6. PLANT CONSERVATION IN SINGAPORE I: HISTORICAL AND LEGAL BACKGROUND

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Of the original about 540 km^2 area of Singapore's main island (Corlett, 1992), it has been estimated that its pristine vegetation would have comprised about 82% dryland dipterocarp forest, 13% mangroves and 5% freshwater swamp forest (Corlett, 1991). Offshore islands accounted for less than 50 km^2. Today, the total land area including offshore islands is approximately 725 km^2, and there is a similar area of sea within Singapore's national boundary.

These figures translate to about 443 km^2 originally covered in dryland dipterocarp forest, of which 192 ha (1.92 km^2, representing 0.43% of the original) remain as primary forest today (Tan et al., 2010). The main phase of deforestation had been largely completed by the end of the nineteenth century (Ng et al., 2011). The roughly 23% increase in land area, and the concomitant reduction in shallow seas, the shifts in coastline, and the impoundment of estuaries, have powerfully affected the areas available to the terrestrial, freshwater, coastal and marine plant communities.

Historical changes in vegetation

Changes in the nineteenth century

The first glimmer of awareness that plant life in Singapore faced threats was already evident in June 1819, when the botanist William Jack wrote to his family that he had 'just arrived in time to explore the woods, before they yield to the axe' (quoted by Ng et al., 2011). Though not expressed in the modern terminology of conservation, this statement contained the ideas that human development posed the greatest of threats to plant life and that opportunities for exploration (and hence for understanding and use) of natural resources were severely time-constrained.

A first practical step to address such constraints was the establishment, in 1822, of a botanic garden on the slopes of Bukit Larangan (Fort Canning Hill), the concept of Stamford Raffles and of Nathaniel Wallich. It emphasised plants of economic and horticultural interest and lasted only until 1829. It was re-established in 1836 and lasted again until 1846.

A botanic garden was re-established in 1859 when the Agri-Horticultural Society acquired 23 hectares of land in Tanglin from Hoo Ah Kay. The gardens were taken over by the government in 1874, and in about 1882 the Gardens' Superintendent, Nathaniel Cantley, was appointed to report on the state of forests in the Straits Settlements. Again, this reflects a conservation ethic, with growing concerns over the quick and unregulated exploitation of timber, to the detriment of the future economy and environment. As a result, eight forest reserves were set up in Singapore in 1884 totalling approximately 8000 acres (Cantley, 1885),

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soon increased to 14 (Cantley, 1887), classified as either town reserves, coast reserves or interior reserves. Cantley's other main recommendations, for legislation and for reforestation of cleared land, also came into play. The forest reserves were delineated by ground surveys (not always accurate), the cutting of boundary paths and firebreaks, and from 1888 onwards by boundary planting with large trees. By 1899 the listing of 20 forest reserves was as presented in Table 1, totalling 12,419 acres (5030 ha). By the following year the coverage of forest reserves had reportedly increased to 14,518 acres (5880 ha) (Ridley, 1891).

The annual reports of the Botanic Gardens make it clear that Ridley was deeply committed to retention and maintenance (i.e. conservation) of the forest reserves. It was he who conducted most of the botanical collecting, boundary planting with trees such as *Syzygium grande* (Wight) Walp., and economic investigations on plant products. Various attitudes to conservation differed significantly from current thinking, but activities in the nineteenth century such as the intensive planting of non-native trees (see below) do not appear to have had long term impacts on Singapore's forests.

Changes in the twentieth century

By 1900 a large percentage of the wild native plant species present in Singapore had been documented by herbarium specimens, but their taxonomy was only put on a firm modern footing, in a regional context, by Ridley (1922–1925) working between the two world wars on the massive amounts of material he had accumulated earlier in his Singapore career.

In accordance with the recommendations of the Retrenchment Committee, the forests had been handed over from 1st January 1895 to the charge of the Collector of Land Revenues (Fox, 1895), precursor of the modern Singapore Land Authority (SLA), indicating a focus on revenue generation rather than conservation. Nevertheless, the scientific staff of the Gardens Department continued a role in the planting of trees such as native *Palaquium gutta* (Hook.) Baill. and *Cyrtophyllum fragrans* (Roxb.) DC., and non-native *Eusideroxylon zwageri* Teijsm. & Binn. and *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. (as documented by Ridley, 1900b, 1901). Gradually, however, with emphasis on rubber (and oil palm) cultivation turning towards the Botanic Gardens (as a testing ground and source of propagules) and private lands (as commercial plantations), and the reduction of emphasis on revenue from timber, competition for other land uses led to a progressive reduction and degazettement of forest reserves until only Bukit Timah, Pandan, Kranji, Labrador cliffs, and forest around the central water catchment remained. While deforestation had probably reached a maximum in the late nineteenth century, agriculture may not have peaked until the 1930s (Corlett, 1992; Ng et al., 2011), the difference being accounted for by the amount of abandoned land. In 1930 the idea was mooted in the Legislative Assembly that protection for these remaining forest reserves should be lifted, and this was done in 1936. After a short but damaging hiatus without legal protection, action by the scientific staff of Singapore Botanic Gardens resulted in redesignation of Bukit Timah and Pandan as forest reserves, with the Director of the Gardens appointed also as Director of Forests.

The forest reserves continued to act as important collecting sites for many herbarium records, but labelling was often not precise enough to specify exact localities. Collecting was not limited to the forest reserves, as place names such as Tanglin appeared frequently on collection labels. It is also unclear whether plants collected in localities such as 'Chan Chu Kang' and 'Mandi' were actually from within the forest reserves of those names, or merely

Table 1. The 20 Forest Reserves in Singapore, their size and condition in 1899 (Carter, 1900). Place names and spellings of the time are retained here.

Name	Area (acres)	Area (ha)	Description
Bukit Timah	847	343	Hilly. Big jungle tailing off on east into scrub
Jurong	412	167	Swamp and hill mixed, not much good jungle
Pandan	2131	863	Almost all mangrove swamp, a little lalang scrub
Ulu Pandan	5	2	A little patch of 25-year old jungle on a small hill
Bukit Panjang	118	48	Practically all lalang, with a crown of fair jungle on hilltop and some wild rubber
Bukit Timah Road 10th Mile	13	5	Small jungle on small hill
Chua Chu Kang	49	20	Low-lying small jungle
Tuas	1602	649	Mostly mangrove swamp. Rest, except in one place, poor jungle
Sungei Murai	314	127	Mostly mangrove swamp. Good jungle on one or two hills
Sungei Buloh	771	312	Mangrove swamp and poor jungle
Kranji	756	306	Mangrove swamp and poor jungle, with one patch of better stuff
Sembawang	1047	424	Hilly. Good jungle and scrub getting worse towards Chan Chu Kang
Mandi	407	165	Hilly, covered with belukar and scrub except Bukit Mandi where the jungle is good
Kranji Road 13th Mile	10	4	High land, scrub covered
Changi	1393	564	Some fair jungle towards north and east, the rest very poor
Selitar	1429	579	Mostly poor scrub and mangrove
Chan Chu Kang	814	330	Several good patches of jungle; the rest better than in many reserves
Ang Mo Kio	296	120	All small scrub and swamp growths
Sempang	5	2	Nice jungle on road side, swamp growths at back
Selitar Extension	Not known	Not known	Mangrove swamp, poor scrub and lalang
TOTAL	**12,419**	**5,030**	

from their vicinity. The administrative structure of the Straits Settlements (including Singapore, Melaka, Penang and the Dindings), and of the Federated and Unfederated Malay States, meant that the role of Singapore as a distinct botanical unit for study was often overlooked, making localisation of records more difficult.

Island vegetation

Elsewhere, most offshore islands were occupied and partly cultivated, to the north (Pulau Seletar, Pulau Punggol, Pulau Serangoon, Pulau Ubin), east (Pulau Tekong, Pulau Tekong Kecil) and south (Pulau Bukom, Pulau Pawai, Pulau Semakau, Pulau Sentosa, Pulau Sudong, St. John's, and many others). Some herbarium collections from these islands were made, but not necessarily labelled precisely, and uncertainties were compounded by island name changes. For example, the name Coney Island was originally applied to an island south of Singapore and only later transferred to an island to the north.

No forest reserves had been designated on any of Singapore's offshore islands. Inconvenient access, small government budgets, and other practical difficulties would have permitted casual fishermen and smallholder farmers to settle and clear coastal vegetation with relative impunity, and with little documentation. This would have been a continuation of past practice seen over previous centuries.

The 1970 population census showed 19,310 people living on 23 (out of a total 68) offshore islands, of whom two-thirds were on Pulau Tekong Besar, Pulau Ubin, Pulau Brani and Pulau Sentosa. The military and industrial uses of islands, from the middle 1960s onwards, were perhaps the key factors in regularising casual settlement, particularly on Pulau Tekong Besar, Pulau Bukom and Pulau Jurong, as well as three of the southern islands, Pulau Sudong, Pulau Pawai and Pulau Senang.

Military use has worked both to protect and to damage plant communities. Training areas often allow periodic regrowth and a patchy mosaic of regenerating vegetation in which rarities can survive or even recolonise. Exclusion of the public can reduce pressures on plant growth. Conversely, military needs can require the permanent removal of vegetation, e.g. for airstrips, or periodic damage by training exercises. The thorny shrub *Guilandina bonduc* L. listed as Critically Endangered at a national level, was for years known to botanists only from a singly heavily damaged individual at Punggol, on the north coast of the mainland. A huge and healthy swathe of this species is now known to have thrived on one of the southern islands from which most native vegetation had long been removed, previously unknown to botanists because of access restrictions. A remnant population of *Dipterocarpus chartaceus* Symington, never previously recorded from Singapore territory, was recently discovered by NParks staff within military land on another of the southern islands (Lim et al., 2018a).

A still more striking example from military land was the discovery in 2007 of a population of *Thottea praetermissa* T.L.Yao within a tiny patch of freshwater swamp forest in the western part of Singapore, possibly the very same clump of plants from which a herbarium specimen (identified by Ridley and other authors as *T. dependens* (Planch.) Klotzsch, a species now known not to be present in Singapore) had been collected by Goodenough more than a century earlier.

Both serendipity and the differing physical characteristics of islands have affected current plant species representation and the scope for conservation. On Pulau Sentosa the disturbed forest on steep slopes is heavily dominated by *Oncosperma horridum* (Griff.) Scheff. but contains scarce and interesting arborescent plants such as *Garcinia celebica* L. and *Dracaena maingayi* Hook.f. The gymnosperm *Nageia wallichiana* (C.Presl) Kuntze is present on Lazarus Island. Pulau Pawai has an important cluster of *Pemphis acidula* J.R.Forst. & G.Forst. on coastal rocks, and outstanding specimens of *Fagraea auriculata* Jack. Those islands all have varied terrain including steep slopes. On the other hand, low sandy cays that have experienced repeated and almost complete vegetation disturbance (e.g. the Sisters' Islands) tend to have few plants of any conservation significance.

Coastal fringes

Approximately 70 km^2 of mangrove vegetation is thought to have existed historically. Mangrove has been lost through direct removal, wave action, coastal reclamation, and the reduced input of fresh water to coastal vegetation. The latter has impacted coastal plant communities in two ways. First, the intensification of land use has led to the removal of transitional vegetation in the zone inland of the mangrove fringe. Second, the impoundment of all the larger estuaries for conversion to freshwater storage reservoirs has reduced outflow to the shallow seas and reduced the amount of sediment reaching the mangroves. Effects on mud content have been observed for example at Sungei Buloh, where loss of mud and exposure of larger grained sands may lead to changes in mangrove plant composition.

Currently, some 80% of the Singapore mainland has a hard, artificial coastline, mostly either of masonry with cement or concrete pointing, or of big granite boulders. The same is true of some of the offshore islands (e.g. Pulau Sudong, Pulau Bukom, Pulau Jurong). Although this has reduced the length of coastline suitable for mangroves to grow, other areas have been deliberately planted (e.g. mangroves at Pulau Semakau).

The marine environment for plants

The expansion of Singapore's land area by about 200 km^2 during the past 200 years has been at the expense of the same area of sea. The changed coastal profile must have affected the directions and speed of the local currents, and ship wakes are known to have affected coastal plants. Although shallow water marine plant communities including algae and seagrasses must have been affected, there is little historical record of the plants and communities lost because mapping of those communities was not sufficiently detailed. However, there are still one or two spectacular surviving communities, notably the rich algal and seagrass beds of Cyrene Reef covering approximately 35 hectares.

Singapore's coral reefs have been exposed to decades of increased sedimentation that reduced underwater visibility from over 10 m in the early 1960s to under 2 m today (Ng et al., 2016). During that period, because of reduced light penetration, the lower depth limit of scleractinian coral growth moved up from –10 m to –6 m, while live coral cover decline is less apparent now than in the early decades of increased sediment loading (Ng et al., 2016). The same factors of reduced light penetration, increased sedimentation (as well as shipping, dredging, and rare pollution events) would have impacted seagrasses and algae too. Nevertheless, general biological surveys suggest that the marine communities have been remarkably resilient to change.

Legal framework

Land law

The word pictures given above, though partial and anecdotal, already indicate the key areas of law that have been most important in affecting plant conservation: land law; military use of land; maritime, shipping and navigation law; and laws relating to water supply.

The Second Charter of Justice (1826), the English law on land and other matters, was introduced into Singapore in 1826, subject to modifications to suit local, religious and family

customs (Ministry of Law, 2018). Thereafter, minor changes to land law were effected through early post-1826 statutes. More significant changes were introduced later through the Land Titles Ordinance (1956), which applied the Torrens system of land registration to all Singapore land (although conversion from the older Registration of Deeds Act to the Torrens system was only completed in 2002). Any uncertainties about the continued application of English statutes in Singapore were resolved by the Application of English Law Act (1993).

All land in Singapore ultimately belongs to the state, and all other persons or legal entities can only own an estate or some lesser interest in the land. Under the State Lands Act, there may be estates in fee simple, estates in perpetuity, leases, temporary occupation licences (TOLs) or tenancy agreements. Individual land titles are granted under the Land Titles Act (Tan et al., 2009). In practice this means that the areas important for plant conservation are predominantly owned by the state and often managed by state organisations and agencies (e.g. Ministry of Defence, Singapore Land Authority, Housing Development Board, National Parks Board, Public Utilities Board). Such allocation of management may be specified in separate laws (e.g. the names, area and boundaries of the Nature Reserves, and the powers to manage them, are specified in the National Parks Board Act and the Parks and Trees Act). Sites granted under land titles granted to private owners (e.g. for industrial or residential use) are generally of lesser importance for plant conservation, not because of the law per se but because of the history of use of the land concerned, that affects both the plants likely to be growing there and the legal status of the land.

The reclamation of land in Singapore has been governed by the Foreshores (Amendment) Ordinance (1964), the amendments placing limits on rights to compensation for any consequential effects of land reclamation works (Ministry of Law, 2018). In 2001, the Singapore Land Authority (SLA) was constituted as the statutory authority with responsibility for land matters in Singapore. The chief executive of SLA is also the Commissioner of Lands. The functions of SLA include, but are not limited to, land registration, compulsory acquisition of land, and the administration of state land. As is also the case on land for mining and quarrying rights, SLA regulates the removal of any marine substrate (e.g. quarrying of reefs, dredging of gravel or sand for materials). In addition, for coastal parks including the Sisters' Islands Marine Park, the areas demarcated as a park (including the foreshore) as set out in the Parks and Trees Act are protected as public parks, so under limited circumstances that Act would apply as well. For example, Section 8(2)(c) of the Parks and Trees Act provides that no person shall clear, break up, dig or cultivate any land within a public park.

The current Planning Act, which is the post-Independence iteration of the Planning Ordinance (1960), was based on the Town and Country Planning Act (1947) of the United Kingdom. The Planning Act controls planning, land use and development, and covers activities on land that require permission such as development, conservation or subdivision of land (Ministry of Law, 2018). The Planning Act provides for a statutory land use Master Plan that is revised approximately once a decade. Recent revisions of the Master Plan have included a great deal of consultation with public interest groups as well as government agencies and have covered both terrestrial and marine space. The latest version is the Master Plan 2014. The Master Plan includes a Parks and Waterbodies Plan that inter alia maps out the nature reserves, public parks and nature areas that are intended to be conserved for as long as possible (though these do not have any basis or legal protection in the Parks and Trees Act), as well as water bodies such as reservoirs, canals and drains.

The crucial significance of land law to plant conservation throughout Singapore's history has been reflected in the retention of forest in the central water catchment area, the establishment of the forest reserves following Cantley's report described earlier, and the carry-over of forest reserves into the nature reserves of today. Land law has also governed the allocation of land to military uses (with some botanical examples mentioned above), and to coastal reclamation affecting mangroves.

Land law does pose challenges for plant conservation. Under the system of allocation of state land to single agencies, the rights and responsibilities of other agencies might not be clearly specified or might be subject to consultation and compromise. For the nature reserves, a Nature Reserves Board set up in 1951 included appointees by the then Governor and later by the President; its later iteration as the Nature Reserves Committee included appointees by various government agencies, such as the fore-runner of the Public Utilities Board (for water management), as well as the Ministry of Defence, so that agencies were able to consult and collaborate on land uses within the areas in which they jointly had interests.

Resolution of broader land use challenges is effected through inter-agency consultation under the Master Planning process, through the five-yearly Structure Plan that elaborates details of the Master Plan, through consultation on individual cases and, since about 2000, an increasingly formalised system of environmental impact assessment.

Parks and Trees Act

The National Parks Board was established in 1990 through the amalgamation of the Parks and Recreation Department, Singapore Botanic Gardens and the Nature Reserves Board. The National Parks Board Act (most recent major revisions in 2005 and 2017) sets up the structure and functions of the Board, while the Parks and Trees Act (with the most recent major revision in 2017) provides all of the detailed actions, permissions and prohibitions. The Parks and Trees Act provides for 'the planting, maintenance and conservation of trees and plants within national parks, nature reserves, tree conservation areas, heritage road green buffers and other specified areas'. The two areas designated as national parks under the Parks and Trees Act are Fort Canning Park (18 ha) and Singapore Botanic Gardens (now 82 ha after recent expansions to include the Tyersall Learning Forest and Gallop Extension). The four nature reserves are Bukit Timah Nature Reserve (163 ha), Central Catchment Nature Reserve (3043 ha including the surfaces of MacRitchie, Upper Peirce, Lower Peirce and Upper Seletar reservoirs), Labrador Nature Reserve (10 ha) and Sungei Buloh Wetland Reserve (131 ha).

Section 7 of the Parks and Trees Act describes the following purposes of the national parks and nature reserves, any or all of which may apply in a particular case:

a) The propagation, protection and conservation of the trees, plants, animals and other organisms of Singapore, whether indigenous or otherwise;
b) The study, research and preservation of objects and places of aesthetic, historical or scientific interest;
c) The study, research and dissemination of knowledge in botany, horticulture, biotechnology, or local and natural history; and
d) Recreational and educational use by the public.

It is an offence to (a) capture, displace or feed any animal; (b) disturb or take the nest of any animal; (c) collect, remove or wilfully displace any other organism; (d) use any animal, firearm, explosive, net, trap, hunting device or instrument or means whatever for the purpose of capturing any animal; or (e) carry or possess any explosive, net, trap or hunting device. Section 8 of the Parks and Trees Act covers offences relating to plants and trees, and Section 9 of the Act covers offences relating to animals. The Act makes it an offence inter alia to cut, collect or displace any tree or plant or part thereof, and from carrying out any activity that may cause alteration, damage or destruction to any property, tree or plant, within a national park or nature reserve.

Similar provisions apply to public parks and playgrounds, public open spaces, park connectors and green verges maintained or managed by the National Parks Board. There are more than 500 public parks in Singapore, ranging from less than 1 ha to more than 185 ha in area. Although most include tended lawns with ornamental flower beds and trees, they act as green lungs, educational resources, and reservoirs of plant and animal populations, and help to form links between other green areas. Several contain important areas of natural or semi-natural regenerating vegetation that may contain locally significant plant species, particularly the larger parks such as East Coast Park and Pasir Ris Park, and parks that abut nature reserves such as Hindhede Park, Venus Drive, Thomson Park, Springleaf Park, Chestnut Park, Dairy Farm Park and Rifle Range Park.

Using the powers of the Parks and Trees Act, the Parks and Trees (Preservation of Trees) Order designates two Tree Conservation Areas in mainland Singapore, one of them from the city centre to Lornie Road, and the other from Netheravon Road to Changi Village. Trees of more than 1 m girth, growing anywhere within the Tree Conservation Areas (i.e. including land privately owned), or growing on vacant land anywhere in Singapore, cannot be cut or damaged without permission of the Commissioner of Parks and Recreation. A landmark legal case was brought concerning the illegal removal of a locally very rare tree, *Hopea sangal* Korth., within the Changi Tree Conservation Area.

The Jurong Town Corporation (JTC) has its own regulations and provisions for the protection of parks and plants therein. For plant conservation, these were most relevant to Jurong Lake Gardens when managed by JTC, but the area has since been transferred to the management of the National Parks Board as Jurong Lake Park. Prevention of the wilful damage or removal of any tree or plant is also listed under the Sentosa Development Corporation Regulations (1997) applying to Pulau Sentosa and 11 other southern islands (Lye, 2008). Finally, the Public Utilities (Catchment Area) Parks Regulations (2006) also prohibit damage to plants in many reservoirs and reservoir parks (Lye, 2008).

International law

Singapore is a signatory to the International Convention on Plant Genetic Resources, including the naming of plant varieties (important to the naming of orchid cultivars and hybrids). National legislation enforces quarantine on imports and exports of plants and their associated soils, water, pots and containers, thus having international implications.

Singapore is a signatory to the Convention on International Trade in Endangered Species of Flora and Fauna in Commerce (CITES). Few species native to Singapore are listed under the annexes to the Convention, but it remains a channel under which species could be listed in future.

An active role has been played by Singapore in the United Nations Framework Convention on Climate Change (UNFCCC). Under the Convention, Singapore is a Non-Annexe I country and has acceded to the Paris Agreement. Singapore conducts a full programme of monitoring Land Use, Land Use Change and Forestry (LULUCF) information, and transitioning to Agriculture, Forestry and Land Use (AFOLU) information derived from permanent plots, tree measurements being used in conjunction with satellite imagery. The UNFCCC encourages, though it does not enforce, the retention of natural vegetation, and thus works indirectly in favour of plant conservation.

Singapore is a signatory to the Convention on Biological Diversity (CBD) and has acceded to the Nagoya Protocol, further encouraging species conservation and the reduction of loss in biodiversity.

Threats

Turner et al. (1994) examined the record of plant extinctions and status in Singapore. Plants were classified as locally extinct, rare or common. Two important summaries have been published by Tan (1995, 2008) (Table 2) and updated statistics are in Chapter 7, Table 1. Building on the earliest of these lists, an informal working group (no official chairman or membership) sat from time to time in the period 2003–2005 to reconsider the status of every species, using the IUCN Red Data List categories (Globally Extinct (EX), Nationally Extinct, Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD)) adapted to the national level. A basic criterion used was the date of last herbarium collection (in SING and SINU) to determine species not recorded for 30 years, to confirm or refute extinctions. However, an important analysis was done by Chong et al. (2012) showing the poor correlation between herbarium records and chances of rediscovery of supposedly locally extinct plants, based largely on the same dataset. It was not realistic to apply some of the other criteria strictly (generation time, rate of decline) but face-to-face discussion amongst a large, knowledgeable group with plenty of field experience was thought to give a credible result. They indicated, as summarised in Tan (2008), that more than 600 taxa had been lost historically although around 140 species have been rediscovered in recent years (see Chapters 1 and 7). Orchids, along with other epiphytes (Niissalo et al., 2017), have been particularly hard hit by the reduction in extent of humid lowland evergreen rain forest. Land use change continues to be the most important determinant of plant conservation status, but several other factors described below have gained recent attention. The listings by the working group were published in the Singapore Red Data Book (Davison et al., 2008). In determining national status, the IUCN advice is to assess a species as though it is endemic to the country concerned, apply the international criteria to arrive at a result, and then to revise that result upwards or downwards according to a further set of criteria that take into account the species' status outside the country (e.g. chances of recolonisation).

Threats from alien introductions

Nghiem et al. (2015) considered nine tree species to be invasive in Singapore: *Acacia auriculiformis* A.Cunn. ex Benth., *Cecropia pachystachya* Trécul, *Falcataria moluccana*

(Miq.) Barneby & J.W.Grimes, *Leucaena leucocephala* (Lam.) de Wit, *Manihot carthagenensis* (Jack) Müll.Arg. subp. *glaziovii* (Müll.Arg.) Allem, *Muntingia calabura* L., *Piper aduncum* L., *Pipturus argenteus* (G.Forst.) Wedd. and *Spathodea campanulata* P.Beauv. These all grow poorly and experience high mortality in forest so long as the canopy is unbroken. In open vegetation they survive better and have high growth rates. Invasive exotics tend to have low wood density (reflecting their rapid growth) and small seeds, when compared with non-invasive exotics. However, these results might be altered if *Hevea brasiliensis* and *Elaeis guineensis* Jacq. were to be considered invasive, as they are large-seeded and survive rather well within disturbed natural forest. Nghiem et al. (2015) considered that none of these invasive tree species is a direct threat to the integrity of native closed-canopy forest but found that they dominate on newly abandoned land and may pre-empt the recovery of native forest on such sites.

Chong et al. (2011) considered that the worldwide spread and establishment of alien plant species continues to accelerate and damage ecological and agricultural systems. Early warning and prevention of high-risk introductions is the most cost-effective approach to minimise losses while maximising benefits, and they viewed the Australian Weed Risk Assessment (A-WRA) system as the most well-developed and successful predictive scheme.

Threats from loss of pollinators

Key studies on bees in Singapore include collections by D.H. Murphy in the 1960s to mid 1970s (Murphy, 1973), honey-baiting surveys of stingless bees (Liow et al., 2001), surveys of flower-visiting bees and other insects in Singapore's parks (Soh & Ngiam, 2013), observations of *Megachile* and other bees visiting orchids (see Ascher et al., 2016), a survey of Singaporean Anthidiini (Soh et al., 2016), and a compilation and survey of bees in Bukit Timah Nature Reserve and surrounding parks (Ascher et al., 2019). There is a limited amount of information on fig-wasps from Singapore. Butterflies are well covered by popular and scientific literature, but pollinators among groups such as beetles, flies and moths are very poorly known. The past and current impacts of pollinator declines are therefore unknown and there is no detailed population monitoring of insect pollinators as there has been for selected invertebrate pests (by the Agri-Food & Veterinary Authority) or mosquitos (by the National Environment Agency). The species of bats that act as pollinators are known, and their roost sites and approximate numbers.

Threats to pollinators include the effects of chemical environmental pollutants, direct poisoning as nuisance animals, removal of nest sites, and removal of habitats.

Threats from climate change

It is not known how most plants will respond to climate change in terms of growth rate and performance, flowering success, timing and frequency, seed set, germination, or energy budget allocation to these different processes. Since the type and amplitude of climate changes (e.g. rainfall, cloud cover, wind strength, frequency and duration of dry spells) are uncertain, the effects on plants are doubly uncertain. Coastal plant communities such as mangroves will certainly alter their distribution as mean sea level rises, but they will be unable to retreat inland as hard defensive structures already exist in many places and it is unlikely that government will

Table 2. Two estimates of the conservation status of the native Singapore flora. Shifting IUCN criteria and categories of threat have been compounded by changing views on the number of native versus introduced plants (a reduction by 229 in the number considered native, between 1995 and 2008). *Infra-specific taxa (varieties, subspecies) are included as 0.5 each. See also estimate of current conservation status in Chapter 7, Table 1.

IUCN category	Tan (1995)	IUCN category	Tan (2008)
Extinct	584	Globally extinct	3
		Nationally extinct	634.5*
Endangered	153	Critically endangered	675.5*
		Endangered	248
Vulnerable	403	Vulnerable	270
Rare	901	Near-threatened and least concern (common)	222
Common	241		
Total	**2,282**	**Total**	**2,053**

permit the loss of significant mainland area due to sea level rise. The coastal plant communities of small offshore islands are likely to experience more natural responses to anthropogenic climate change than are the equivalent plant communities of the mainland.

Going forward, the frequency and severity of El Niño and La Niña episodes will be of special interest. Their effects on dipterocarps and other plants that participate in mass flowering events, and knock-on effects on vertebrates and invertebrates, must be studied.

Threats from land use change

Human population change and the demands for housing, working and recreational space will drive land use changes. Singapore has long planning horizons (in the region of 50 years) but even these are short with respect to the life cycles of forest trees and even some herbs. Environmental impact assessments have had some effect on project implementation in the recent past, but few sure predictions can be made about future plant losses due to land use change.