5. VEGETATION OF SINGAPORE

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Singapore (1°21'07.6"N 103°49'11.3"E) is a tropical island-state situated south of Peninsular Malaysia, and north of the Riau Archipelago. Similar to tropical areas elsewhere, Singapore's climate is characterised by abundant rainfall (mean annual: 2165.9 mm), and generally high temperature (diurnal range: 23–33°C) and humidity (mean annual relative: 83.9%) throughout the year (Meteorological Service Singapore, 2018). Singapore's terrain is generally low-lying, with about three quarters of the island below 15 m. The highest point is the summit of Bukit Timah, which is at 163.63 m elevation (Wong, 2011). In 1963, the land area was 581.5 km^2, and by 2018 had increased to 724.2 km^2 through land reclamation (Singapore Land Authority, 2019). There are 62 offshore islands—the two largest (Pulau Ubin and Pulau Tekong) are located northeast of the main island, and the rest are mostly found south of the main island.

Before the arrival of the British in 1819, Singapore was likely covered mostly by lowland mixed dipterocarp forest (Fig. 1), similar to the original forest that was dominant in this part of Southeast Asia (Corlett, 1991, 1992). Mangrove forest likely occurred near river mouths with the vegetation transiting into freshwater swamp forest further inland. Stretches of sandy beach and rocky shore would have lined parts of the coast. Early human settlements (fourteenth to eighteenth centuries) have been recorded at the mouths or estuaries of the Singapore River, Kallang River, Seletar River and Punggol River.

Singapore underwent tremendous landscape and ecological transformation after British colonisation (see Corlett (1992) and O'Dempsey (2014) for detailed accounts). Large tracts of lowland dipterocarp rain forest were cleared for timber, then converted to plantations of various crops, including black pepper, gambier, and pineapple. By the early 1900s, most lowland dipterocarp rain forest had been cleared and the remaining few patches were mostly gazetted as forest reserves. Extensive black pepper and gambier plantations had rendered the soil infertile in many areas. After H.N. Ridley's arrival in Singapore in 1888 and his experiments with the excision method to tap rubber more effectively and sustainably, large areas were converted into rubber plantations (Wycherley, 1959; Wee & Corlett, 1986). Kampungs (traditional villages) also increased in number as the island became more developed. Mangrove habitats were also affected by over-exploitation although later, in 1939, Pandan and Kranji mangrove areas were gazetted as forest reserves to allow regeneration (Wee & Corlett, 1986).

After Singapore became independent from Malaysia in 1965, the new island nation began to focus on its industrial infrastructure resulting in the discontinuation or down-scaling of many agriculture-based activities. The growth of public housing estates to cater to the basic needs of a growing population saw most residents of the rural kampungs eventually resettled to high-rise public housing by the 1990s. Plantations and kampungs were gradually abandoned and/or cleared. At the same time, rivers were canalised and major river mouths dammed to develop reservoirs. Active land reclamation was also undertaken. These activities led to the destruction of many mangrove and coastal habitats. For example, the mangrove area

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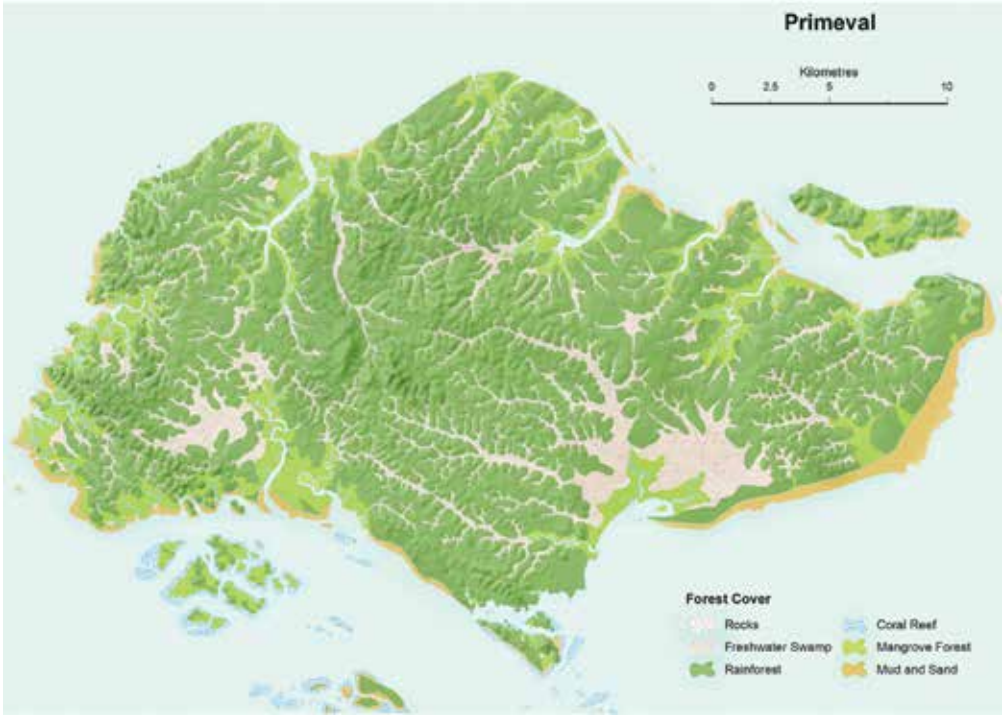

Figure 1. Primeval vegetation of Singapore (From O'Dempsey, 2014, reproduced with author's permission).

in the Kranji Forest Reserve gave way to a reservoir development and the coastal habitats at Ayer Islands were reclaimed and converted for industrial use (Wee & Corlett, 1986; Hilton & Manning, 1995; Tan et al., 2010).

Against this backdrop, however, the Singapore government also early recognised the importance of greenery in the ever-expanding urban areas (Er et al., 2016). Trees were planted ubiquitously, not just in parks but also along streets and in housing areas. Initially, large numbers of fast-growing exotic tree species were introduced, including acacia (*Acacia auriculiformis* A.Cunn. ex Benth.), albizia (*Falcataria moluccana* (Miq.) Barneby & J.W.Grimes) and mahogany (*Swietenia macrophylla* King). In recent years, the planting preferences have shifted towards species with more ecological functions (e.g. food plants for birds and butterflies) and/or native species. In 2018, the National Parks Board, which oversees the greenery of Singapore, was reported to be managing around two million trees along the streets of urban areas (The Straits Times, 2018). These greening efforts have paid off: Singapore is now one of the greenest cities in the world based on a 2017 study that quantifies greenery of different cities using Google Street View (Choo, 2017).

In a recent study, about 50% of Singapore's land area was estimated to be vegetated (Fig. 2) (Yee et al., 2011). Approximately half of that land is managed and another half is wild or spontaneous. Of the wild vegetation, there is about 200 ha of primary forest consisting of lowland dipterocarp rain forest and/or freshwater swamp forest. These patches can be found in the Bukit Timah Nature Reserve (BTNR) and Central Catchment Nature Reserve (CCNR).

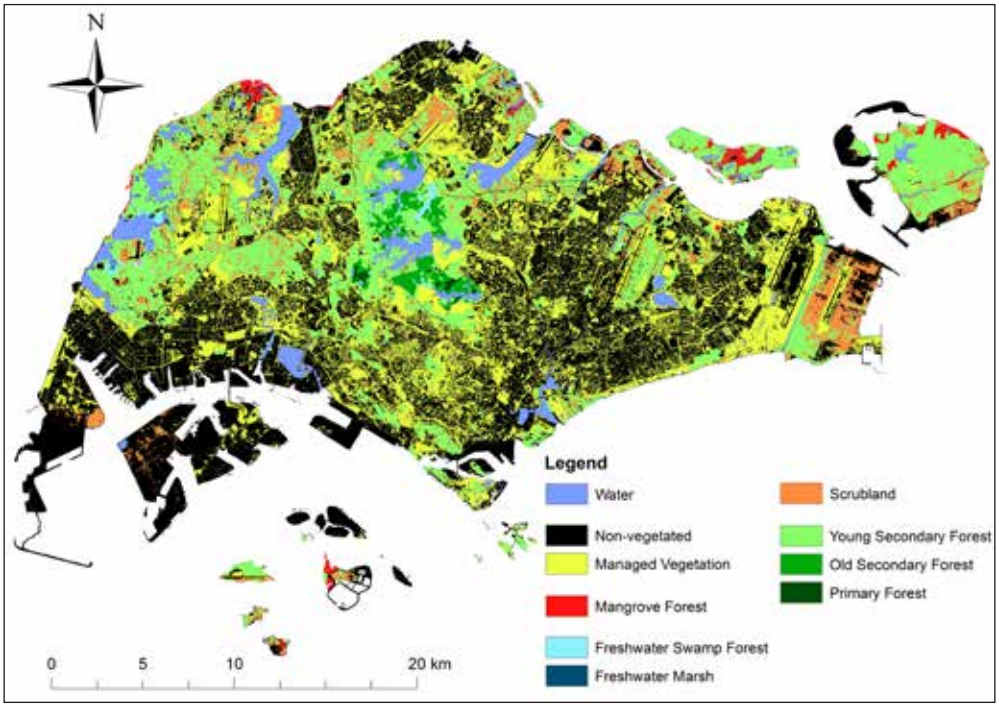

Figure 2. Vegetation map of present-day Singapore (From Yee et al., 2011, reproduced with permission of Gardens' Bulletin Singapore).

Relatively intact mangroves can still be found in the north-western coast of mainland Singapore (i.e. from Sungei Buloh Wetland Reserve (SBWR) to Mandai Mangrove) and some offshore islands: Pulau Tekong, Pulau Ubin and Pulau Pawai. The rest of the spontaneous vegetation, including all other mangrove forests, is secondary in nature and is dispersed throughout the island. This chapter briefly introduces the different types of existing vegetation in Singapore.

Vegetation description and classification

In general, Singapore's terrestrial vegetation is lowland evergreen rain forest owing to its aseasonality, low elevation and flat terrain. The rest of this discussion will focus on the numerous local vegetation types that are found in Singapore and the surrounding region.

Wyatt-Smith (1995) provided a good primer to the vegetation types and their classification in the Malayan region. Subsequent authors, e.g. Whitmore (1998) and Ashton (2014), also summarised the main types of vegetation found in Southeast Asia. For Singapore, Cantley (1884) documented the state of vegetation and enumerated the extent of forest used for timber production in the 1880s. The different vegetation types can also be inferred from early topographic maps made by the survey department. For example, Hill (1977), who produced vegetation maps of Singapore, identified the different types of (abandoned) plantations and kampung areas from topographic maps. Wee & Corlett (1986) gave detailed descriptions of

the different vegetation types in Singapore and recognised reclaimed land and waste-land as vegetation dominated by new species compositions. The descriptions were updated and introduced in a more concise manner in Tan et al. (2010) and Ng et al. (2011). Yee et al. (2016) reorganised the classification of terrestrial secondary vegetation to reflect the current ecological state of Singapore's forests and included categories with novel assemblages of mostly exotic tree species.

In classifying and identifying vegetation types, it is important to note that transition or intermediate types do often exist. We have adopted Corlett's (1994) definition of secondary vegetation, which states that it is vegetation with a distinct species composition growing on previously cleared or disturbed land. In Singapore, all land is disturbed to varying degrees but it may or may not have this distinct species composition. Therefore, what is considered 'primary' terrestrial vegetation in Singapore is almost always to some extent impacted by fragmentation and edge effects, but the plant species composition is still generally that of lowland dipterocarp rain forest. On the other hand, forest regeneration on former and abandoned plantations have species compositions clearly distinct from primary forest.

Notwithstanding the above, the vegetation description is loosely organised in the following manner:

1. **Lowland mixed dipterocarp primary forest**
2. **Native-dominated secondary forest**
3. **Exotic-dominated secondary forest**
   a. Abandoned land forest
   b. Waste-woodland
4. **Freshwater swamp forest and riparian vegetation**
5. **Waterbodies and marshland**
6. **Mangrove**
7. **Coastal vegetation**
   a. Seashore and rocky cliffs
   b. Reclaimed land
8. **Seagrass meadow**
9. **Urban vegetation**

1. Lowland mixed dipterocarp primary forest

This vegetation type constitutes the remaining primary dryland forest of Singapore. The lowland mixed dipterocarp forest of Singapore is characterised by high species richness and the presence of many poorly dispersed plant species (Corlett, 1991). Structurally, this vegetation consists of five layers sensu Richards (1996): (1) emergents, (2) a tall main canopy, (3) the subcanopy, (4) understorey treelets or shrubs, and (5) the forest floor with herbaceous terrestrial species and other seedlings (Tan et al., 2010). The forest is dominated by members of the Dipterocarpaceae family especially at the emergent and main canopy layers. Other common plant families include Fabaceae (e.g. *Koompassia malaccensis* Maingay ex Benth., *Dialium* L., *Sindora* Miq.), Burseraceae (e.g. *Canarium* L., *Dacryodes* Vahl, *Santiria* Blume) and Anacardiaceae (e.g. *Gluta* L., *Parishia* Hook.f.). Following the descriptions of Wyatt-Smith (1995), two subtypes of Malayan mixed dipterocarp forest can be observed in

Singapore: coastal hill dipterocarp forest (seraya-ridge forest) and lowland dipterocarp forest (red meranti-keruing forest).

The coastal hill dipterocarp forest can be found at the hilly Bukit Timah Nature Reserve and is the largest contiguous patch of lowland dipterocarp primary forest in Singapore. Based on Wyatt-Smith (1995), this forest could be further recognised as seraya-ridge forest, albeit at a lower elevation (LaFrankie et al., 2005). As suggested by the Malay name, this forest is characterised by the presence of *Shorea curtisii* Dyer ex King which is typically found growing on ridges (Fig. 3), and is one of the most abundant canopy tree species in the 2-ha ForestGEO plot (formerly Center for Tropical Forest Science – CTFS) situated in BTNR. *Gluta wallichii* (Hook.f.) Ding Hou (Anacardiaceae) is another characteristic canopy tree ridge species of coastal hill dipterocarp forest frequently observed throughout the reserve. Of the other dipterocarps, *Dipterocarpus caudatus* Foxw. subsp. *penangianus* (Foxw.) P.S.Ashton is notably locally abundant (Wee & Corlett, 1986). Other common tree species include *Pimelodendron griffithianum* (Müll.Arg.) Benth. ex Hook.f. (Euphorbiaceae), *Streblus elongatus* (Miq.) Corner (Moraceae), and *Santiria apiculata* A.W.Benn. (Burseraceae) (Wong, 1987; LaFrankie et al., 2005).

The lowland dipterocarp forest can be found in patches scattered throughout CCNR and Singapore Botanic Gardens. The primary forest patches are characterised by the high percentage of the red meranti group of *Shorea* Roxb. ex C.F.Gaertn. (e.g. *S. leprosula* Miq. and *S. macroptera* Dyer) and the keruing (e.g. *Dipterocarpus kunstleri* King and *D. sublamellatus* Foxw.) at the emergent and main canopy layers (Fig. 4). Hence, they could be further recognised as the red meranti-keruing forest sensu Wyatt-Smith (1995). Owing to the relatively flat terrain in these forest patches, *Shorea curtisii* rarely occurs. These forest patches are fragmented, surrounded by secondary forest or man-made features such as roads and reservoirs. Hence, the aforementioned forest layers might not all be present given varying degrees of past disturbances, such as selective logging (Wee & Corlett, 1986).

Despite the differences in the species composition of dipterocarps at the emergent and main canopy layers, the composition of non-dipterocarp tree species is similar between the two subtypes (Corlett, 1999). These non-dipterocarp species include the tall *Koompassia malaccensis, Dialium indum* L. as well as members of the Burseraceae. Members of Anacardiaceae, Calophyllaceae, Myristicaceae and Myrtaceae are also common at the canopy and subcanopy layers. At the shrub and ground layers, *Agrostistachys borneensis* Becc., *Ardisia* spp., *Licuala ferruginea* Becc., *Scrotochloa urceolata* (Roxb.) Judz. are sometimes locally common.

Similar to other mixed dipterocarp forests of the Malesian region, general flowering and masting occur irregularly, possibly driven by synergistic interaction of drought and cold temperature influenced by the El Niño Southern Oscillation (Chen et al., 2018; Sakai & Kitajima, 2019). During this period, many members of Dipterocarpaceae, as well as other forest taxa, flower synchronously and then set fruit (Appanah, 1993; Sakai et al., 2006). Corlett (1990) also noted that species in BTNR that otherwise reproduced frequently nevertheless reached their reproductive maximum during general flowering and masting events. A recent study, conducted during the 2014 masting event in Singapore, showed that seeds of four dipterocarp species were heavily predated (Chong et al., 2016). The study also suggested that inbreeding as a result of low conspecific tree density leads to lower seed viability. These findings imply possible negative consequences on the long-term persistence of dipterocarps in Singapore's forests.

Figure 3. *Shorea curtisii* Dyer ex King with grey crowns at Bukit Timah Nature Reserve. (Photo: A.T.K. Yee).

2. Native-dominated secondary forest

These are secondary forests that have regenerated from vegetated areas cleared before the 1950s and are currently dominated by plant species native to Singapore. They can be found in BTNR and CCNR, as well as in pockets outside of the nature reserves, including the Western Catchment, Labrador Nature Reserve and the Southern Ridges.

Native-dominated secondary forest can be interpreted along successional gradients depending on the forest structure and tree communities. At one end of the gradient is early-successional forest, in which the tree communities are dominated by light-demanding pioneer tree species, and at the other end is late-successional forest, where the pioneers have been replaced by old-growth species. Wong et al. (1994) named the early-successional forest as FT2, the primary forest as FT4, and the intermediate to late-successional forest as FT3.

The Adinandra belukar (Fig. 5) is an extreme example of early-successional forest in Singapore, which is dominated by almost monospecific and uniform stands of *Adinandra dumosa* Jack (Holttum, 1954b; Sim et al., 1992). These are forests that have established on highly degraded soil, usually following poor agricultural practices, and can also be observed in the surrounding region approximately within 150 km of Singapore. Other plant species associated with this forest type include *Cyrtophyllum fragrans* (Roxb.) DC., *Dicranopteris linearis* (Burm.f.) Underw. and *Dillenia suffruticosa* (Griff. ex Hook.f. & Thomson) Martelli.

Figure 4. Trunks of red meranti trees (*Shorea* spp.) in the Central Catchment Nature Reserve. (Photo: A.T.K. Yee).

Figure 5. Adinandra belukar, a form of early-successional native-dominated secondary forest, at Kent Ridge Park. (Photo: A.T.K. Yee).

Adinandra belukar is usually succeeded by plants of later succession such as *Rhodamnia cinerea* Jack and *Calophyllum* spp. etc., and this has largely been the case in CCNR. However, in places such as the Kent Ridge Park or Rifle Range Nature Park, the Adinandra belukar persists, arrested at the early-successional stage likely owing to a combination of extremely disturbed soil and dispersal limitation arising from their relative isolation from seed sources.

The Adinandra belukar is also fire-prone and pioneer tree species such as *Trema* spp. and *Macaranga heynei* I.M.Johnst. have been observed to quickly establish in burnt areas and then be succeeded by later-successional species (Wee & Corlett, 1986). Choong et al. (1992) and Tan et al. (2010) called it the Trema-Macaranga belukar, which also establishes in tree fall gaps in lowland dipterocarp forest where the soil is relatively undisturbed by agriculture. However, this is rarely observed to be a persistent, extensive forest type, and is usually confined to narrow strips at the forest margins or in tree fall gaps in native-dominated forest.

As succession progresses, the early-successional forest slowly accrues late-successional species, usually in the genera *Calophyllum* L., *Elaeocarpus* L., *Garcinia* L. and *Syzygium* P.Browne ex Gaertn., into the understorey and then the canopy layer. Hence, in late-successional forest (Fig. 6), the forest structure is more diverse with trees of varying sizes. This can also be observed via airborne or high-resolution satellite images, in which early-successional forest has relatively uniform tree crowns while the later-successional forest has more heterogeneous crown sizes (Turner et al., 1996). The late-successional forest is also more species-diverse but still lacks the canopy or emergent members of lowland dipterocarp forest, such as trees from the Burseraceae and Dipterocarpaceae.

Figure 6. Late-successional forest in the Central Catchment Nature Reserve. (Photo: A.T.K. Yee, from Yee et al. 2016, with permission from Lee Kong Chian Natural History Museum).

Overall, succession of the native-dominated secondary forest of Singapore is known to be arrested with primary forest species not being recruited into the canopy layer despite the forest having been regenerating for more than 70 years. Multiple reasons have been suggested, including degradation of the soil and the thick leaf litter layer produced by some long-lived pioneer species (Chua et al., 2013, 2016). In some parts of CCNR, the resam (*Dicranopteris* spp.) form dense thickets (Fig. 7) that inhibit the establishment of even early-successional forest (Shono et al., 2006).

Nonetheless, the native forest is surprisingly resistant against invasion by exotic species (Teo et al., 2003). The exotic shrub, *Clidemia hirta* (L.) D.Don, can be commonly seen along forest trails or in tree fall gaps but has yet to cause any negative ecological impacts, likely because it is light-demanding and is therefore very sparsely distributed under closed canopies. There may be greater cause for concern over pioneer-specialist exotics, such as *Cecropia pachystachya* Trécul, which could invade the tree communities given increasing disturbance (Raphael et al., 2015). In 2011, a strong wind event blew down more than 40 ha of native secondary forest in Mandai in CCNR (Yee et al., 2019). While *Clidemia hirta* quickly formed thick thickets in the first two years, they were soon shaded out by native seedlings and saplings that also responded to the sudden increase of light levels and rapidly formed a short tree canopy. Despite being surrounded by exotic-dominated forest, the monitoring of vegetation plots in the area revealed no persistent establishment of exotic species, especially into the tree canopy layer.

Figure 7. Thickets of resam (*Dicranopteris* spp.) in the Central Catchment Nature Reserve. (Photo: A.T.K. Yee).

3. Exotic-dominated secondary forest

These are forests that form on land that has recently been abandoned (i.e. after the 1950s), primarily formerly kampung or plantation sites. This type of forest is located mainly outside of the nature reserves. They are also usually on land intended for development, which is often the reason for its abandonment to begin with. Some patches are now designated as nature parks surrounding the nature reserves (Fig. 8). Some patches have also persisted in military training grounds.

Two main types of exotic-dominated secondary forest can be observed in Singapore. The first type grows on land abandoned without clearing the standing vegetation, which Yee et al. (2016) term abandoned-land forest. As a result, the species assemblage is primarily composed of what was there when the land was first abandoned. This forest type usually arises from former kampungs (Fig. 9), where the plants are a mix of cultivated crops (e.g. *Colocasia esculenta* (L.) Schott, *Manihot esculenta* Crantz), fruit trees (e.g. *Durio zibethinus* L., *Nephelium lappaceum* L.) and ornamentals (e.g. *Heliconia* spp.) or from abandoned plantations (Fig. 10), usually dominated by rubber (*Hevea brasiliensis* (Willd. ex A.Juss.)

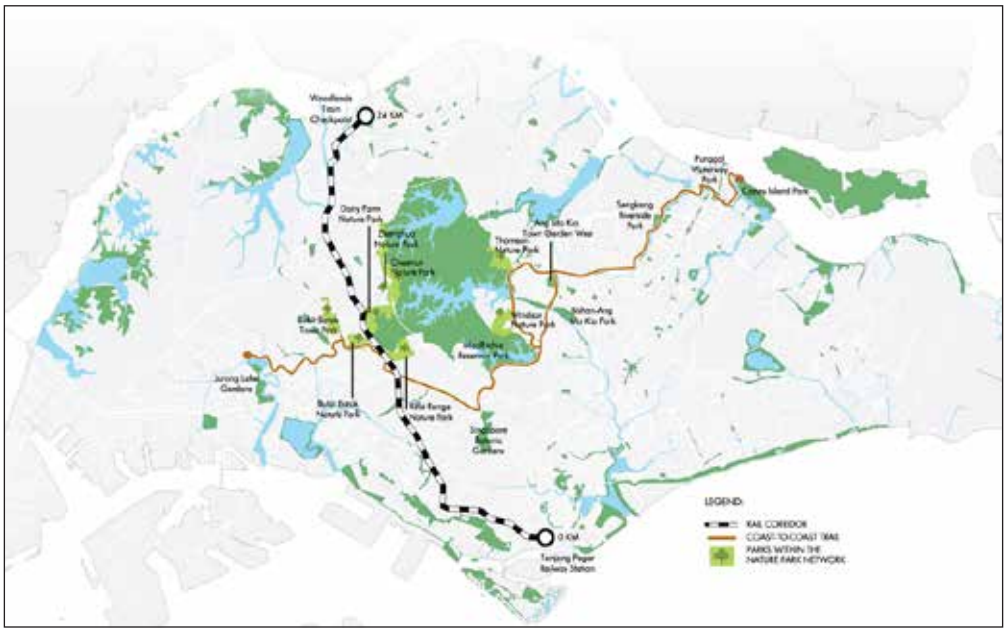

Figure 8. Distribution of Nature Parks in Singapore. (National Parks Board website, reproduced with permission).

Figure 9. Abandoned kampung on Rifle Range Road with exotic *Heliconia* species in the understorey. (Photo: A.T.K. Yee).

Figure 10. Abandoned rubber tree plantation at Windsor Nature Park. (Photo: L. Neo, from Yee et al. 2016, with permission from Lee Kong Chian Natural History Museum).

Müll.Arg.), an important cash crop of the past. The understorey usually consists of either cultivated herbs or seedlings of the main tree communities, i.e. abandoned kampungs would typically have more seedlings of fruit trees and abandoned plantations would have rubber seedlings. Examples of this forest type can be found at Bukit Batok, Chestnut, Rifle Range, Thomson, and Windsor Nature Parks.

The other type of exotic-dominated secondary vegetation establishes on recently cleared land, which is termed waste-woodlands (Yee et al., 2016). The plant communities are dominated by exotic species that were available as seed sources in the surrounding landscapes during the initial plant colonisation period. In the early stages, the waste-woodland is scrubland (Fig. 11) dominated by sun-loving herbs and shrubs such as *Cenchrus purpureus* (Schumach.) Morrone, *Imperata cylindrica* (L.) Raeusch., *Melastoma malabathricum* L., *Mimosa pigra* L., *Piper aduncum* L., and *Pipturus argenteus* (G.Forst.) Wedd. Exotic tree seedlings and saplings later establish and transform the scrubland into forest (Fig. 12). The exotic tree species that dominate the canopy layer include *Acacia auriculiformis* and *Falcataria moluccana.* In recent years, the exotic *Leucaena leucocephala* (Lam.) de Wit and *Cecropia pachystachya* are becoming more common and forming monospecific stands. Examples of this forest type can be found in the southern part of Chestnut Nature Park and at Tampines Eco Green.

Although dominated mainly by exotics, native species that can be observed in both abandoned-land forest and waste-woodlands include *Ardisia elliptica* Thunb., *Caryota mitis* Lour., *Claoxylon indicum* (Reinw. ex Blume) Hassk., *Leea indica* (Burm.f.) Merr. and *Terminalia catappa* L.

Figure 11. Scrubland, which is an early stage of waste-woodland, at Tengah. (Photo: A.T.K. Yee).

Figure 12. Tall albizia trees (*Falcataria moluccana* (Miq.) Barneby & J.W.Grimes) in waste-woodland at Kranji. (Photo: A.T.K. Yee).

4. Freshwater swamp forest and riparian vegetation

The freshwater swamp forest occurs in low-lying areas where the soil is inundated with freshwater for extended periods. Many trees in this type of forest have adaptive features such as stilt roots or pneumatophores to aid in gaseous exchange (Turner et al., 1998), e.g. *Alstonia pneumatophora* Backer ex Den Berger*, Ploiarium alternifolium* (Vahl) Melch. and *Syzygium papillosum* (Duthie) Merr. & L.M.Perry. The only substantial remnant of relatively intact freshwater swamp forest in Singapore is the Nee Soon swamp forest (Fig. 13) located within the CCNR. Small patches of swamp forest can also be found along the reservoir inlets of CCNR, e.g. near the Jelutong Tower at MacRitchie Reservoir and also at the Western Catchment (O'Dempsey & Chew, 2013).

The floristic composition of Nee Soon swamp forest is similar to the historic freshwater swamp forest in Mandai described by Corner (1978), which is now submerged by the Upper Seletar Reservoir. Among the trees, common species include *Baccaurea bracteata* Müll.Arg., *Palaquium xanthochymum* (de Vriese) Pierre ex Burck*, Pometia pinnata* J.R.Forst. & G.Forst.*,* and many members of the Myristicaceae (Turner et al., 1998; Chong et al., 2018). In the understorey, *Benstonea atrocarpa* (Griff.) Callm. & Buerki and *Eleiodoxa conferta* (Griff.) Burret are also common. Although no formal plot data exists for the secondary freshwater swamp forest in Singapore, anecdotal observations suggest that *Campnosperma squamatum* Ridl. and *Dillenia suffruticosa* are rather common as well.

Similar to the freshwater swamp forests are riparian vegetation and vegetation along forest streams. Singapore's forest streams are generally shallow, with slightly acidic water (pH range: 5.5–6.0) and are well-shaded by plant canopies. Natural streams can be found within the two inland nature reserves (Fig. 14), with native aquatic plants such as *Cryptocoryne* spp. and *Barclaya motleyi* Hook.f. commonly seen there (Lok et al., 2009a; Yeo & Lim, 2011).

Streams can also be observed in other secondary forest patches scattered around Singapore. Plants commonly found on these stream banks include *Angiopteris evecta* (G.Forst.) Hoffm., *Alsophila latebrosa* Wall. ex Hook. and *Dillenia suffruticosa*. In the native forest (i.e. lowland mixed dipterocarp or native-dominated secondary forest), the vegetation along stream banks is more diverse and includes plants such as *Cyrtosperma merkusii* (Hassk.) Schott, *Lasia spinosa* (L.) Thwaites and *Hanguana* spp.

5. Waterbodies and marshland

Singapore did not have large natural inland water bodies in the past, but there are now 17 man-made reservoirs (Public Utilities Board, 2018). These open waters have become habitats (Fig. 15) for floating aquatic plant species, such as the exotic water hyacinth (*Eichhornia crassipes* (Mart.) Solms). Along the edges of reservoirs and in other shallower waterbodies (e.g. ponds), exotic semi-submerged aquatic plant species, such as hydrilla (*Hydrilla verticillata* (L.f.) Royle), the water sensitive plant (*Neptunia oleracea* Lour.), and lotus (*Nelumbo nucifera* Gaertn.), thrive (Tan et al., 2010). These could have been deliberately planted or were spontaneous. The hydrilla population is actively managed in Singapore for aesthetic reasons (Public Utilities Board, 2017). Water hyacinth and water spangle (*Salvinia molesta* D.S.Mitch.) also used to be rampant in the reservoirs from the 1970s to 1990s, but their population is now controlled through active management (Tan et al., 2010).

Figure 13. Tree with modified roots in Nee Soon swamp forest. (Photo: H.K. Lua).

Figure 14. Natural stream in MacRitchie in the Central Catchment Nature Reserve. (Photo: H.K. Lua)

Figure 15. Open waters at Kranji Reservoir, where aquatic plants are regularly dredged. (Photo: K.Y. Chong)

There are also low-lying marshlands (Fig. 16) in Singapore that are dominated by freshwater scrub (non-woody) vegetation, such as Kranji Marsh, Tuas, Tampines Eco-Green, and Western Catchment. Common plant species found there include *Dillenia suffruticosa* as well as herbs such as the native fern *Stenochlaena palustris* (Burm.f.) Bedd., both native and exotic species in the genera *Cyperus* L. and *Fimbristylis* Vahl, and exotics such as *Cenchrus purpureus* and *Ipomoea aquatica* Forssk. (Ho, 2002).

6. Mangrove

Mangroves (Fig. 17) are forests established in the intertidal zone, between the highest- and mid-tide levels, and with muddy substrate deposition (Corlett, 1991; Tan et al., 2010). A mangrove is dominated by plants that are adjusted to its anaerobic, muddy and brackish conditions, developing adaptions such as salt secretion, prop roots and vivipary. In Singapore, large patches can be observed in Sungei Buloh Wetland Reserve, Mandai Mangrove, and Pasir Ris Park, as well as offshore islands such as Pulau Ubin, Pulau Tekong and the southern islands (Yee et al., 2010; Yang et al., 2013). Strips of mangrove have also re-established along man-made canals (Fig. 18) that have a tidal influence, e.g. Berlayar Creek, Sungei Api-Api. As some of these canals became part of the freshwater reservoirs with no tidal influence, e.g. Punggol Reservoir and Serangoon Reservoir, mangrove trees in turn start to grow in freshwater conditions.

Figure 16. Marshland at Bulim. (Photo: H.K. Lua).

Figure 17. Mangrove forest on Pulau Tekong with the dense prop roots of *Rhizophora* trees in the background and the snaking buttress roots of *Xylocarpus granatum* J.Koenig in the foreground. (Photo: S. Yang).

Figure 18. A fringe of mangrove lining the canal of Serangoon Reservoir. (Photo: A.T.K. Yee).

There are 20 major mangrove species sensu Tomlinson (1986) in Singapore (excluding the hybrid *Bruguiera* × *hainesii* C.G.Rogers), represented by the following genera: *Avicennia* L., *Bruguiera* Savigny, *Ceriops* Arn., *Kandelia* (DC.) Wight & Arn., *Lumnitzera* Willd., *Nypa* Steck, *Rhizophora* L. and *Sonneratia* L.f. Vegetation zonation within the mangroves is not obvious in Singapore owing to past prolonged disturbance (Wee & Corlett, 1986; Yang et al., 2013). Nonetheless, fronting the foreshores are usually species of *Avicennia* and *Sonneratia*, especially *Avicennia alba* Blume and *Sonneratia alba* Sm. At the back mangrove, where the swampy substrate transitions into dry land, common mangrove associates including *Acanthus ilicifolius* L., *Acrostichum aureum* L. and *Taliparititi liliaceum* (L.) Fryxell are found.

7. Coastal vegetation

This is the spontaneous vegetation that establishes on land adjacent to the sea. It can be found along the few remnant natural sandy shores (Fig. 19) and rocky shores or cliffs (Fig. 20) of Singapore, e.g. at Labrador Nature Reserve, Changi and Coney Island, as well as offshore islands such as Pulau Semakau, St. John's Island, Sisters' Islands and Pulau Tekukor. Low-lying coastal plants such as *Canavalia cathartica* Thouars, *Ipomoea pes-caprae* (L.) R.Br. and *Ischaemum muticum* L. can be found on sandy shores nearer to the sea. At the back of the sandy shores, where the soil substrates are more consolidated, the vegetation becomes taller, and coastal shrubs and trees such as *Casuarina equisetifolia* L., *Planchonella obovata* (R.Br.)

Figure 19. Sandy shore vegetation on Pulau Tekukor. (Photo: A.T.K. Yee).

Figure 20. Rocky shore and cliff vegetation on Pulau Tekukor. (Photo: A.T.K. Yee).

Pierre, *Scaevola taccada* (Gaertn.) Roxb., *Syzygium syzygioides* (Miq.) Merr. & L.M.Perry, *Talipariti tiliaceum* (L.) Fryxell and *Ximenia americana* L. are found. On rocky shores or cliffs, plants such as *Fagraea auriculata* Jack, *Rhodomyrtus tomentosa* (Aiton) Hassk. and *Tristaniopsis obovata* (Benn.) Peter G.Wilson & J.T.Waterh. can be found.

Land reclamation in Singapore is typically carried out in the shallower areas of the sea along the coast (Tan et al., 2010). The unmanaged or spontaneous vegetation growing on it is influenced by the type of fill material used. If the fill-material is marine sand, then the plant community will be similar to the sandy shore vegetation as described above. If subsoil is used, then it will be more similar to the exotic-dominated waste-woodlands. In addition, reclaimed lands are also planted with hardy fast-growing trees that can tolerate the brackish and/or sandy conditions, e.g. *Casuarina equisetifolia*, *Terminalia catappa* and *Acacia auriculiformis* (Er et al., 2016). This often develops into almost monospecific stands of *Casuarina* forest (Fig. 21) with exotic understorey shrubs such as *Lantana camara* L. and *Chromolaena odorata* (L.) R.M.King & H.Rob. This can be observed in the reclaimed part of Coney Island, Changi and Tanah Merah. If no planting is carried out, then the reclaimed area will be very similar to waste-woodland where exotic tree species are common, e.g. *Acacia auriculiformis*, *Leucaena leucocephala* and *Mimosa pigra*.

8. Seagrass meadows

The intertidal areas of Singapore also support the establishment of true marine plants: seagrasses, forming meadows in the sea. Notable locations of seagrass meadows (Fig. 22) in Singapore are off the coast of Labrador Nature Reserve, at Changi, the Cyrene Reef, Pulau Semakau and Chek Jawa of Pulau Ubin (Yaakub et al., 2013). The two most ubiquitous seagrass species found in the meadows of Singapore are *Halophila ovalis* (R.Br.) Hook.f. followed by *Enhalus acoroides* (L.f.) Royle. The species *Halophila beccarii* Asch. tends to be found in muddy substrates associated with mangroves while the rest of the seagrass species are commonly found in association with sandy and rocky shores.

9. Urban vegetation

The urban vegetation is actively managed, i.e. pruned regularly. It is now the most ubiquitous vegetation type in Singapore owing to a government commitment to plant up the landscapes surrounding residential, industrial and commercial areas (Tan et al., 2010; Er et al., 2016). The planting choices have changed over time. In the 1960s to 1970s, large and fast-growing tree species such as *Samanea saman* (Jacq.) Merr. and *Pterocarpus indicus* Willd. were planted. In the late 1970s and 1980s, trees with attractive flowers such as *Peltophorum pterocarpum* (DC.) Backer ex K.Heyne and *Tabebuia rosea* (Bertol.) DC. were favoured, followed by fruit trees such as *Mangifera indica* L. Around this time, plants with fragrant flowers, such as *Magnolia* × *alba* (DC.) Figlar and *Gardenia jasminoides* J.Ellis were introduced to the urban environment. Since early 2000, the focus has been to plant either native species, e.g. *Melaleuca cajuputi* Powell and *Ardisia elliptica*, or species that have a desirable ecological function, such as providing food for pollinators, i.e. the native *Premna serratifolia* L. and the exotic *Asclepias curassavica* L.

Figure 21. *Casuarina* forest on reclaimed land on Coney Island. (Photo: A.T.K. Yee).

Figure 22. Seagrass meadows at Pulau Semakau. (Photo: R. Tan).

Figure 23. Streetscape of Singapore. (Photo: J. Loh).

Although the urban vegetation is highly human-influenced, there are a few forms worth mentioning, particularly turf, streetscape and skyrise greenery.

Turf, mainly *Axonopus compressus* (Sw.) P.Beauv., except those at the golf courses, is a very common feature of urban vegetation in Singapore. If left unmanaged for some time, it will transition to the early-stages of waste-woodland, i.e. it will be invaded by species such as *Imperata cylindrica*, *Mimosa* spp., *Pipturus argenteus* and *Leucaena leucocephala.*

The current streetscape (Fig. 23) of Singapore consists of about two million trees, which are inspected and maintained regularly (The Straits Times, 2018). Common street tree species include *Samanea saman*, *Peltophorum pterocarpum*, *Hopea odorata* Roxb. and *Khaya senegalensis* (Desr.) A.Juss. Although street plantings could be ephemeral (e.g. subjected to road widening), two regions, Tanglin-Orchard-Bukit Timah and Changi, were designated as Tree Conservation Areas in 1991. They are regions dedicated to the preservation of mature trees, i.e. ≥ 1 m girth (NParks' Publication, 2009). On top of that, five Heritage Roads, i.e. Arcardia Road, Lim Chu Kang Road, Mandai Road, Mount Pleasant Road and South Buona Vista Road, were gazetted in 2006 to preserve the mature tree-lined landscapes.

Skyrise greenery (Fig. 24), where plants are propagated on rooftops and wall façades, has been gaining popularity in the built environment of Singapore. This is recognised as a means to continue to provide greenery in land-scarce Singapore. Governmental schemes and programmes such as Landscaping for Urban Spaces and High-rises (LUSH), Skyrise Greenery Incentive, and Landscape Excellence Assessment Framework (LEAF) were set up to promote the adoption of skyrise greenery among building developers and owners (Er et al., 2016). Today, there are already 100 ha of skyrise greenery in Singapore and this could double over the next decade (National Parks Board, 2019). Plants on rooftops are usually small trees, shrubs and

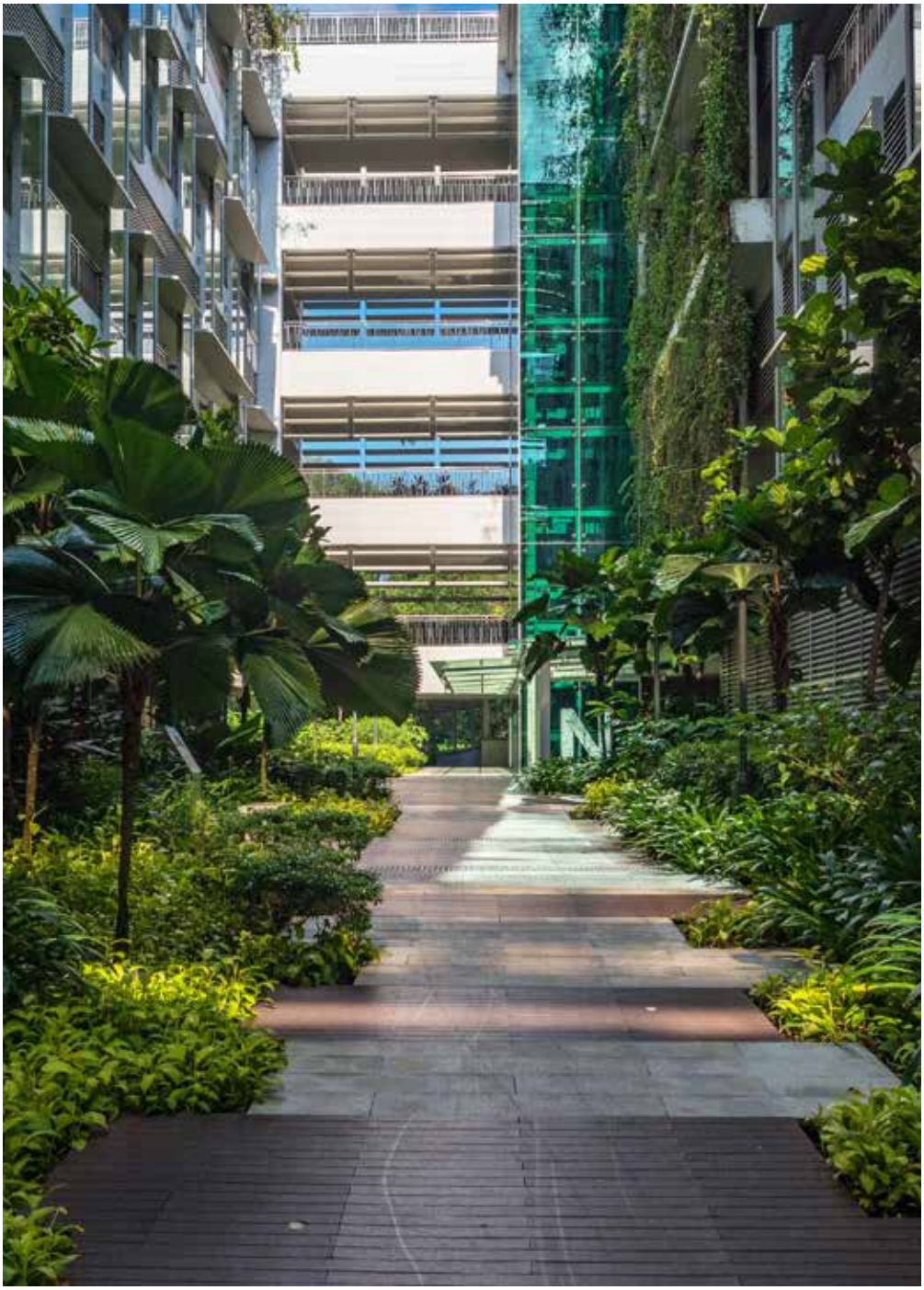

Figure 24. Roof garden with green façade at JTC CleanTech Park. (Photo: A.T.K. Yee).

Figure 25. Hybrid vegetation planting along a canal in Ulu Pandan that incorporates natural stream elements. (Photo: A.T.K. Yee).

herbs. Popular choices include *Syzygium myrtifolium* Walp., *Melanthera biflora* (L.) Wild and *Pandanus pygmaeus* Thouars. On vertical surfaces, the plantings are of climbers on trellises or planters with medium in a vertical structure. Popular plant choices include *Thunbergia grandiflora* Roxb., *Tristellateia australasiae* A.Rich. and *Philodendron* spp.

Future outlook

This chapter recognises nine main types of vegetation that can currently be observed in Singapore. Given climate change, habitat fragmentation and other anthropogenic disturbances, it is uncertain what the secondary forest plant composition will be like in the future because these forests are either experiencing arrested succession or are dominated by exotic species. We hope that future well-planned and well-executed reforestation programmes will help to facilitate forest succession. Within the urban areas, we expect more hybrid vegetation (Fig. 25) where managed vegetation is created to mimic natural systems (e.g. forest and stream) or to look 'wild' owing to the growing interest in biophilic landscape designs to provide ecosystem services and reconnect people with nature (Er, 2018; Housing & Development Board, 2018).