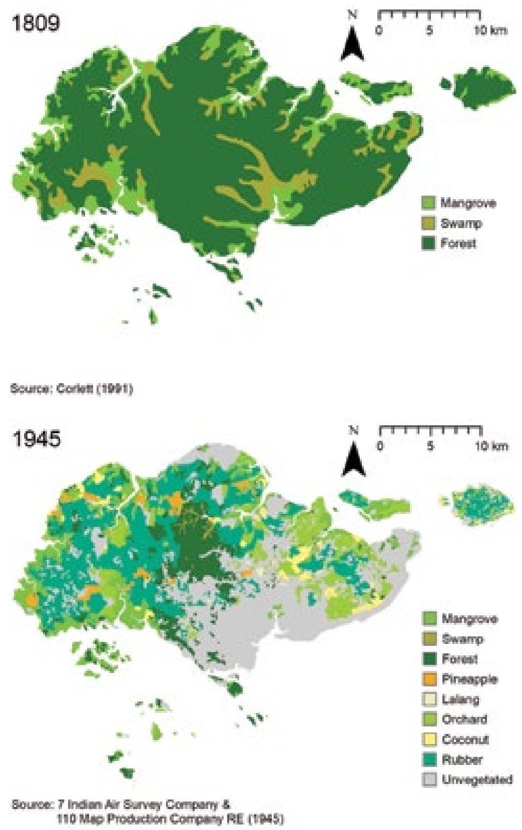

Fig. 2 Maps documenting the historical vegetation cover of Singapore in 1809 and 1945.

Fig. 3 Gambier and pepper plantation in Singapore, circa 1900. About 20 gambier plantations existed in Singapore at the time of Raffles' arrival in 1819. Their cultivation flourished after 1836, due to an increasing demand for gambier by the dyeing and tanning industries [37].

Fig. 4 Rubber plantations. By the early 1900s, rubber plantations occupied large areas of Singapore [34].

PART 2:
SINGAPORE'S URBAN VEGETATION
Recent History of Singapore's Vegetation

Less than 3% of the original primeval or primary forest remains to this day. We can still locate patches of primary lowland dipterocarp forest and freshwater swamp forest in Bukit Timah Nature Reserve and Central Catchment Nature Reserve. Most of the original mangrove forests were cleared for coastal aquaculture production or lost through land reclamation or the construction of freshwater reservoirs [34]. The few relatively intact patches are at Sungei Buloh Wetland Reserve, Mandai Mudflats and Mangroves, and on some offshore islands.

The situation is not all grim, though. Wherever land was abandoned, vegetation established spontaneously and developed into what is called secondary forest. The botanical composition of this new forest varies, depending on what the land was used for previously and when it was abandoned or cleared [38, 39]. As a result we can recognise different types of forest on land cleared before 1950s (where native species often dominate), on abandoned plantations (e.g. rubber), on abandoned kampungs, and in former orchards with fruit and ornamental trees. Secondary forest currently occupies some 138km^2, or roughly 19% of Singapore's land area [40].

In the 1960s, to offset the impact of rapid urbanization and soften the concrete landscape, then Prime Minister Lee Kuan Yew initiated Singapore's nationwide Tree Planting Campaign [41, 42]. This was the first of a series of greening initiatives that guided the development of Singapore, initially into a Garden City, later into a City in a Garden, and now a City in Nature. Thanks to the ambitious greening strategy of Singapore, 49% (ca. 359km^2) of the total land area is covered by vegetation [40], with about 26% of total land area being managed vegetation (ca. 195km^2) and the remainder spontaneous vegetation.

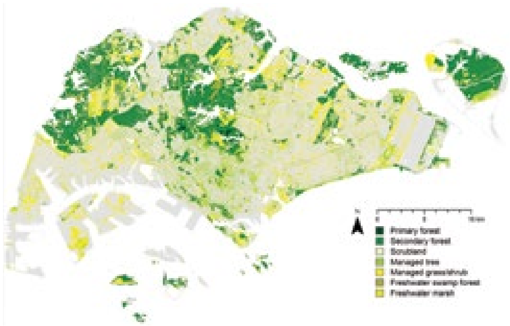

Fig. 5 Distribution of vegetation types in Singapore based upon satellite images taken between 2003 and 2018 [40].

Ecosystem Type	Past Cover (km^2)	Present Cover (km^2)
Lowland dipterocarp forest	410	1.15
Mangrove forest	74	9.61
Freshwater swamp forest	87	2.18
Secondary forest	-	137.48

Table 1 Past and present forest cover.

Sources: Past and present ecosystem type cover [35, 40]. For current lowland dipterocarp forest, O'Dempsey [35] reported 2.01km^2 instead. Note that the secondary forest here refers to terrestrial forest. The mangrove and freshwater swamp forest patches may also be secondary in origin.

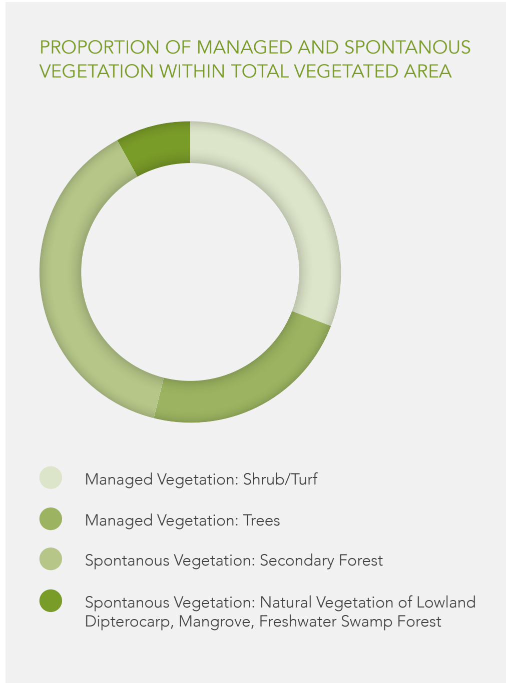

Fig. 6 Pie chart represents the total vegetated area which equals to 49% of the land area of Singapore. Approximately half of the total vegetated area of Singapore is managed vegetation and the remainder is spontaneous vegetation [40].

The greening of Singapore was accomplished in several phases [41, 42]. The first involved protecting established trees within developments, planting new trees, and allowing succession of fast-growing canopy trees in vacant lots. Road sides were replanted with canopy trees such as angsana (*Pterocarpus indicus*) and rain tree (*Samanea saman*) that provided shade. In a second phase, more colour was introduced into the landscape by planting species such as yellow flame tree (*Peltophorum pterocarpum*), flame-of-the-forest (*Delonix regia*), trumpet tree (*Tabebuia rosea*), and bougainvillea (*Bougainvillea spp.*). During this phase, many other now-common roadside trees were introduced. These include the Senegal mahogany (*Khaya senegalensis*) and sea apple (*Syzygium grande*); fruit trees such as mango (*Mangifera spp.*); trees with fragrant flowers such as cempaka (*Michelia x alba*), tembusu (*Cyrtophyllum fragrans*) and wild water plum (*Wrightia religiosa*); and several palm species including Alexandra palm (*Archontophoenix alexandrae*) and royal palm (*Roystonea regia*).

With its current vision of a City in Nature, it becomes essential to recognise the contributions of forests, both primary and secondary, in providing ecosystem services and sustaining native biodiversity. Hence, the conservation of these tropical forests in nature reserves and nature parks has been taken into consideration at the planning level, along with other types of urban infrastructure. Furthermore, one of the aims of the current vision to become a City in Nature is to have more mixed plantings of shrubs and trees that recreate the structural diversity of a tropical forest. Another is to favour native species such as gelam tree (*Melaleuca cajuputi*) and Malayan ixora (*Ixora congesta*). Species with other desirable ecological properties – for example, buas-buas (*Premna serratifolia*), which is attractive to birds and bees – are also increasingly planted.

Photo Credit: Future Cities Laboratory at the Singapore-ETH Centre, Carlina Teteris

PART 2: SINGAPORE'S URBAN VEGETATION

Vegetation Types Highlighted In This Booklet

Ecologists usually classify vegetation according to the main types of plants – for example, trees, shrubs or grasses – and the presence of particular plant species. This is because different plants need different soil and climatic conditions, and so the presence of certain species is not only a good way to distinguish vegetation types, but tells us something about local conditions.

For this book, we are interested in the different types of urban vegetation in Singapore, and the ecosystem services they provide. We use a simpler classification of vegetation types that is intended to be useful for planning and managing ecosystem services. This classification recognises five main types of urban vegetation as *grass*, *shrubs*, *trees*, *trees over shrubs* and *secondary forest*.

We discuss each type in greater detail as managed and spontaneous vegetation. Throughout the book, we use italics to indicate one of these types of vegetation. For example, *shrubs* means the vegetation type composed of the plants that fall into the *shrubs* category as defined here; *trees* means the vegetation type composed of *trees* as defined here.

Primary forest and mangrove forest are not included, as they have been well described and discussed in many publications. We also do not consider planted vegetation on buildings, though this component is increasing rapidly in Singapore.

Both managed and spontaneous types of vegetation provide valuable ecosystem services, which we compare in a later chapter. This way of looking at urban vegetation is rather new, and readers may have their own ideas about how the city's green cover can be improved to deliver even more benefits.

Grass

Managed herbaceous ground cover.

Shrubs

Managed herbaceous and woody vegetation usually less than 2m in height.

Trees

Managed woody perennial vegetation usually more than 2m in height.

Trees over shrubs

Managed vegetation of trees and shrubs in at least two distinct layers.

Secondary forest

Spontaneous vegetation growing on previously disturbed land.

Fig. 7 Simple classification of vegetation types into *grass*, *shrubs*, *trees*, *trees over shrubs* and *secondary forest*. *Photo Credit: Tze Kwan Fung and Zuzana Drillet*

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MANAGED VEGETATION

By managed vegetation, we mean plant communities that are actively tended for a particular purpose. These communities are often established on highly disturbed soils that are very different in physical structure and chemical composition from soils under natural and secondary forest (see the soil chapter for more details). The local microclimate may also be very different from that in more natural vegetation, making these sites unsuitable for many plant species. For example, some managed sites are always in the shade, while others are exposed to direct sunlight and radiation reflected from nearby buildings.

Many of the plants in managed vegetation have been deliberately introduced, though wild species that are suited to local conditions may also establish. Some of these unintended species are a nuisance, and are usually regarded as weeds. One example is the lalang grass (*Imperata cylindrica*), which can quickly become overgrown and increase the risk of bush fires; another is the snakewood tree (*Cecropia pachystachya*), an exotic species which competes aggressively with slower-growing native trees. However, many more spontaneous species are attractive and a welcome source of biodiversity in the urban area. Examples include ground-dwelling plants such as the sensitive plant (*Mimosa pudica*) and two-flowered oldenlandia (*Hedyotis corymbosa*); epiphytes such as bird's nest fern (*Asplenium nidus*), pigeon orchid (*Dendrobium crumenatum*) and Malayan banyan (*Ficus microcarpa*); and hemi-parasitic plants such as the common Malayan mistletoe (*Dendrophthoe pentandra*).

Managed vegetation also provides a habitat for many animals; a few of these may be considered as pests, but many more can be welcomed as adding richness to our urban wildlife. The most prominent animals are the birds, which can be seen and heard even in the most built-up areas. Examples include native species such as Asian glossy starling (*Aplonis panayensis*), olive-backed sunbird (*Cinnyris jugularis*), common iora (*Aegithina tiphia*), yellow-vented bulbul (*Pycnonotus goiavier*), pink-necked green pigeon (*Treron vernans*) and collared kingfisher (*Todiramphus chloris*); and non-natives such as house crow (*Corvus splendens*), Javan myna (*Acridotheres javanicus*) and rock pigeon (*Columba livia*)[43].

Although these types of vegetation are all, by definition, managed, the intensity of management varies greatly. For example, reserve land awaiting development may be mown occasionally, while the fine turf of a golf course is cut frequently and also treated with fertilizer and pesticides. These differences are important for wildlife, with higher biodiversity occurring in vegetation that is less intensively managed. For a general introduction to managing urban vegetation in Singapore, readers can refer for more details to the CUGE publication "Sustainable Landscape", published in 2015[44].

8	9
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Fig. 8 Yellow-vented bulbul (*Pycnonotus goiavier*). *Photo Credit: Ron Yeo*

Fig. 9 Collared kingfisher (*Todiramphus chloris*). *Photo Credit: Tze Kwan Fung*

Fig. 8 Pink-necked green pigeon (*Treron vernans*). *Photo Credit: Tze Kwan Fung*

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Vegetation Types Highlighted In This Booklet

GRASS

Grass is perhaps the most ubiquitous managed vegetation type in Singapore. Together with *shrubs*, *grass* occupies about 112km^2 of Singapore's land area, based on a recent mapping exercise [40]. This vegetation type is often used for aesthetic and recreational purposes. It can be found across urban Singapore, along roadsides, in housing estates, in parks, sites awaiting development, sports fields and golf courses.

The most common grass species in Singapore is cow grass (*Axonopus compressus*). Other frequently used species include Manila grass (*Zoysia matrella*), seashore paspalum (*Paspalum vaginatum*) and St. Augustine grass (*Stenotaphrum secundatum*).

Site conditions are important to establish *grass* vegetation. Before sowing, the site must be prepared to ensure there is sufficient grading and drainage. The water-holding capacity and resilience of turf depend greatly upon the soil texture, and a particular soil mix – Approved Soil Mix (ASM; soil:compost:sand = 3:2:1) is recommended by the NParks in Singapore [45]. Regular mowing is needed to maintain *grass* vegetation. The best turf grasses are low growing, mat-forming varieties like Manila grass that respond well to regular cutting.

Fig. 11 Map of *shrubs* and *grass* cover [40].

Fig. 12 Predominant vegetation type, *grass*.
Photo Credit: Tze Kwan Fung

SHRUBS

In this book, the vegetation type *shrubs* refers to woody or herbaceous plants that are maintained to be shorter than a *tree* (usually less than 2m in height) but taller than *grass* vegetation. *Shrubs* often have multiple stems or branches arising at or near the ground, which gives them their bushy appearance. This type of vegetation is used for screening, for boundaries, to protect landmarks and for aesthetic purposes. There are hundreds of shrub species that grow well in Singapore. Increasingly, landscape designers are choosing species that attract and provide food for birds, bees and butterflies. Commonly planted species include bougainvillea (*Bougainvillea spp.*), miagos bush (*Osmoxylon lineare*), ixora (*Ixora spp.*), yellow creeping daisy (*Sphagneticola trilobata*), heliconia (*Heliconia spp.*), red lip (*Syzygium myrtifolium*), wild pepper (*Piper sarmentosum*), and broad sword fern (*Nephrolepis biserrata*).

Most *shrubs* are managed by trimming and pruning. Growth may be improved by adding soil enhancers and fertilizer occasionally, and pest control measures may also be necessary. To keep these treatments to a minimum, it is recommended to select shrub species that are suited to local soil and light conditions.

Fig. 13 Shrub species of ixora (*Ixora spp.*).
Photo Credit: Tze Kwan Fung

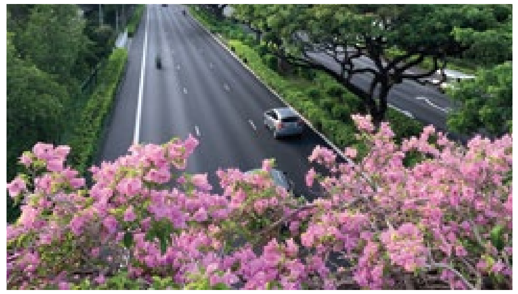

Fig. 14 Flowering shrubs such as bougainvillea (*Bougainvillea spp.*) are commonly planted to improve aesthetic quality of a space, and this can also support psychological well-being in people.
Photo Credit: Zuzana Drillet

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Vegetation Types Highlighted In This Booklet

TREES

Managed *tree* vegetation is another prominent urban feature of Singapore. Its total coverage is 82km², based on the latest mapping exercise [40]. *Trees* are woody perennial plants, growing to a considerable height, and planted over bare ground or *grass*. Tall single-stemmed palms with woody trunks (e.g. Alexandra palm) are often categorised as *trees*. This vegetation type is the most common along streetscapes, but also occurs commonly in public and private housing estates, parks and gardens in Singapore. NParks alone manages about two million trees planted along Singapore’s roadsides, parks and state land, and recently produced an online map showing the locations of around 500,000 trees (trees.sg) [46].

The previous section has described the phases of tree planting in Singapore. The earliest phase used a few large, fast-growing species such as the rain tree (*Samanea saman*), which resulted in rather uniform, plantation-like streetscapes. Many more tree species have been introduced during the past decade, however, in particular native trees and species that fulfil ecological functions such as attracting birds. Amongst the most common managed tree species are rain tree (*Samanea saman*), Senegal mahogany (*Khaya senegalensis*), trumpet tree (*Tabebuia rosea*), golden penda (*Xanthostemon chrysanthus*), chengal pasir (*Hopea odorata*), tembusu (*Cyrtophyllum fragrans*) and casuarina (*Casuarina equisetifolia*). Native tree species that are now frequently planted include sea gutta (*Planchonella obovata*) and gelam tree (*Melaleuca cajuputi*).

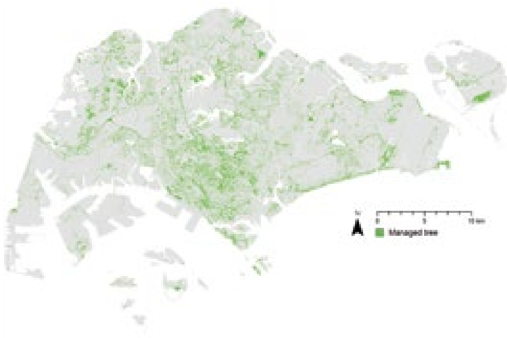

Fig. 15 Map of managed *tree* cover [40].

Fig. 16 Street trees. *Photo Credit: Zuzana Drillet*

Managing trees is a major responsibility. Trees in urban areas have to be inspected and pruned regularly for safety reasons and to minimise damage to structures such as pavements and buildings. To keep management costs as low as possible, it is important to plant trees with sufficient space for both their crowns and roots to grow, and to ensure access for pruning and maintenance.

Richards and Edwards [11] developed a new method of using Google Street View photographs for quantifying shade. The total canopy cover of street trees at the city scale was estimated using Google Street View photos. Results showed that a median of 13% of the annual diffuse and direct solar radiation was shaded by street trees in Singapore, and over 70% of this shading effect was due to the tree canopy. This research allows city planners to identify areas that need more trees.

Street Trees	
Rain Tree	*Samanea saman*
Yellow Flame Tree	*Peltophorum pterocarpum*
Golden Penda	*Xanthostemon chrysanthus*
Sea Gutta	*Planchonella obovata*
Chengal Pasir	*Hopea odorata*
Red Lip	*Syzygium myrtifolium*
Broad-Leafed Mahogany	*Swietenia macrophylla*
Senegal Mahogany	*Khaya senegalensis*
Trumpet Tree	*Tabebuia rosea*
Sea Apple	*Syzygium grande*

Park Trees	
Trumpet Tree	*Tabebuia rosea*
Yellow Flame Tree	*Peltophorum pterocarpum*
Casuarina	*Casuarina equisetifolia*
Rain Tree	*Samanea saman*
Coconut	*Cocos nucifera*
Sea Apple	*Syzygium grande*
Golden Penda	*Xanthostemon chrysanthus*
Tembusu	*Cyrtophyllum fragrans*
Chengal Pasir	*Hopea odorata*
Pink Mempat	*Cratoxylum cochinchinense*

Table 2 Common street and park trees, including coastal parks.

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SINGAPORE'S URBAN VEGETATION
Vegetation Types Highlighted In This Booklet

TREES OVER SHRUBS

This vegetation type consists of any combination of trees and shrubs that produces a canopy with two or more distinct layers. Two-layered vegetation is common along roadside and in HDB estates, with the lower layer consisting of either herbaceous plants or woody shrubs. More complex vegetation is to be found in the Nature Ways, that were first introduced by NParks in 2013. These multi-tiered plantings along roadsides are designed to imitate the structural complexity of natural forest, with emergent, mid-canopy, understorey, and undergrowth layers [42]. A main aim of the Nature Ways is to provide green corridors connecting areas of high biodiversity. Plants species are chosen that provide food and shelter for animals, and the corridors are intended to help them move through the urban landscapes.

Species planted in *trees over shrubs* sites as part of Nature Ways include shrubs such as red tree-vine (*Leea rubra*) and Singapore rhododendron (*Melastoma malabathricum*), as well as trees such as batoko plum (*Flacourtia inermis*) and kelat nasi-nasi (*Syzygium zeylanicum*). Other common species that are incorporated into multi-tiered vegetation planting are shrubs such as dwarf umbrella-tree (*Schefflera arboricola*) and red button ginger (*Costus woodsonii*).

Fig. 17 Sidewalks planted with *trees over shrubs*.
Photo Credit: Zuzana Drillet

SPONTANEOUS VEGETATION

Spontaneous vegetation refers to plant communities that are not actively managed. This type of vegetation, colloquially called 'wild' vegetation, includes a few remaining areas of primary lowland dipterocarp forest and extensive areas of *secondary forest* that have developed and established without human intervention. Although these areas receive almost no pruning or soil enhancement, occasional interventions may be made to improve the quality of the vegetation and promote regeneration. It is also necessary to inspect and prune trees growing along edges and trails to ensure their safety and to protect nearby infrastructure.

Photo Credit: Alex T.K. Yee

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SECONDARY FOREST

Secondary forest is the vegetation that develops on land that has been disturbed and then abandoned, such as former agricultural land. The ecological process by which this happens is called 'secondary succession'. *Secondary forest* currently occupies some 137km^2 or roughly 19% of Singapore's land area [40]. It usually has a very different structure and species composition from primary forest [38, 47], and the species entering the forest are mostly different from those of lowland dipterocarp forest.

Secondary forest is very variable, but two main types can be distinguished in Singapore [38, 39]. The first is secondary forest dominated by native species, including tiup-tiup (*Adinandra dumosa*), silverback (*Rhodamnia cinerea*), mahang (*Macaranga heynei*) and various species of *Calophyllum, Elaeocarpus, Garcinia* and *Syzygium*. This *native-dominated secondary forest* is mostly found on land cleared before the 1950s, especially in areas such as the Central Catchment Nature Reserve, where there are fragments of primary forest. The second type of *secondary forest* is dominated by exotic species such as albizia (*Falcataria moluccana*) and snakewood (*Cecropia pachystachya*). Some *exotic-dominated secondary forest* developed on former plantations, and its previous use is indicated by the presence of trees like rubber (*Hevea brasiliensis*), rambutan (*Nephelium lappaceum*) and durian (*Durio zibethinus*). This type of forest also develops on land that was cleared more recently and was invaded by rapidly growing invasive trees (i.e. waste woodlands).

Secondary forest often has a dense understorey of small trees and shrubs, making it difficult to enter. In a busy city, patches of *secondary forest* are some of the most secluded areas, because people never visit them. While this may seem like a waste of space, these forests are important reservoirs for wildlife. Many species, especially of birds and mammals, are highly sensitive to disturbance, especially during the breeding season, and would not exist in Singapore without these inaccessible refuges.

In general, *secondary forest* is not managed, though occasional interventions may be necessary, such as removing dead trees for safety reasons or clearing understorey to deter illegal activities. In principle, landscape designers could take advantage of the successional process that produces *secondary forest* as a simple way to create more diverse urban landscape [44]. For example, a uniform area of *grass* could be transformed into a mosaic of secondary woodland and grassland simply by restricting mowing to certain areas. This more diverse landscape would not only be aesthetically pleasing but also support more wildlife and deliver greater ecosystem services.

Fig. 18 *Secondary forest. Photo Credit: Alex T.K. Yee*

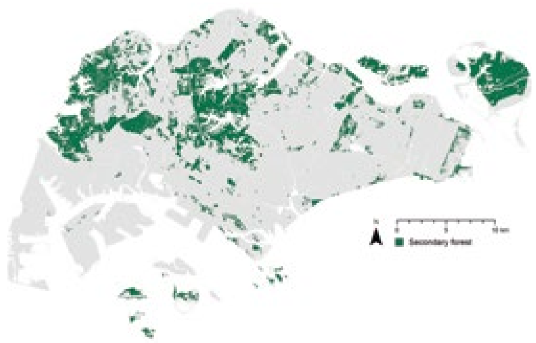

Fig. 19 Map of *secondary forest* cover [40].

Photo Credit: Zuzana Drillet

PART 3:
URBAN SOILS
Urban Soils and Soil Management

Soil is an essential dynamic natural resource that provides a wide diversity of ecosystem services. It is a medium for plant growth, providing plants with essential minerals and nutrients, and a habitat for microorganisms. Soil also retains water and stores carbon. In spite of its pivotal role in terrestrial ecosystems, most studies of ecosystem services have paid little attention to the soil, which is often not even mentioned in policy documents about ecosystem services [48].

Most soils research has concentrated on natural and agricultural ecosystems, and soils in urban and suburban areas have been largely neglected. It is known that urban tree health and growth are affected by soil conditions, but exactly which soil properties are most influential in the urban landscape remains largely unknown. However, it is gradually being recognised that healthy urban soils are crucial for supporting many ecosystem services [49].

Urban soils are strongly influenced by human activities such as deforestation, industrial and construction activities, transportation, addition of foreign materials and pollutants. As a result, they are often very variable in their physical, chemical and biological properties. For example, urban soils may be severely compacted [50], which inhibits root growth, reduces aeration and leads to lower rates of water infiltration. Compared with more natural soils, urban soils are likely to have higher bulk densities, lower porosities, less organic matter, poorer soil structure, lower rates of infiltration, higher levels of salinity and environmental contaminants, and altered pH and microbial communities [51] [52]. The most extreme differences in these physical, chemical and biological properties are often found in soils that are entirely derived from introduced materials such as building rubble or industrial waste.

As the importance of urban ecosystem services becomes better understood, it is also being recognised that the soil is a valuable resource that needs protection. There are strategies that can be adopted to protect and improve our soils, most of which are not difficult or expensive. Soil material removed during development should be collected, carefully stored, and reused, preferably at the same site but elsewhere if necessary [53]. Mulching is an effective way to improve aeration, conserve moisture and nutrients, and stimulate the soil microbial community. Rather than importing mulch from elsewhere, leaf litter should be allowed to accumulate on the soil surface whenever possible [54]. Soil loss through erosion could be prevented by planting over bare soil.

Photo Credit: Subhadip Ghosh

PART 3: URBAN SOILS

Singapore's Soils

Soil properties are strongly influenced by the climate and the parent materials from which the soil develops. The geology of Singapore can broadly be classified into three major formations – igneous rocks, sedimentary rocks and unlithified sediments [55]. The soils forming on the igneous rocks, in particular, tend to be acidic and have very low concentrations of important plant nutrients. A study in Bukit Timah Nature Reserve found that the vegetation and soils in this remaining fragment of primary forest had much lower nutrient levels than most tropical rainforests, because the soils were derived from acidic igneous rocks [56]. A more recent study of nutrients and trace elements in forest soils confirmed that irrespective of geology the soils are mainly acidic and contain low concentrations of important plant nutrients, especially phosphorus [55].

The period of plantation agriculture during the 19th and first half of the 20th centuries caused significant damage to Singapore's fragile rainforest soils. A study comparing a site on Kent Ridge that had once been used for plantations with undisturbed forest at Bukit Timah showed that the former agricultural soils were acidic and had very low concentrations of total nitrogen and phosphorus [56].

Rapid urbanisation in Singapore began in the mid-20th century and the island underwent a remarkable topographic transformation, with some 18% of Singapore's land surface being lowered through excavation, and a further 11% being raised through infilling [57]. These changes must have destroyed the original soil surface and created new surfaces composed of subsoil. Other changes must have occurred through importing of building and other materials, though relatively little information is available. A study on roadside soils in Singapore showed that the concentration of essential nutrients varied widely across the island [58]. More recent research also showed that soil conditions varied under different vegetation types, which certainly influenced their capacity to support ecosystem functions [59].

Reference	Soil & Rock Type	General Description	Geological Formation (PWD, 1976)
B	BEACH (Littoral)	Sandy, sometimes silty, with gravels, coral and shells	KALLANG Littoral, possibly also part of all other member & TEKONG
E	ESTUARINE (Transitional)	Peats, peaty and organic clays, organic sands	KALLANG Transitional possibly part of a Alluvial and Marine
F	FLUVIAL (Alluvial)	Sands, silty sands, silts and clays	KALLANG Alluvial, possibly part of all other members and TEKONG
F1		Predominantly granular soils including silty sands, clayey sands and sandy silts	Bed of Alluvial Member of KALLANG
F2		Cohesive soil including silty clays, sandy clays and clayey silts	Bed of Alluvial Member of KALLANG
M	MARINE	Very soft to soft blue or grey clay	Kallang Marine Member
O	OLD ALLUVIUM	Very weak to weak beds of sandstone and mudstone. See C-5 for weathering classification	OLD ALLUVIUM
FC	FORT CANNING BOULDER BED (also known as S3, Boulder Clay or Boulder Bed)	A colluvial deposit of boulders in a soil matrix. The matrix is typically a hard silty clay, but can be granular. The material is largely derived from the rocks and weathered rocks of the Jurong Formation	Not shown in PWD (1976)
S	SEDIMENTARIES (Rocks & associated soils)	Sandstones, siltstones mudstones, conglomerate and limestone. The rock has been subjected to a various degree of metamorphism.	JURONG Tengah, Rimau, Ayer Chawan and Queenstown Facies (plus the Pandan Limestone, which was not identified in PWD (1976)
G	GRANITE (Rock and associated Residual soils)	Granitic rocks, including granodiorite, adamellite and granite	BUKIT TIMAH GRANITE

Table 3 Classification of soils and rock type in Singapore [61].

Increasingly, efforts are being made to improve urban soils using a variety of techniques. These include:

- use of Approved Soil Mix (soil:compost:sand = 3:2:1) as a growing medium, and the periodic addition of compost for shrubs [60];
- addition of wood chips which are often used for soil mulching of planted trees, palms, shrubs and ground covers to help retain moisture and nutrients in the soil [45];
- addition of slurry components (mulch, grass sprigs, fertiliser, tackifier and water) used for turf planting in golf courses, roadside planting and larger grass areas.

These are welcome developments, but a broader concept that is officially recognised in legislation and the urban planning framework is still needed for managing Singapore's soils.

Soil property	Central	East	North	Northeast	West	Prob>F
Bulk density (Mg m^{-3})	1.24a	1.21ab	1.22ab	1.24a	1.14b	0.0136
pH	7.39a	6.56ab	6.04b	6.53ab	7.06a	0.0003
Electrical conductivity (dS m^{-1})	0.19a	0.05c	0.16a	0.10b	0.09bc	<0.0001
Phosphorus (mg kg^{-1})	1.77b	1.56b	2.87a	1.72b	1.52b	0.0004
Potassium (mg kg^{-1})	47.5b	129.6a	27.6b	48.3b	107.2a	<0.0001
Calcium (mg kg^{-1})	1699a	1132b	1056b	1442ab	1326ab	0.0005
Magnesium (mg kg^{-1})	631a	451ab	313b	440ab	438ab	0.0172
Sodium (mg kg^{-1})	130b	192a	193a	163ab	207a	0.0026
Organic C (%)	10.6	10.0	10.8	11.4	8.7	0.2132

Table 4 Properties of soils in streetscapes across Singapore [58].

Fig. 20 Bare soil is susceptible to erosion. Planting over bare soil surfaces is an easy way to prevent soil erosion.
Photo Credit: Zuzana Drillet

Photo Credit: Zuzana Drillet

PART 4: ECOSYSTEM SERVICES AND BIODIVERSITY

In this chapter, we consider how the five vegetation types described earlier differ in their capacity to support biodiversity and deliver ecosystem services. The results come from studies conducted at the Future Cities Laboratory between 2017 and 2019. The researchers chose particular indicators of biodiversity and ecosystem function that enabled them to compare the performance of the different types of vegetation. These indicators, which are described as follows, were:

- Bird species richness: numbers of bird species as an indicator of biodiversity;
- Litter decomposition: rate of decomposition as an indicator of nutrient turnover and soil fertility;
- Cooling: air temperatures as an indicator of the cooling effect of vegetation;
- Infiltration: rate of water infiltration into soil as an indicator of the capacity of vegetation to reduce surface runoff after heavy rain.

PART 4:
ECOSYSTEM SERVICES AND BIODIVERSITY
Bird Species Richness

BIRD SPECIES RICHNESS

With more than 400 bird species and 2,100 species of native vascular plants, Singapore is remarkably rich in biodiversity [62]. Many of these species are rare or threatened [63]. Given that so little of Singapore's primary or original vegetation remains, the common types of urban vegetation described in this book are obviously very important for supporting this biodiversity.

Birds are some of the most charismatic forms of urban biodiversity, and a source of pleasure and inspiration to many people. Public interest in birds is clear from the large numbers of bird guides sold each year, and from the social media and websites where enthusiasts share their photographs and observations. Birds are also ecologically important because of the diverse roles that different species play in ecosystems. Some birds feed on fruits and help disperse seeds, for example, while others feed on insects and help keep pest populations in check.

Because birds are ecologically diverse, the numbers of species present in a particular community is often used as an indicator of biodiversity more generally. This indicator, which is called 'bird species richness', is obtained by recording all the birds seen or heard in a particular area during a specified period. A recent study in Singapore found that bird species richness was usually highest in forests or in areas with a high cover of managed *trees* [64], and was much lower in areas with *grass*. This is probably because vegetation with trees is structurally complex and so offers shelter and food for many more bird species.

In our study, we recorded bird species richness at 108 locations in Singapore. We documented all birds that could be seen or heard within a radius of 50m during a 15 minute period. We then mapped the vegetation types and urban areas by hand in the field to estimate the cover of the five vegetation types within the circular study area of 50m radius. In this study, excluding flying individuals, we recorded a total of 3,633 birds belonging to 63 species, of which 47 were native species and four were locally important conservation species within our study sites. Our results also confirm the earlier findings that bird species richness increases with both forest and tree cover.

The common species in parks and gardens with a high tree cover include: black-naped oriole (*Oriolus chinensis*), common iora (*Aegithina tiphia*), olive-backed sunbird (*Cinnyris jugularis*), yellow-vented bulbul (*Pycnonotus goiavier*) and collared kingfisher (*Todiramphus chloris*). Species recorded in secondary forest for instance include: pink-necked green pigeon (*Treron vernans*), olive-winged bulbul (*Pycnonotus plumosus*), greater-racket tailed drongo (*Dicrurus paradiseus*) and straw-headed bulbul (*Pycnonotus zeylanicus*).

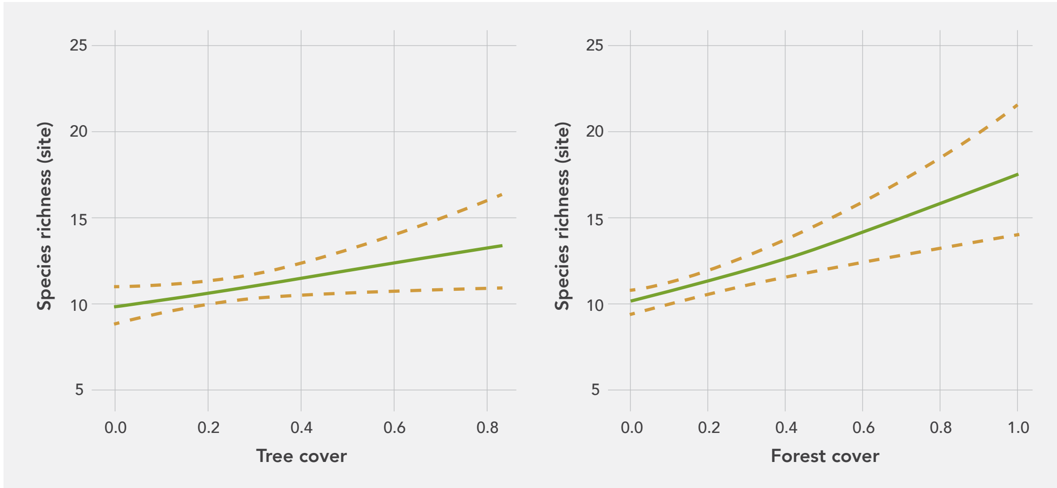

Fig. 21 Predicted bird species richness per site plotted against tree cover (left) and forest cover (right), based on 15min point count surveys. Dashed lines represent 95% confidence interval.

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Fig. 22 Olive-winged bulbul *(Pycnonotus plumosus). Photo Credit: Xu Weiting*

Fig. 23 Olive-backed sunbird *(Cinnyris jugularis). Photo Credit: Fung Tze Kwan*

For further research findings please see Fung, T. K., Richards, D. R., Leong, R. A. T., Tan, C. Y. T., & Edwards, P. J. (2018) Influence of vegetation and urban form on bird diversity in a dense tropical city, Singapore. In British Ecological Society Annual Meeting 2018, Birmingham, UK, December 16-19, 2018.

PART 4:
ECOSYSTEM SERVICES AND BIODIVERSITY
Bird Species Richness

Key Points
- Bird species richness increases with a greater amount of tree and forest cover;
- Forests are important for the conservation of birds.

Recommendations for Planning and Management
- To promote bird diversity in urban landscapes, green space management should aim at increasing tree cover while conserving remaining secondary and primary forests [65];
- Structural complexity of vegetation is important for birds;
  - Older and bigger trees are especially valuable for birds as they have more complex structure;
  - Land that is destined for development can provide spaces for spontaneous elements of greenery with less management intensity. Allowing the vegetation to grow "wild" (i.e. to have varying elements of tall grasses and spontaneously occurring shrubs and tree saplings) instead of a manicured managed single-layer *grass* vegetation could add more structural complexity to attract more numbers and types of birds;
  - Having a variety of plant species with different growth forms (grass, shrubs, trees, climbers, etc.), as well as flowering and fruiting plants, can also increase the diversity of birds.

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Fig. 24 Flowering grass. *Photo Credit: Zuzana Drillet*
Fig. 25 Black-naped oriole. *(Oriolus chinensis) Photo Credit: Tze Kwan Fung*

Fig. 26 People photographing birds in Singapore Botanic Gardens. *Photo Credit: Alex T.K. Yee*

PART 4:
ECOSYSTEM SERVICES AND BIODIVERSITY
Litter Decomposition

LITTER DECOMPOSITION

Ecologists use the word decomposition to describe the process by which organic materials such as leaf litter are broken down to release nutrients essential for growth. The rate of decomposition has a big influence upon the properties of an ecosystem. If decomposition is slow, nutrients are in short supply and plants grow slowly; where decomposition is fast, plants can have access to plenty of nutrients. In urban soils, decomposition is sometimes slow for reasons that include poor soil structure, compaction, lack of humus, exposure to direct sunlight, and low numbers of soil organisms such as earthworms.

We compared decomposition rates by adapting the Tea Bag Index method [88]. This measures decomposition across the five vegetation types by comparing the loss in weight from plastic mesh teabags containing green tea and rooibos tea. The teabags were placed in the soil for 60 days. We found that both kinds of tea decomposed most rapidly in *secondary forest* and *trees over shrubs* vegetation; and most slowly in *grass* vegetation. Our result suggest that the presence of *shrubs*, invertebrates and leaf litter are important for rapid decomposition.

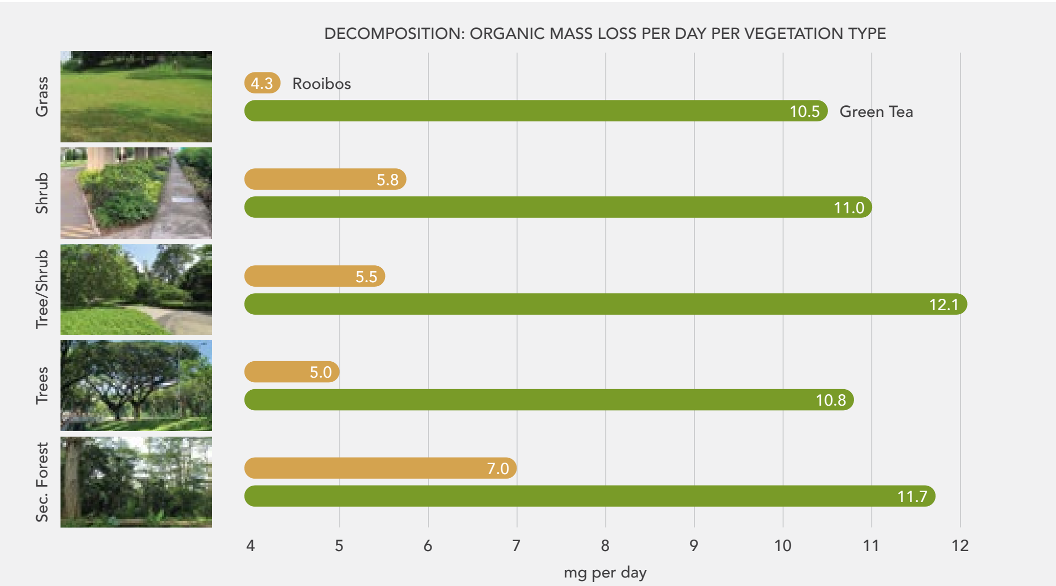

Fig. 27 *Trees over shrubs*, *secondary forest* and *shrubs* sites had the fastest decomposition (graph shows median value of decomposition effect for each vegetation type). Brown bars indicate rooibos samples, green indicate green tea samples.

For further research findings please see Fung, T. K., Richards, D. R., Leong, R. A. T., Ghosh, S., Tan, C. W. J., Drillet, Z., Leong, K. L. & Edwards, P. J. Litter decomposition and infiltration capacities in soils of different tropical urban vegetation types. In review.

Key Points
- Rates of decomposition vary among different urban vegetation types;
- Decomposition is fastest in *secondary forest* and in managed vegetation with *shrubs*;
- Decomposition increases with higher invertebrate activities and leaf litter cover;
- Soils with a high clay content support lower rates of decomposition.

Recommendations for Planning and Management
- Urban planners and managers should prioritise conservation of forests and their soils;
- Decomposition can be promoted by increasing the understorey density and structural complexity of managed vegetation;
- Leaf litter should be allowed to remain on the soil where possible;
- Ecosystem function can also be improved by adding biochar, mulch or compost to increase the soil organic content.

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Fig. 28 Leaf litter. *Photo Credit: Zuzana Drillet*
Fig. 29 Mulching. *Photo Credit: Subhadip Ghosh*

PART 4:
ECOSYSTEM SERVICES AND BIODIVERSITY
Cooling

COOLING

Cities are often warmer than surrounding rural areas, which is called the urban heat island effect. Vegetation can cool the environment by shading bare surfaces and by losing water through their leaves, a process known as transpiration. It is important to know what types of vegetation reduce temperatures most effectively.

We recorded air temperatures at 88 locations in Singapore [10]. For this purpose, we used small sensors known as iButtons to record ambient air temperature every hour for a period of 18 months.

Statistical modelling of the resulting data showed that different amounts and types of vegetation at the various locations had a very clear effect on air temperatures. The biggest cooling effect was at locations with a high cover of *secondary forest*, where the average air temperatures were 1.7°C lower than in locations with very little vegetation. Locations with a high cover of *trees over shrubs* came next, with an average reduction of 0.9°C, while *trees* alone only reduced air temperatures by 0.6°C.

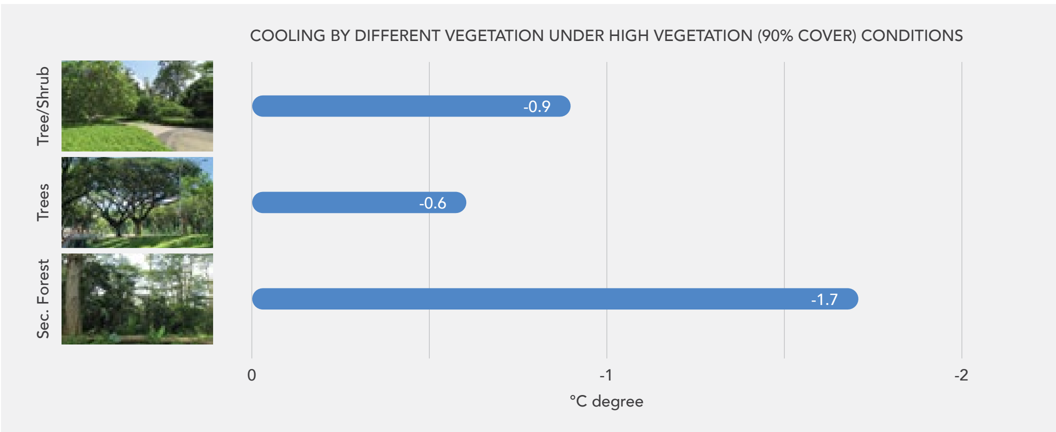

Fig. 30 *Secondary forest* showed the largest cooling effect (-1.7°C), followed by *trees over shrubs* (-0.9°C) and *trees* (-0.6°C).

For further research findings please see publication Richards, D. R., Fung, T. K., Belcher, R. N., & Edwards, P. J. (2020) Differential air temperature cooling performance of urban vegetation types in the tropics. Urban Forestry and Urban Greening, vol. 50, pp. 126651.

Key Points

- Secondary forest showed the largest cooling effect, followed by trees over shrubs and then trees;
- Grass and shrubs had no significant cooling effect.

Recommendations for Planning and Management

- Conserving secondary forest for its cooling function should be prioritised during planning and design of urban vegetation;
- The cooling benefits of managed vegetation can be improved by multi-tiered planting;
- Cooling effect can be enhanced with tree plantings that allow formation of large canopies;
- Any planting of managed vegetation should not obstruct the flow of air, which could even reduce thermal comfort.

Fig. 31 People seek shade under a tree in the Singapore Botanic Gardens. *Photo Credit: Shimona A. Quazi*

PART 4:
ECOSYSTEM SERVICES AND BIODIVERSITY
Infiltration

INFILTRATION

Many cities are vulnerable to flash floods during heavy storms, partly because of the high cover of impermeable surfaces. This problem has been aggravated in recent years because the intensity of the heaviest storms has increased as cities have grown larger [8]. Singapore and other cities increasingly make use of natural areas and urban greenery to help reduce the risk of flooding. PUB recommends various types of green and grey infrastructure features to manage stormwater at upstream sources and to reduce the peak flow of stormwater into the public drainage system [66].

Much of the rain falling on vegetation soaks into the soil and this process, known as infiltration, is one of the ways that surface runoff can be reduced. We measured saturation infiltration rates at 70 sites in Singapore using an instrument called a double ring infiltrometer. Our results show big differences in infiltration rates among the five vegetation types. Infiltration was fastest in *secondary forest*, followed by *trees over shrubs* and *shrubs*, and was very slow in *grass* vegetation. Bulk density was found to be a significant factor. These differences are probably due to the better soil structure from lower compaction beneath *secondary forest* and *trees over shrubs*, as well as the presence of larger root channels through which water can percolate.

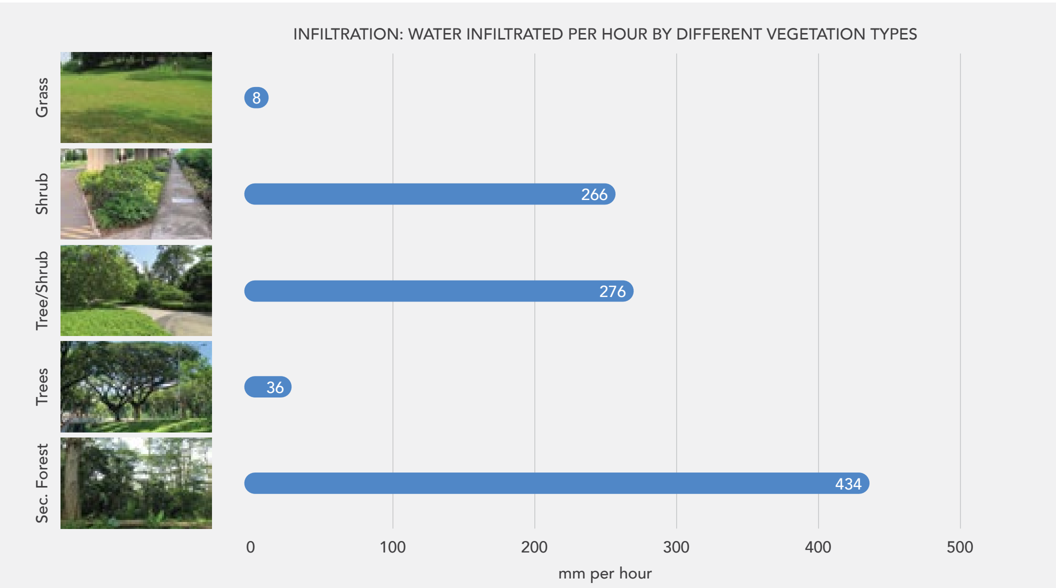

Fig. 32 The fastest infiltration was in *secondary forest* soil, followed by *trees over shrubs* and *shrubs* (image shows median rate of infiltration for each vegetation type).

For further research findings please see Fung, T. K., Richards, D. R., Leong, R. A. T., Ghosh, S., Tan, C. W. J., Drillet, Z., Leong, K. L. & Edwards, P. J. Litter decomposition and infiltration capacities in soils of different tropical urban vegetation types. In review.

Key Points
- Infiltration rates were fastest in secondary forest, then in managed vegetation consisting of trees over shrubs and shrubs;
- Infiltration rates were slowest in grass;
- Compacted soils and soils with a higher bulk density had lower infiltration rates.

Recommendations for Planning and Management
- In managed vegetation, infiltration rates can be significantly improved by planting trees over shrubs or shrubs;
- Soil structure can be improved by adding biochar or compost to increase the organic content, which also improves infiltration;
- Soils that are compacted or have a high clay content require special attention.

Fig. 33 Restoration of Bishan-Ang Mo Kio Park transformed a concrete canal into a naturalized river, increasing its infiltration capacity. *Photo Credit: Future Cities Laboratory at the Singapore-ETH Centre, Carlina Teteris*

Photo Credit: Shimona A. Quazi

PART 5: GREEN SPACES FOR PEOPLE

There is more and more evidence that urban green spaces are important for people's physical and mental well-being. Partly for this reason, planning authorities make great investments in improving green spaces. In this chapter we ask two questions: 1) How do residents in Singapore use green spaces? and 2) What do they see as the benefits and problems (disservices) of green spaces? Answers to these questions are important to ensure that green spaces are designed to meet people's needs and concerns. The results are based upon two questionnaire surveys conducted by researchers at Future Cities Laboratory, as well as a study of photographs uploaded on social media platforms.

PART 5:
GREEN SPACES FOR PEOPLE
How People Use Green Spaces in Singapore

HOW PEOPLE USE GREEN SPACES IN SINGAPORE

In a 2018 nationwide online survey, 1,000 Singapore residents were asked how often and why they visited green spaces. The results show that parks and neighbourhood open spaces are among the most commonly visited green spaces, with around half of respondents visiting neighbourhood parks and park connectors at least once a month [22]. These areas tend to be integrated within urban neighbourhoods, and ease of access is certainly one major reason for their popularity [67, 20, 21].

In contrast, people visited natural and semi-natural outdoor spaces less frequently, with over half the respondents visiting a nature reserve or other natural space not more than once a year. Such places are often further away from residential areas, and the inconvenience of reaching them is probably one reason for the lower frequency of visits.

People use green spaces for a wide variety of activities, including relaxation, family excursions, art, photography and physical exercise [22]. This means that preferences for particular types of green spaces are strongly influenced by individual interests and needs. In our survey, the most popular uses of green spaces were for sitting outdoors and running, with over half of respondents using them for these purposes at least once a month, followed by activities such as field sports, art and photography. Activities typically associated with more natural areas, such as nature recreation and hiking, were less common, with over half of respondents engaging in these activities only once a year or less.

The use of green spaces can also be assessed by data obtained from social media. For example, the numbers of geo-located photographs uploaded to image sharing platforms can provide useful information on which spaces are most popular. Our analysis of about 300,000 photographs on Instagram and 100,000 photographs on Flickr showed that green spaces vary greatly in popularity, with large regional parks and tourist attractions being far more popular than many others [68].

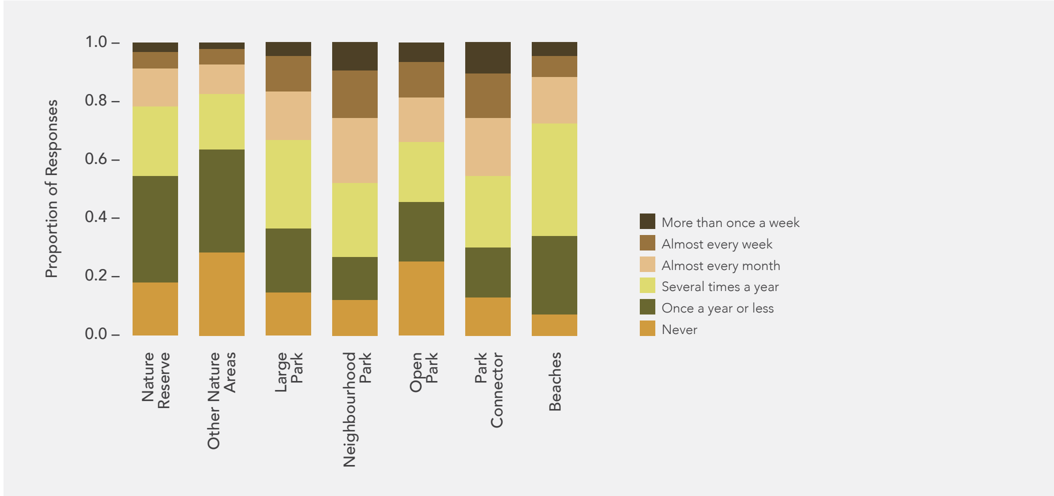

Fig. 34 Frequency of visits to different types of outdoor space in Singapore [22].

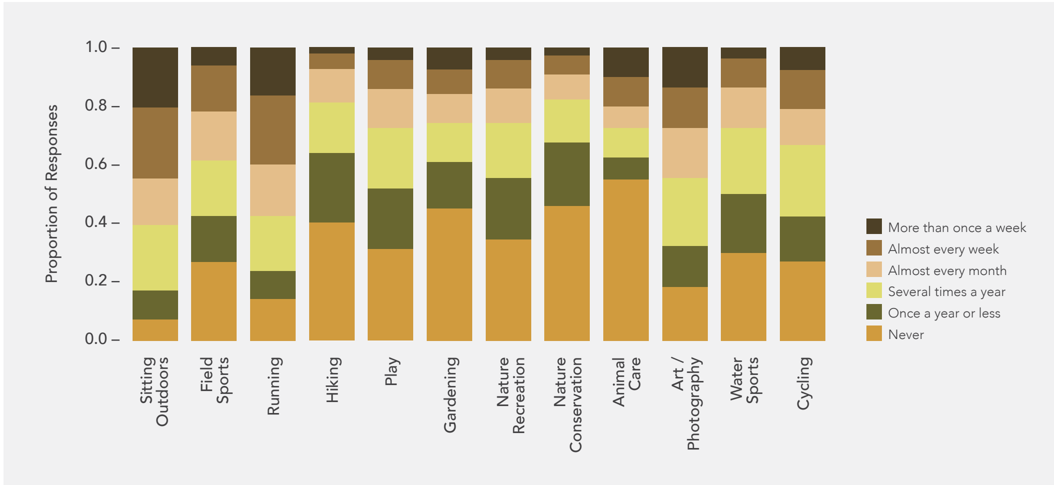

Fig. 35 Frequency of engagement with different nature-related activities in Singapore [22].

For further research findings see publication Richards, D. R.*, Fung, T. K.*, Leong, R. A. T., Sachidhanandam, U., Drillet, Z. & Edwards, P. J. (2020) Demographic biases in engagement with nature in a tropical Asian city. Plos One, 15(4), e0231576.

PART 5:
GREEN SPACES FOR PEOPLE
How People Use Green Spaces in Singapore

Analysing the content of these photos showed the ways in which people use different green spaces [69, 70]. The majority of both Instagram and Flickr photographs showed people engaged in recreation at green spaces well-served by public transport, while fewer photographs captured subjects like wildlife and greenery [68]. In another study [70], we classified park users according to their residency status and the content of the photographs they uploaded and 'favourited'. Our results showed that different groups, for example tourists and locals, tended to photograph different things, suggesting that their reasons for visiting green spaces were also different.

Providing for recreation is an important consideration when planning green spaces, but other types of value and use must also be considered. These include value for conservation (e.g. biodiversity, cultural heritage), network connectivity (e.g. for transport, ecology, hydrology, tourism) and aesthetic quality. There are often trade-offs to be made among these diverse uses, and the kinds of information collected in these studies can help planners and designers make better decisions [71].

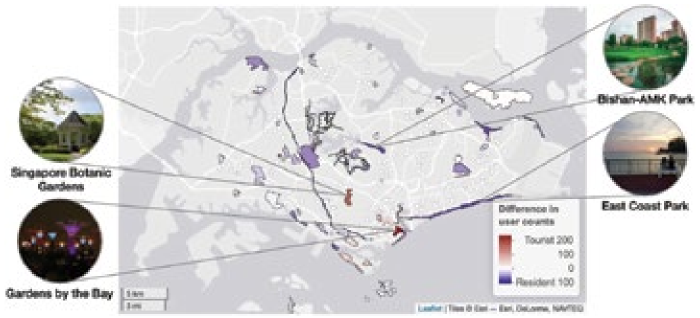

Fig. 36 Variation across green spaces in Singapore according to the residency status of social media users that they attract. Figure adapted from [70].

For further research findings see publications:
Song, X. P., Richards, D. R., & Tan, P. Y. (2020) Using social media user attributes to understand human–environment interactions at urban parks. Scientific Reports, 10(1), 808.

Song, X. P., Richards, D. R., He, P., Tan, P. Y., Does geo-located social media reflect the visit frequency of urban parks? A city-wide analysis using the count and content of photographs. In review.

Key Lessons
- Parks and neighbourhood open spaces were among the most commonly visited outdoor spaces in Singapore;
- Accessibility is an important factor that contributes to the use of green spaces.
- Common activities in green spaces include sitting outdoors, art and photography, running, gardening and cycling;
- Planning and management of green spaces for recreation should consider differences between parks as well as among groups of users;
- The aims of park design and planning often extend beyond visit frequency or popularity, as planners need to balance between multiple goals such as ecological functionality, network connectivity and heritage value, alongside the amenity offered by green spaces to city residents;
- Green spaces in Singapore are unevenly used, with some being far more popular than others.

Recommendations for Planning and Management
- Urban green spaces should be planned and designed to cater for the interests and needs of diverse groups;
- Improving the accessibility of urban green spaces is an effective way to promote outdoor recreation and nature engagement. Ways to improve accessibility include creating new entrance points, removing barriers in surrounding areas and improving transport links [72];
- The use of outdoor spaces can be increased by public outreach programmes that explain their benefits [73, 74];
- The pressure on the most popular green spaces could be eased by encouraging people to visit areas that are currently underused.

PART 5:
GREEN SPACES FOR PEOPLE
How People Perceive Ecosystem Services and Disservices Provided by Urban Vegetation

HOW PEOPLE PERCEIVE ECOSYSTEM SERVICES AND DISSERVICES PROVIDED BY URBAN VEGETATION

To plan and manage green spaces effectively, it is important to understand how people perceive and value these areas. Repeated consultations with members of the public can reveal how perceptions change with time [75], which can be useful in designing green spaces that continue to meet people's needs [76].

We conducted an online survey to quantify how urban vegetation services and disservices were perceived by residents in Singapore. The survey also explored which types of urban vegetation were considered most important in providing these services and disservices. The survey was conducted in 2018 and was restricted to 1,000 Singapore residents.

The results show that residents perceived ecosystem services provided by urban vegetation to be considerably more important than possible disservices [77]. Services that influenced environmental conditions (regulating ecosystem services) were considered more important than those with a cultural or social impact (cultural ecosystem services). The regulating services that were most valued were those contributing to shade, air quality and flood regulation. Among the cultural ecosystem services, benefits related to improved aesthetics, well-being and positive interactions with wildlife were highly appreciated. More than 40% of answers about disservices concerned problems of pest and disease.

Survey participants also stated the types of vegetation they would like to see more of in their neighbourhood. The most preferred types were *trees*, *grass*, and *trees over shrubs*; these were followed by *secondary forest*, and finally by *shrubs*.

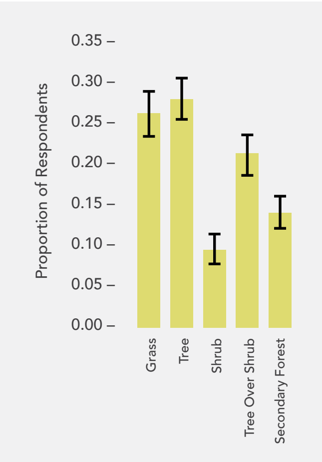

Fig. 37 Types of vegetation that respondents would like to have more of in their neighbourhood (n = 1000) [77].

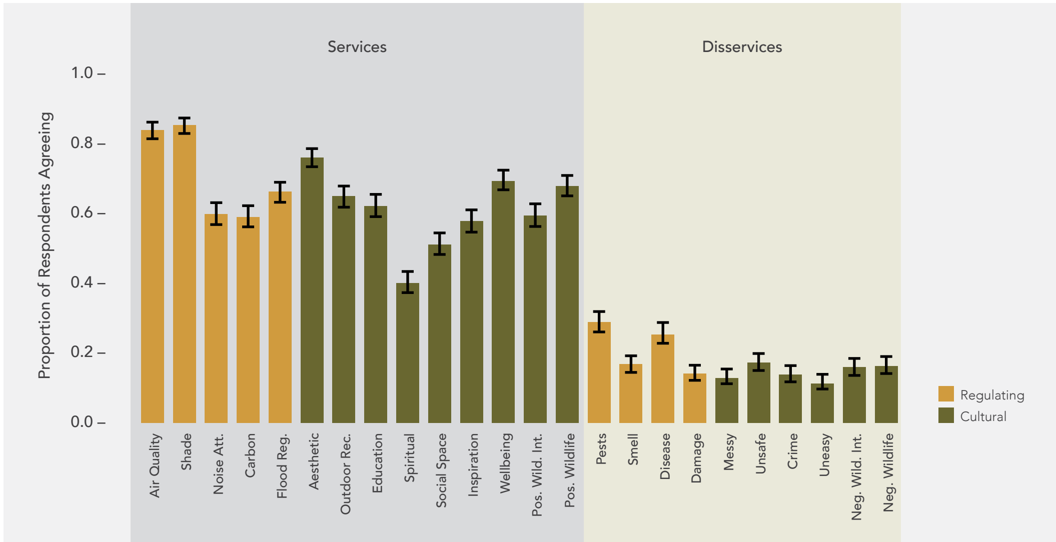

Fig. 38 Perception of the importance of ecosystem services and disservices of vegetation in Singapore (n = 1000) [77].

Vegetation Type	Top 3 most commonly associated Ecosystem Services	Top 3 most commonly associated Ecosystem Disservices
Grass	Social space, Outdoor recreation, Wellbeing	Pests, Smell, Disease
Shrubs	Aesthetic, Inspiration, Wellbeing	Safety hazard, Pests, Disease
Trees	Air quality, Cooling, Noise attenuation	Property damage, Safety hazard, Messy
Trees over shrubs	Aesthetic, Inspiration, Outdoor recreation	Property damage, Pests, Smell
Secondary forest	Positive wildlife interactions, Education, Carbon storage	Messy, Crime risk, Pests

Table 5 Perception of the relative importance of five broad vegetation types providing ecosystem services and disservices (top three most commonly associated services and disservices) in Singapore [77].

For further research findings see publication Drillet, Z.*, Fung, T. K.*, Leong, R. A. T., Sachidhanandam, U., Edwards, P. J. & Richards, D. R. (2020) Urban vegetation types are not perceived equally in the provision of ecosystem services and disservices. Sustainability. 12(5): p. 2076.

PART 5:
GREEN SPACES FOR PEOPLE
How People Perceive Ecosystem Services and Disservices Provided by Urban Vegetation

Fig. 39 Grass was perceived as the most important vegetation type for provision of social space and outdoor recreation for Singapore citizens. *Photo Credit: Shimona A. Quazi*

Key Lessons

- *Grass* cover had the strongest association with the provision of social space and outdoor recreation in Singapore; *grass* was also associated with disservices such as pests and unpleasant smells;
- *Shrubs* were associated with benefits related to improved aesthetics and well-being; however, they were also associated with pests, disease, and a lack of safety;
- *Trees* were associated with cooling, air quality and noise attenuation, as well as services relating to spirituality and well-being; however, they were also associated with infrastructure damage;
- *Trees over shrubs* were associated with aesthetic function, artistic inspiration, and outdoor recreational spaces; among disservices, this vegetation type was associated with property damage;
- *Secondary forest* was associated with education and positive wildlife interactions, as well as services with regulating functions such as carbon storage and flood regulation; however, it was also perceived as messy and associated with the risks of crime and pests.
- Residents in Singapore prefer managed landscapes (*trees*, *grass*, *trees over shrubs*) over *secondary forest*.

Recommendations for Planning and Management

- The value of *secondary forest* needs to be clearly communicated to the public, given the perceived disservices associated with this type of vegetation;
- Multi-tiered planting could be more commonly incorporated in highly urbanised residential areas, parks, gardens and along roads in Singapore;
- Public surveys are a useful for understanding people's perceptions, priorities and concerns about green spaces.

PART 6:
RECOMMENDATIONS AND CONCLUSIONS

Singapore is a green city - though not by chance! Through careful planning, it was able to increase its total green cover from 36% to over 47% of the total land area over the past 30 years [78], despite rapid economic and population growth. Most of the green cover is either secondary vegetation that has developed spontaneously on previously cleared or abandoned cultivated land, or actively planted as managed vegetation. In this book we recognise four main types of managed vegetation, namely *grass*, *shrubs*, *trees*, and *trees over shrubs*, which together account for around 55% of all Singapore's green spaces.

Singapore's different types of green spaces, especially those with spontaneous and managed vegetation, are enormously important for residents' quality of life. Indeed, in a city-state with no rural hinterland, green spaces are arguably even more valuable for sustainability, resilience and liveability than they are in most large cities.

This value is of three main kinds. First, green spaces provide a wide range of regulating ecosystem services, notably cooling the air, reducing flood risk, protecting soil surfaces from erosion, and cycling soil nutrients. The research findings presented here show that different vegetation types are not equal in providing these services. In general, more complex, multi-tiered types of vegetation perform better. All of the three indicators we measured – cooling effect, litter decomposition and infiltration – were highest in *secondary forest*, closely followed by *trees over shrubs*, with *grass* in last position. This is not to say that *grass* is of no value, and this type of vegetation is much appreciated for recreation, but extensive *grass* areas can be greatly improved for ecosystem services by turning them into a mosaics that include patches of woody vegetation.

Second, Singapore's green spaces support a truly remarkable diversity of wildlife. Many of the rarest species live in the nature reserves or nature parks with patches of primary or old secondary vegetation, and these areas rightfully enjoy special legal protection. However, many other species of great beauty and scientific interest are to be found in other areas of spontaneous as well as managed vegetation. It is no coincidence that the internationally recognised 'City Biodiversity Index', which measures biodiversity in cities and highlights how this can be increased, was originally proposed by Singapore. This index, also known as the Singapore Index on Cities' Biodiversity, includes indicators on native biodiversity, water and climate regulating ecosystem services, and the use of green areas for education and recreation, which were mentioned in this booklet.

Third, green spaces are directly important in the lives of many Singapore residents. Using a combination of questionnaires and data from social media, we gained many insights into how people use these areas. The most common uses of green spaces are sitting outdoors and running, but they are used for many other purposes as well. Our results suggest that there is great variation in the use of different areas, with parks and neighbourhood gardens being especially popular due to their ease of access. We also asked residents about how they perceived green areas and the ecosystem services they provide. In general, they preferred managed vegetation over *secondary forest*, which some respondents saw as a source of pests and diseases. However, they were well aware of the benefits provided by *secondary forest*, and most rated these more highly than any possible disservices. There was a high acceptance, and even preference for, structurally complex vegetation with *trees over shrubs*. Since this vegetation type generally supports more biodiversity and ecosystem services, we recommend incorporating more of it into residential areas, parks, gardens and along roads.

PART 6: RECOMMENDATIONS AND CONCLUSIONS

As to the future, there can be little doubt that Singapore's urban vegetation will become even more important than it is today for making the city liveable. On the one hand, Singapore expects to see further economic growth and a larger population; on the other hand, it will increasingly have to cope with global climate change, including higher temperatures and changing rainfall patterns. Under these changing conditions, maintaining and even enhancing the benefits from urban vegetation will pose significant challenges for planners and managers.

One challenge will be to compensate for an inevitable decline in the total area of *secondary forest* due to development. As we show in this booklet, this type of vegetation provides valuable ecosystem services and is important for biodiversity. Hence, it will be necessary to conserve these forests in nature reserves and nature parks. Following that, to replace the ecosystem services lost, it will be necessary not only to manage other green areas more effectively but also develop ambitious replacement strategies. At the landscape level, additional green measures could be introduced, including reforestation of other available areas, or by creating Nature Ways, pocket parks, gardens and green roofs in dense urban fabric. And at the building level, planners could encourage designs that include more structurally complex vegetation, both on the ground and the buildings.

A second challenge will be coping with climate change. If, as seems likely, temperatures and the intensity of storms increase significantly, the importance of vegetation in cooling the air and reducing the risk of flooding will become even greater. We should consider, however, that some of Singapore's most common plant species may not grow well in a future climate. To prepare for this possibility, we need to make urban ecosystems resilient to climate change, for example by planting a wider diversity of species.

Fortunately, many things can be done to improve the delivery of ecosystem services. In previous chapters, we make many recommendations relating to particular ecosystem services, and in the following pages we present some general principles for designing and managing urban green spaces. Along with these technical issues, however, it is important to ensure that the general public understands and supports efforts to preserve, diversify and enhance Singapore's green spaces. Our research suggests that many people know rather little about the benefits and biodiversity these spaces provide. Educational and outreach programmes will be needed to help people, especially children and youth, understand the importance of urban green spaces. In addition to factual information, these programmes should offer a direct experience of the beauty and benefits that nature can provide. With this knowledge and experience, the public is much more likely to support ambitious plans aimed at making Singapore's green spaces even better.

PART 6:
RECOMMENDATIONS AND CONCLUSIONS

General Principles for Planning and Managing Urban Vegetation

- **Take a systems approach.** Recognise that the elements of a landscape are connected to form larger systems, e.g. through the flow of water, movement of animals, turnover of nutrients.
- **Plan for secluded areas.** To persist in an urban environment, many species require patches of habitat free from human disturbance.
- **Recognise the special importance of primary and secondary forest for ecosystem services and wildlife.** Spontaneous vegetation is not designed, but it is especially valuable for wildlife and ecosystem services.
- **Strengthen ecological connectivity.** Given that any landscape involves many interconnected systems, strengthen ecological linkages in relevant ways.
- **Plan for multi-functional uses.** In land-scarce cities, all green areas should be designed to fulfil many functions, e.g. cooling, flood mitigation and recreation.
- **Plan for high tree cover in new urban neighbourhoods.** Trees, especially large, old trees, are an important source of biodiversity and ecosystem services.
- **Make use of natural successional processes.** Allowing vegetation to develop spontaneously can be good for biodiversity, while reducing management costs.
- **Plan for vegetational mosaics.** Uniform areas of grass can be converted into more diverse habitat mosaics, taking advantage of successional processes.
- **Consider all green spaces.** Small patches and parcels awaiting development account for a significant proportion of Singapore's green cover and also contribute to ecosystem services.
- **Care for the soil.** A healthy soil is the basis for a healthy ecosystem; many urban soils need to be rehabilitated.
- **Make the best possible use of native biodiversity.** Take advantage of the wealth of tropical plant growth forms to mimic the complexity of natural ecosystems.
- **Plant species that promote biological diversity.** Many trees, especially native species, are attractive to animals, while others support a high diversity of epiphytes.
- **Choose plant species that can withstand hostile urban environments.** In the face of climate change, it will be important that urban vegetation is resilient to higher temperatures and more extreme weather conditions.
- **Consider user needs and preferences.** Singapore's green spaces are used for many different purposes, and the needs and concerns of different user groups should be considered in designing green spaces.
- **Ensure that green spaces are easily accessible.** Differences in accessibility are a major reason for the uneven use of Singapore's green spaces.
- **Strengthen user connectivity.** As far as possible, green spaces should be connected not only ecologically but also for people using them for active mobility.

Several of these principles are already embedded in the planning and management of Singapore's green spaces, but are included here for completeness.

PART 7:
CASE STUDIES FROM SINGAPORE

Environmental problems such as urban warming and the risk of flooding are likely to increase in the future due to continuing urbanization and climate change. Conventional man-made solutions may provide short-term relief from these problems, but usually do not address their root causes. For example, air-conditioning is effective in providing indoor cooling, but the heat it generates may reduce thermal comfort outdoors. There is therefore a need for more long-term and sustainable answers to urban challenges, and ecosystem services can potentially form the basis of such nature-based solutions.

In fact, Singapore has been very innovative in developing nature-based solutions for different urban situations. Here we present four case studies that illustrate how the design principles described previously can be applied creatively in practice.

LET NATURE SHOW THE WAY

Singapore's roadsides have been abundantly planted since the inception of the Garden City vision in 1967, but how can the movement of wildlife across Singapore's urban environment be further enhanced?

One solution is to look to nature for inspiration. Implemented by NParks starting in 2013, Nature Ways are roadside green corridors that have been planted in a multi-tiered manner to resemble the layered structure of natural forests. Planted shrubs near ground level may play a role similar to that of the forest undergrowth—many are flowering species that provide nectar for birds and butterflies, which bring a dose of colourful activity to human road users. Nature Ways also include a tree layer comprising species of various heights. Trees and shrubs such as the various species of *Syzygium* produce berries that attract fruit-eating birds. Taller trees along Nature Ways are akin to the canopy layer in natural forests, and can provide roosting sites for birds of prey and other canopy-dwelling birds.

By offering food and shelter for a variety of species, Nature Ways may facilitate the movement of animals between major nature areas in Singapore. This is important for helping animals seek out new sources of food and potential mates. By bringing people and wildlife closer together, Nature Ways can foster opportunities for the public to appreciate Singapore's biodiversity. Moreover, Nature Ways also provide cool, shaded avenues for humans and animals alike.

Nature Ways are currently located in areas such as Admiralty, Tampines, Yishun and Clementi. Existing schemes have a total length of about 130km, and more are planned for the future. Birds observed along Nature Ways include the large and distinctive white-throated kingfisher (*Halcyon smyrnensis*), with its prominent brown and blue feathers and chuckling call [79]. Butterflies such as the orange-and-black tiger butterflies (*Danaus spp.*) and the tawny coster (*Acraea terpsicore*) can also be seen.

Fig. 40 Clementi Nature Way planted with trees over shrubs. *Photo Credit: Zuzana Drillet*
Fig. 41 Tawny coster (*Acraea terpsicore*). *Photo Credit: Zuzana Drillet*
Fig. 42 Changeable lizard (*Calotes versicolor*) basking on a shrub along a Nature Way. *Photo Credit: Zuzana Drillet*
Fig. 43 Heliconia flowers along Clementi Nature Way. *Photo Credit: Zuzana Drillet*

PART 7:
CASE STUDIES FROM SINGAPORE

BIRDS AND HUMANS ABOVE ONE ROOF: ROOF GARDEN AT 180 EDGEFIELD PLAINS

Roof gardens are a form of skyrise greenery designed to be accessible for human recreational and social use. This roof garden in the Punggol estate not only connects occupants of nearby residential flats to each other, but also provides a corridor for the many birds that visit this green space.

Twenty-five bird species have been recorded from this roof garden [80], ranging from common species such as the scaly-breasted munia (*Lonchura punctulata*), to less frequently-encountered species such as the Sunda pygmy woodpecker (*Yungipicus moluccensis*).

The roof garden at 180 Edgefield Plains is unsheltered and exposed to full sunlight, allowing for the lush growth of a variety of planted trees, shrubs and ground covers spanning a large area of approximately 3,700m^2. In addition to providing a range of bird habitats, many of the plants could also provide food resources such as nectar, fruits and seeds for visiting birds. Insects drawn to these plants can in turn also attract insectivorous bird species.

Located at 12m above ground level, this roof garden provides a relatively quiet refuge (49-61dB) where bird song is not obliterated by the noise of traffic. As it has an elevation similar to that of the surrounding tree canopy, it is thought to facilitate bird movement across the urban landscape and strengthen ecological connectivity.

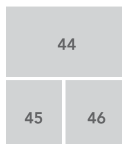

Fig. 44 Roof garden in Punggol estate. *Photo Credit: Kenny W.J. Chua*

Fig. 45 Olive-backed sunbird (*Cinnyris jugularis*). *Photo Credit: Emmanuel R. Goh / Dense and Green research project*

Fig. 46 Yellow-vented bulbul (*Pycnonotus goiavier*). *Photo Credit: Emmanuel R. Goh / Dense and Green research project*

PART 7:
CASE STUDIES FROM SINGAPORE

INTEGRATING URBAN BLUE AND GREEN: PAYA LEBAR QUARTER

Paya Lebar Quarter is a mixed-used development that is notable for its prominent use of skyrise greenery and rain gardens.

This development incorporates rain gardens as green elements in an outdoor recreational and refreshment area. Rain gardens are planted features designed to promote treatment of stormwater and slow their discharge into downstream waterways. Infiltration rates in urban environments are typically low owing to the large proportion of impervious surfaces and compacted soils. Consequently, urban stormwater runoff may carry impurities and contribute to high peak flow in drainage canals during heavy rain.

Paya Lebar Quarter is the first private mixed-use development to achieve PUB's ABC Waters certification for its use of stormwater detention and treatment design features towards addressing issues of stormwater runoff [81]. The dense vegetation of the rain gardens is intended to slow the flow of water, trapping sediment and absorbing nutrients, while the use of porous planting media promotes infiltration, which also reduces runoff and traps sediment. Thus, rain gardens can reduce the risk of flash flooding while ensuring that water entering the drainage system is clean.

This development also includes green roofs and vertical greenery systems, which are generally thought to reduce the flow of stormwater [82]. In addition, their cooling effects due to shading and evaporation may reduce the cost of air-conditioning [83]. Paya Lebar Quarter was awarded the Building and Construction Authority's Green Mark Platinum Rating in recognition of its energy and water saving features.

47 48

Fig. 47 Paya Lebar Quarter. *Photo Credit: Kenny W.J. Chua*
Fig. 48 Rain gardens at Paya Lebar Quarter. *Photo Credit: Kenny W.J. Chua*

PART 7:
CASE STUDIES FROM SINGAPORE

USING LEAF LITTER AT THE SINGAPORE BOTANIC GARDENS

Mulching is the practice of applying a layer of usually organic material on the soil surface around the base of plants, and is known to be beneficial for both the soil and plant growth. It is common practice in the Singapore Botanic Gardens, and increasingly elsewhere, to use leaf litter and pruned branches for this purpose.

The application of leaf mulch promotes the regeneration of soil nutrients as in natural forest [84]. Over time, the decomposition of leaf mulch by bacteria and fungi breaks down complex organic compounds into smaller molecules, releasing inorganic compounds containing nitrogen and phosphorus into the soil. In these simpler forms, the nutrients can be taken up by plants roots. The use of leaf mulch therefore reduces the need for artificial fertilisers.

In addition, leaf mulch provides benefits that are particularly relevant in the warm tropical climate of Singapore. By providing an insulating cover, it prevents the soil from becoming too warm or dry [85]. Moreover, mulch can also regulate surface runoff and soil erosion by intercepting rainfall [86] - a key consideration for the relatively high levels of rainfall in Singapore. This helps to retain soil nutrients that may otherwise be washed off by heavy rain. Finally, leaf mulch provides a habitat for a vast diversity of litter-dwelling invertebrates, which in turn attract animals such as the red junglefowl (*Gallus gallus*) and clouded monitor lizard (*Varanus nebulosus*).

49 50

Fig. 49 Accumulation of leaf litter for mulching at Singapore Botanic Gardens (I). *Photo Credit: Kenny W.J. Chua*

Fig. 50 Accumulation of leaf litter for mulching at Singapore Botanic Gardens (II). *Photo Credit: Kenny W.J. Chua*

GLOSSARY

bulk density – in soil science, the mass of soil per unit volume. Bulk density affects many soil properties relevant for plant growth, including aeration, water-holding capacity, mobility of nutrients, and structural support. Bulk density is higher in compacted soils and tends to increase with depth.

biodiversity – the variety and number of life forms within a specified area. This variety is most commonly measured at the level of species, but can also be measured at the genetic level. Most of the world's biodiversity is in the tropics.

cooling effect – vegetation can moderate the effects of higher temperatures by cooling the air, which happens through *evapotranspiration* and *shading*.

cultural ecosystem services – (see also *ecosystem services*) tangible and intangible benefits to human culture and society that derive from the natural environment, e.g. sports, recreation, and tourism; spiritual beliefs; heritage, traditions, history, and identity; certain types of knowledge, discovery, and creativity; and therapeutic uses.

detention – in the context of stormwater, the containment of excess rainwater for a short period of time before it enters downstream waterways.

ecosystem disservices – urban nature can sometimes be a nuisance to urban dwellers, for instance as a source of strong smells, allergens and mosquito-borne disease.

ecosystem services – direct and indirect benefits to humans derived from the natural environment, e.g. production of food, water and raw materials; clean air; fertile soils; pollination; moderating climate and disease; nutrient cycles and oxygen production. Four major categories of ecosystem services are *provisioning*, *regulating*, *cultural* and *supporting* services. Some processes may be considered as providing two or more services.

evapotranspiration – the sum of water evaporating from surfaces (land, water bodies, etc.) and water taken up by plants and evaporating from leaves (transpiration). Evapotranspiration affects the local microclimate by reducing air temperature while increasing humidity.

flowering plant – a type of plant that reproduces by means of *flowers* that develop into *fruits* protecting *seeds*. They are also called *angiosperms* and are the largest group of land plants with about 300,000 species. The tropics is especially rich in flowering plant species including grasses, herbs, shrubs and trees.

grass – (see also *turfgrass*) herbaceous plants with narrow leaves growing from the base, often used as ground cover for lawns. True grasses belong to the family *Poaceae* (previously called *Gramineae*).

infiltration – in soil science, the process by which water soaks into the soil, typically by gravity and capillary action. It is important because it affects plant health as well as underground water resources. If infiltration is very slow, water tends to accumulate on the surface and may cause flooding.

managed vegetation – vegetation that is tended by humans for various purposes. Urban management practices include branch pruning, mulching, brush removal, use of herbicides and tree growth regulators, removing dangerous trees, removing vegetation under and near power lines, and weed control.

mulch – a layer of organic or non-organic material applied to the surface of soil, either to conserve moisture, improve soil, suppress weeds or add visual interest. Commonly used materials are dry leaves, grass cuttings, wood chips, coconut husk, straw, manure or compost, jute sacking, plastic sheeting and cardboard.

nutrient cycle – the process by which mineral nutrients (e.g. calcium, magnesium, potassium, nitrogen, phosphorus) are exchanged between living systems and the environment (the atmosphere, water, and soil). It is through nutrient cycling that nutrients become available for plant and animal growth, making it one of the most important ecosystem processes.

peak flow – in hydrology, the maximum flow of water in streams and rivers after a storm.

percolation – (see also *infiltration*) in soil science, the process by which water already in the soil moves downwards through the soil profile.

provisioning ecosystem services – (see also *ecosystem services*) material benefits to humans produced or provided by the natural environment, e.g. food, water, minerals, fuels, fibre, chemical substances and genetic resources.

regulating ecosystem services – (see also *ecosystem services*) tangible benefits to humans that derive from natural processes that tend to stabilize the environment, e.g. climate regulation, population control of pests and diseases, decomposition of wastes, purification of air and water, flood and drought control.

supporting ecosystem services – (see also *ecosystem services*) natural processes that provide the basic conditions for other ecosystem services to take place, e.g. nutrient cycling, primary production, soil formation, habitat creation, pollination and seed dispersal.

rain garden – a planted garden that is designed to manage excess stormwater runoff. It may do this by providing a physical barrier that slows stormwater and prevents it from surging into waterways. Rain gardens also help purify the water by removing sediments, pollutants and harmful microbes.

refuge – for wildlife, a place or state of safety or shelter from predators, noise, heat or other threat.

roof garden – (also referred to as *rooftop greenery*) a garden on the roof of a building. They may be planted for ornamental reasons, recreation, reducing building temperature, improving air quality, growing food, attracting wildlife or moderating the flow of stormwater from a building.

runoff – (also referred to as *surface runoff* or *surface flows*) in hydrology, water from rain or other sources that flows over the land surface. Runoff occurs either when the soil is saturated and cannot hold any more water or when the ground is covered with an impermeable material such as concrete, tiles or tarmac that prevents water from *infiltrating*. Excessive runoff can cause flooding and soil erosion, and may carry pollutants (e.g. petroleum, pesticides, fertilisers, mud, leaves) into water bodies.

secondary forest – forest that has regrown on land that was either disturbed (e.g. logging, fire, insect infestation, high winds) or used for some other purpose and then abandoned (e.g. agriculture, former settlement).

shading effect of trees – reduces solar radiation that reaches the ground and improves the outdoor thermal comfort.

shrub – a woody or herbaceous plant that is smaller than a tree and usually has several main stems arising at or near the ground.

skyrise greenery – vegetation on high-rise buildings, including roof gardens, podium gardens, and vertical greenery on facades and balconies. Singapore has been a pioneer in this form of greenery.

species richness – the number of different species in a specified area. Species richness is a different measure from *species diversity*, which also takes into account the numbers of individuals of each species in an area.

street tree – a single tree or a line of trees located along the road verge.

soil decomposition – (see also *nutrient cycling*) the breakdown of organic matter in the soil into smaller components. The process is carried out by a vast diversity of soil organisms called *decomposers*, including earthworms, nematodes, insects, fungi and bacteria. It is an essential ecosystem process that releases nutrients in a form that plants can use.

soil management – interventions that lead to the enhancement of soil physical, biological and/or chemical properties, such as improving soil health and fertility.

soil type – soils that share similar properties based on the soil classification. The first soil map of Singapore [87] distinguishes soils on igneous rocks, soils on sedimentary rocks, soils on alluvial deposits, soils on alluvium, soils on recent marine sediments and organic soils.

spontaneous or 'wild' vegetation – plant communities that are not actively managed, e.g. almost no pruning or soil enhancement. In Singapore, these communities include primary lowland dipterocarp forest that existed prior to human settlement and secondary forest that has arisen spontaneously. Some management interventions may be undertaken for safety reasons or to encourage regeneration.

thermal comfort – a person's state of mind regarding their thermal environment. This is not the same as temperature alone, but a subjective condition that takes into account several environmental and personal factors (e.g. air temperature and wind speed, humidity, insulation due to clothing, and a person's physical characteristics).

tree – a woody perennial plant, growing to a considerable height planted over bare ground or *grass*.

tree over shrub – type of planting consisting of at least one layer of *shrubs* and *trees*.

turfgrass – vegetation type consisting of grass species grown for lawns, of a type that forms a dense even turf if mown and maintained.

vegetation type – this booklet recognises five types of urban vegetation based upon structure and management: *grass*, *shrubs*, *trees over shrubs*, *trees* and *secondary forest*.

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