RAFFLES BULLETIN OF ZOOLOGY Supplement No. **32**: 11–21
Date of publication: 6 May 2016
http://zoobank.org/urn:lsid:zoobank.org:pub:B5F19CB2-ABBB-4BD0-939A-3597AC85F3EA

Updating the classification system for the secondary forests of Singapore

Alex Thiam Koon Yee*, Kwek Yan Chong, Louise Neo & Hugh T.W. Tan

Abstract. Singapore has undergone rapid deforestation since 1819 mainly for timber and plantations and subsequently, modernisation. Consequently, most of the spontaneous vegetation in Singapore is now secondary vegetation. Previous secondary vegetation classification systems for Singapore have been focused on the forests within the Bukit Timah Nature Reserve and Central Catchment Nature Reserve. Here, we update the classification system for secondary vegetation, focusing on dryland forest types in the whole of Singapore. Our classification system is based on past land-use history which shapes the floristic composition observed today. We recognise three forest types: native-dominated secondary forest, abandoned-land forest, and waste-woodlands. Native-dominated secondary forests are forests regrown on land cleared before the 1950s, and are dominated by native tree species. Abandoned-land forests are forests regrown from land that was previously used for plantations or kampungs which were abandoned with the mature trees largely intact. Waste-woodlands are forests regrown on land that was usually cleared after the 1960s, and are dominated by exotic tree species, and whatever species that are present is dependent on the seed source availability of the surroundings during the time of clearance, and succession. Reclaimed land forest, strictly considered, should be a product of primary and not secondary succession but is structurally similar to waste-woodlands and its plant species composition is likely dependent on the fill material used. Although secondary forests generally contain less species compared to primary forests, they can still be important for the conservation of biodiversity, especially in Singapore.

Key words. Singapore, secondary forest, plantations, wasteland, native plants, exotic species

INTRODUCTION

Singapore has undergone a tremendous landscape transformation since of its founding by Sir Stamford Raffles in 1819. Rapid deforestation for timber and plantations occurred since then, and by the late 19th century most of the original forest cover had already been destroyed (Wee & Corlett, 1986; Corlett, 1992). In areas left to regrow, the grass, lalang (*Imperata cylindrica*) became the most dominant species. Most parts of Singapore in the early 1900s became plantations of rubber (*Hevea brasiliensis*). Other areas were "kampungs" (= villages) that were commonly planted with ornamental plants and fruit trees. Self-governance in 1959 and the subsequent independence of Singapore in 1965 led to a shift in the landscape, with more areas becoming built-up (Savage, 1992), and the kampungs and plantations were abandoned and cleared for development. In the 1960s, active land reclamation began in Singapore, which increased Singapore's land area yearly (Wong, 1969). Singapore's historical changes in vegetation have been described in detail by Wee & Corlett (1986) and Corlett (1992), and O'Dempsey (2014) described early vegetation changes before the 1900s.

Department of Biological Sciences, National University of Singapore. 14 Science Drive 4, Singapore 117543; Email: haloriyee@gmail.com (*corresponding author)

ISSN 2345-7600 (electronic) | ISSN 0217-2445 (print)

Currently, vegetation covers about 56% of Singapore's land area (Yee et al., 2011). Only about half of the vegetation can be considered spontaneous, i.e., vegetation that has arisen without human intervention. Primary lowland dipterocarp forest and freshwater swamp forest cover less than 1% of Singapore's total land area, and these forest types can only be found in the Bukit Timah Nature Reserve (BTNR) and the Central Catchment Nature Reserve (CCNR). The rest of the spontaneous vegetation of Singapore is secondary vegetation.

Here, we define secondary vegetation as plant communities that have regrown on previously disturbed land (i.e., cleared land or cultivated land) and which have developed a distinct structure and species composition compared to those of the original primary forest (e.g., lowland dipterocarp forest in Singapore) (Corlett, 1994; Chazdon, 2014). Secondary forest is secondary vegetation with a defined tree canopy layer. Here, we will only discuss dryland vegetation that grows on land not inundated by water for most of the year. Secondary vegetation dominated by herbs, grasses, and shrubs without a defined tree canopy layer will be referred to as scrubland in this paper. Scrubland will eventually succeed into secondary forest.

Secondary forests in Singapore have been described and classified by various authors in the past into categories which reflect the vegetation of their time. Gilliland (1958) recognised secondary forests in successional stages, starting from adinandra belukar (= secondary woody vegetation), followed by the *Rhodamnia-Champereia* stage, and then the

Arthrophyllum-Anisophyllea stage. Wee (1964) classified secondary forests into belukar muda (or younger belukar stage) and belukar tua (older belukar stage). Hill (1977) recognised grass and scrub vegetation types, low secondary forest, and tall secondary forest in his vegetation map of Singapore. He also included messicol vegetation (or planted crop vegetation) and noted that some were already abandoned at that time. Wee & Corlett (1986) provided a good description of the vegetation at that time that included the categories of secondary forest and wasteland. Corlett (1991a) divided secondary vegetation into four successional stages, and called the final stage "tall secondary forest". Wong et al. (1994) and Turner et al. (1996) classified the forest in the CCNR based on interpretations of the evenness of the canopy layer as seen from aerial photographs. Coupling this with field surveys of the vegetation, secondary forests in the CCNR were classified into two categories: Forest Type 2 (FT 2, forest with small trees and small crowns) and Forest Type 3 (FT 3, forest with a higher density of stems, larger trees, and large crowns distinguishable from aerial photographs). Following Corlett (1991b), Tan et al. (2010) summarised the classification of Singapore habitats, and secondary vegetation was subdivided as herbaceous vegetation (i.e., reclaimed or wasteland vegetation), low secondary forest or scrub, and tall secondary forest. The abandoned rubber plantation vegetation type was considered as a transitional state on its way to becoming tall secondary forest.

The emphases in the past classifications and descriptions of vegetation have mainly been given to the forests in the BTNR and CCNR, which are mostly native-dominated. Hence, this paper intends to update the classification system for secondary forests in the whole of Singapore, so that it can better reflect what is currently observed. Plants characteristic of the secondary vegetation will be included in this classification system to aid in identifying the vegetation types.

The classification system for secondary forests that we are proposing here is based on the hypothesis that land-use history of the forest patches affects secondary succession and tree species composition (Thomson et al., 2002). Resources and species availability are two major determinants of successional pathways (Pickett & Cadenasso, 2005; Chazdon, 2014). Land-use history, e.g., forest clearance and rubber plantations, will impact soil nutrient levels, the soil seed bank, as well as the surrounding propagule pressure of a site, therefore affecting the species composition. Conversely, the past land-use of a site can in turn be inferred by looking at its current species composition.

In this paper, we recognise three main types of secondary vegetation which have distinct land-use histories and thus species compositions. One of them is forests regrown on land that was cleared and left to regrow before the 1950s, which is now dominated by native species, and which we will hereafter call "native-dominated secondary forest". The other two are: forests regrown on abandoned cultivated land— "abandoned-land forest", and forests regrown on land that was cleared and left to regrow after the 1960s—"waste-woodlands". The latter two forest types not only arise from human action but are usually also dominated by exotic species, hence they can be considered novel ecosystems (Hobbs et al., 2006).

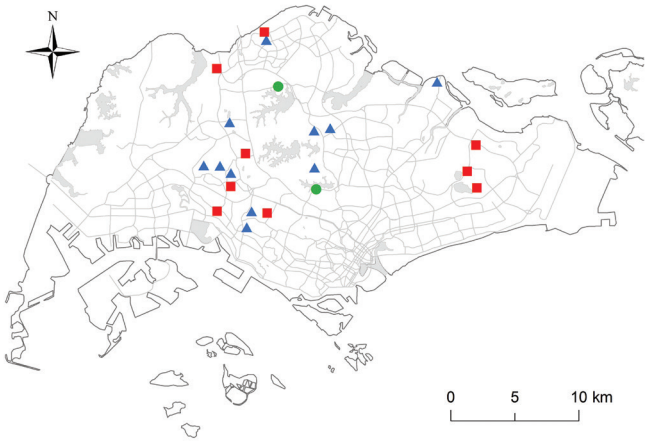

Fig. 1. Locations of surveyed forest patches. Green circles represent native-dominated secondary forest patches. Blue triangles represent abandoned-land forest patches. Red squares represent waste-woodlands patches.

MATERIALS AND METHODS

The land-use history of each forest site was inferred from a series of topographic maps where possible (Surveyor-General, Federated Malay States and Straits Settlements, 1924; Survey Production Centre, South East Asia, 1945; Surveyor-General, Malaya, 1953; Chief Surveyor, Singapore, 1969; Ministry of Defence, Singapore, 1975; Singapore Mapping Unit, 1982, 1987, 1992, 2000, 2008). Some of the older maps were viewed at the National Library of Singapore and National Archives of Singapore.

The proposed secondary forest classification system was based on the cumulative field experience of the authors in various parts of Singapore, including the offshore islands. In addition to that, we organised or participated in plot-based surveys in 22 secondary forest patches across Singapore from 2011 to 2014 (Fig. 1). For the two exotic species-dominated forest types, 11 patches of abandoned-land forest and nine patches of waste-woodlands were surveyed by Kee (2012) and Neo (2012). In each forest patch, five plots of 20 × 20 m each were established, and all stems ≥ 5 cm in diameter-at-breast height (dbh) were measured and identified. For the native-dominated forests, we surveyed 14 plots of 10 × 10 m each along Mandai Road, in which all stems ≥ 5 cm in dbh were measured. Furthermore, we included data from Eun et al. (2014) who worked on the native-dominated forest surrounding MacRitchie Reservoir, and surveyed 62 circular plots of 10 m-radius each, and measured and identified all stems ≥ 5 cm in dbh.

We performed non-metric multidimensional scaling (NMDS) on the plot data to assess our classification scheme. NMDS was conducted at the generic level owing to taxonomic uncertainty in the data from the native-dominated forest. The different plot sizes (the largest being 400 m^2 and the smallest, 100 m^2) will introduce bias in ordination, especially

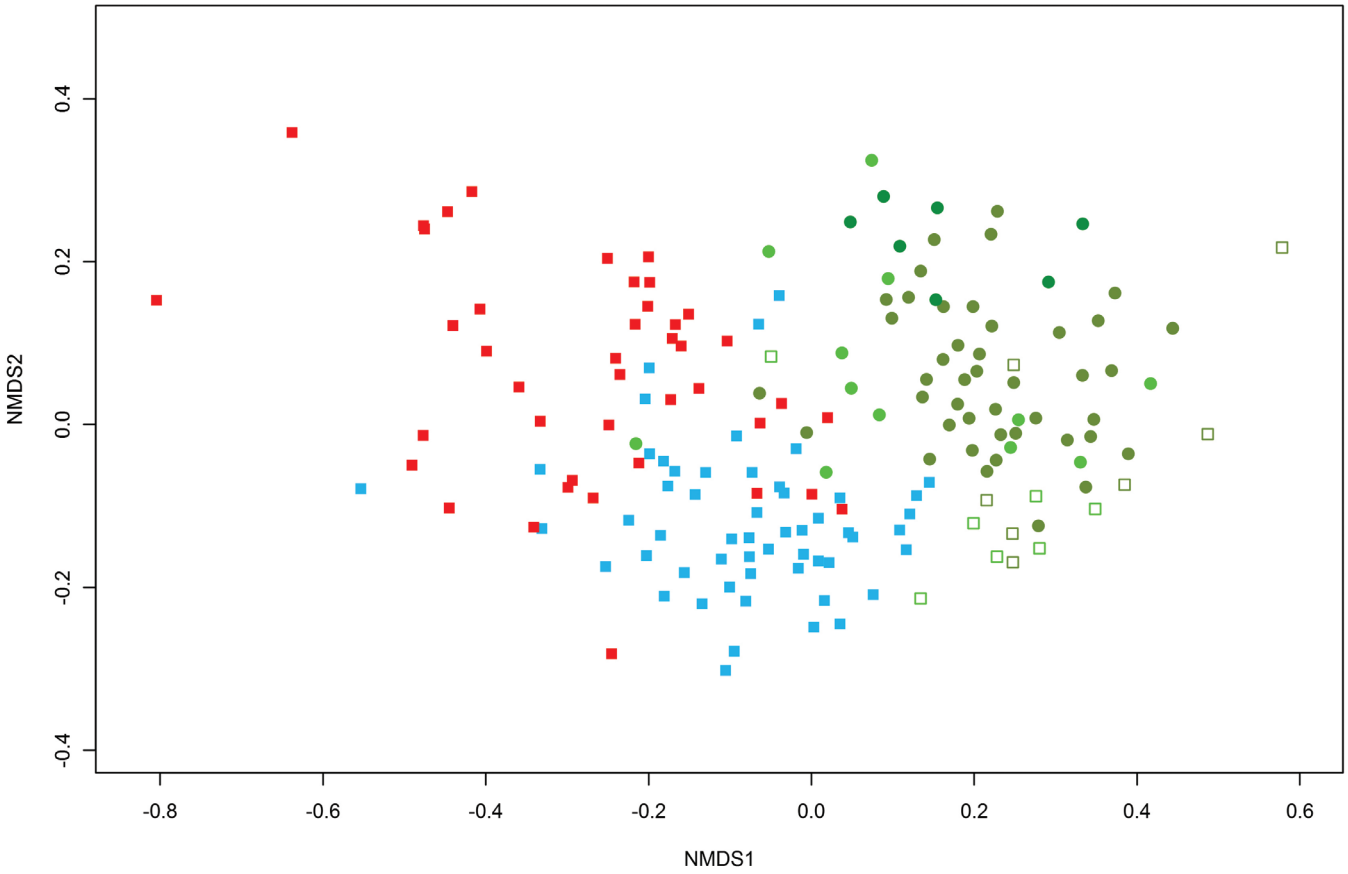

Fig. 2. NMDS plot of dryland secondary forest plots based on generic composition. Blue squares represent plots from regrowth forests on abandoned land. Red squares represent plots from waste-woodlands. Light-green and olive-green circles represent plots from short and tall secondary forest types, respectively. Dark green circles represent primary forest plots. Filled squares represent 20 × 20 m plots. Open squares represent 10 × 10 m plots. Filled circles represent 10 m-radius circular plots. The stress for the NMDS plot is 0.1873.

so for homogeneous datasets (Zdenka & Milan, 2006). However, the bias can be reduced if presence-absence data are used, and if the smallest plot size is not less than half the size of the largest plot. We argue that our dataset is not homogeneous as it represents species compositions arising from three different land-use histories in a tropical country, hence it is justifiable to include the smallest plot size in the analysis. Nonetheless, the Jaccard dissimilarity index was used to reduce possible biasness, and the ordination of the smallest plots (in Mandai Forest)—which were one quarter the size of the largest plots—was interpreted with caution. We followed up the NMDS with Permutational Multivariate Analysis of Variance (PERMANOVA) using the Jaccard dissimilarity index, and the plots were considered to be nested within their respective forest patches to analyse the community data. All statistical analyses were performed using R version 3.0.2 (R Development Core Team, 2013) and the package vegan 2.0-10 (Oksanen et al., 2013).

PROPOSED CLASSIFICATION SCHEME

The NMDS plot (Fig. 2) shows that the three secondary forest types of different land-use histories segregate into three groups based on the generic composition of trees. The floristic communities of the three groups are significantly different based on the results of the PERMANOVA (p-value = 0.006).

Native-dominated secondary forests. These are forests regrown on sites cleared before the 1950s, and are dominated by native tree species. This forest type can be found mainly in the BTNR, CCNR, and on the Southern Ridges. It has been sub-classified into young (or "short") secondary or FT 2, and old (or "tall") secondary or FT 3 in the past by several authors (Wee, 1964; Corlett, 1991b; Wong et al., 1994; Turner et al., 1996; Tan et al., 2010; Yee et al., 2011). The former usually consists of species from the early successional stage, while the latter contains more species from the late successional stage. Some of these early-successional secondary forest patches are postulated to be at least 50 years old, while the late-successional ones could be at least 100 years old (Corlett, 1991a).

Early-successional forests consist of light-demanding species, and in late-successional forests the light-demanding species have been replaced (Corlett, 1991a; 1997; Turner et al., 1997). The rate of succession has been postulated to be dependent on the soil fertility level. Turner et al. (1997) noted that the total basal area per plot is similar between the "short" and "tall" native-dominated secondary forests. Floristically, there are overlaps between these two subtypes, as they occur along a successional gradient (Corlett, 1991a; 1997; Turner et al., 1997), and this is in accordance with our NMDS plot (Fig. 2). Nonetheless, the extreme ends of the successional gradient are still identifiable on site.

Fig. 3. Adinandra belukar in Kent Ridge. Tiup-tiup (*Adinandra dumosa*) is the most dominant tree species, as seen in the photo.

Adinandra belukar (Fig. 3) can be considered to be one extreme end of the early-successional, native-dominated, secondary forest type (Corlett, 1991a, 1997; Turner et al., 1997). It is a secondary growth dominated by the tree species *Adinandra dumosa*, on degraded land with soils of low pH (Sim et al., 1992). Holttum (1954) reported a large stretch of adinandra belukar in the CCNR, which is now presumed to have been replaced by late-successional secondary forest (Corlett, 1991a). On the other hand, at Kent Ridge, where Holttum (1954) described the initial successional stages of the forest which started regenerating from around the 1920s, the forest is presently still dominated by *Adinandra dumosa*. It has been suspected that succession is impeded in adinandra belukar because of the highly degraded soil (Sim et al., 1992; Corlett, 1997). Currently, adinandra belukar can still be found at the Southern Ridges, and in some parts of the BTNR and CCNR, as well as the Western Catchment (consisting of the areas surrounding the reservoirs in the west of Singapore Island).

Trema belukar or trema-mallotus-macaranga belukar is another type of early-successional native-dominated secondary forest that grows on less degraded soil compared to that of adinandra belukar (Choong et al., 1992; Wyatt-Smith & Panton, 1995; Tan et al., 2010). It has been described to be dominated by light-demanding pioneer tree species

Fig. 4. Native-dominated secondary forest along Mandai Road. Leechwood (*Anisophyllea disticha*) can be seen in the centre of the photo.

from the genera *Macaranga*, *Mallotus*, and *Trema*. It is now uncommon to observe extensive patches of such belukar in the native-dominated secondary forest, probably because they have already been succeeded by later-stage species. However trees of the three aforementioned genera can still be found commonly in tree-fall gaps and along forest edges.

Elsewhere within the BTNR and CCNR where the forest has already succeeded from adinandra belukar or trema belukar (Fig. 4), tree genera such as *Alstonia*, *Calophyllum*, *Campnosperma*, *Elaeocarpus*, *Garcinia*, *Litsea*, *Rhodamnia*, and *Syzygium* (Fig. 5A–D) commonly occur in the tree canopy layer (Wee & Corlett, 1986; Corlett, 1991a, 1997). Secondary forests of the older successional stage tend to be more species-rich. Trees of old-growth species from the families Burseraceae and Myristicaceae can occasionally be found in tall dryland secondary forest of this stage. Understorey plant species such as *Agrostistachys borneensis* and *Anisophyllea disticha* (Fig. 5E, F) have been found to be associated with late-successional secondary forest (Wee & Corlett, 1986; pers. obs.).

Abandoned-land forests. These are forests regrown from land that was previously used for plantations (usually rubber, *Hevea brasiliensis*) or kampungs, but which were abandoned largely intact with the mature trees still standing (Fig. 6). The rubber industry dwindled after World War II, and the subsequent industrialisation and urbanisation of Singapore in the 1960s led to the abandonment of plantations and resettlement of villagers from their kampungs (Corlett, 1992; Turnbull, 2009). Larger continuous stretches of abandoned-land forests can presently be found adjacent to the nature reserves, e.g., Windsor Forest (Neo et al., 2014b), or contained within military-restricted areas, such as the forest around the Western Catchment (pers. obs.). Other smaller fragments are embedded in the urban matrix throughout Singapore. Many of these fragments of abandoned-land forests are designated to be cleared for future development. However, some of these small fragments are also located within parks, such as in the Bukit Batok Nature Park, Bukit Batok Town Park

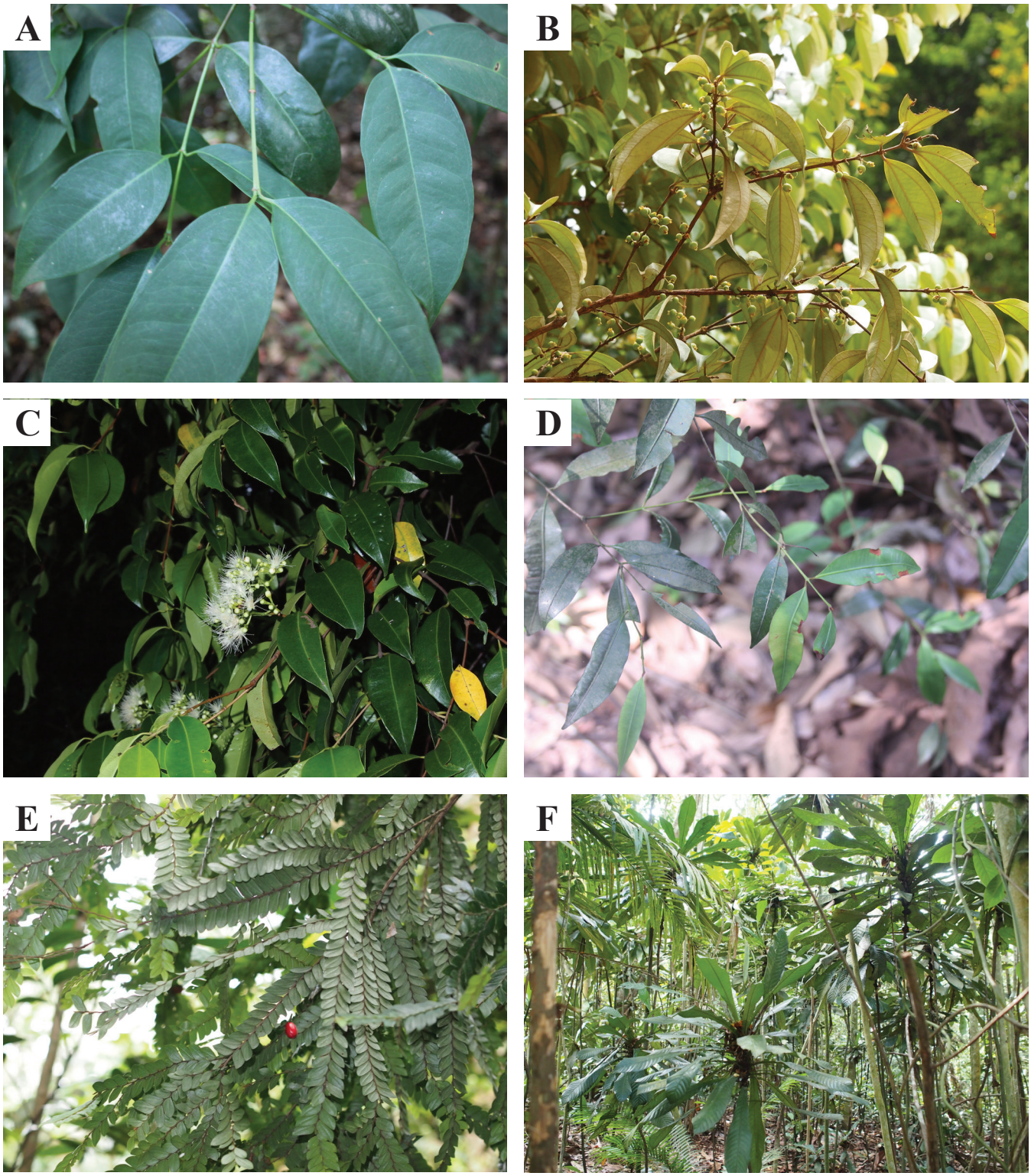

Fig. 5. Examples of common tree species in native-dominated secondary forest in Singapore, A) *Garcinia parvifolia* B) *Rhodamnia cinerea* C) *Syzygium lineatum* D) *Calophyllum pulcherrimum*. E) *Anisophyllea disticha* F) *Agrostistachys borneensis* are common treelets in the understorey of late-successional secondary forests.

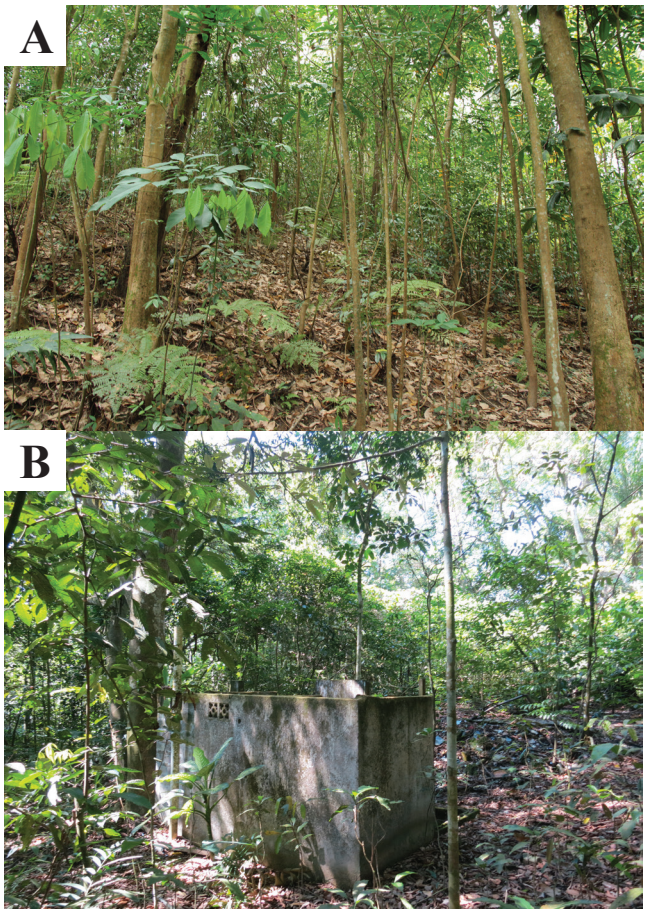

Fig. 6. A) An abandoned rubber plantation in Bukit Batok Hillside Park. B) An abandoned kampung near Yio Chu Kang Road. Remnants of buildings can still be seen in some of the abandoned-land forests.

(Neo et al., 2013b), and Dairy Farm Nature Park, and on the outskirts of the BTNR, which would offer some degree of protection.

The existing patches of abandoned-land forests were often categorised as "sundry tree cultivation" in past topographic maps of Singapore, especially in those from more recent years. The trees that form the main canopy layer of these abandoned-land forests are usually remnants from past cultivation, and are mainly of exotic species. Although a mixture of tree and crop species were usually planted (Hill, 1977), we can observe two subtypes of the abandoned-land forest, namely abandoned plantations (mainly comprising rubber), and abandoned kampungs or orchards (mainly comprising fruit and ornamental trees). It should be noted that abandoned-land forests tend to be spatially heterogeneous: both subtypes can often be observed within the same patch of forest.

Hevea brasiliensis can usually be found in abandoned-land forests, and it is especially abundant in the abandoned-plantation subtype. *Durio zibethinus*, *Nephelium lappaceum*, and *Spathodea campanulata*, are also common in the abandoned-land forest, and this is especially so in the abandoned-kampung subtype (Fig. 7). These four species flower and fruit regularly, so their seedlings and saplings are often found in the understorey layer of abandoned-land forests. *Nephelium lappaceum* is considered to be nationally Critically Endangered in Singapore by the Singapore Red Data Book (Tan et al., 2008), but the populations in the abandoned-land forest are likely relics of past cultivated stock and not dispersed naturally from the native-dominated forests of Singapore. One can also find cultivated herbs and shrubs such as *Aglaonema commutatum*, *Dieffenbachia seguine*, *Heliconia* spp., and *Piper sarmentosum* in the understorey layer. Abandoned-land forests nearer to a native-dominated forest tend to be richer in native species. It is not uncommon to observe native tree species such as *Macaranga* spp., or *Syzygium* spp. in the abandoned-land forest type.

Waste-woodlands. These are forests regrown on land that was recently cleared, usually after the 1960s (Fig. 8). Similar to abandoned-land forests, waste-woodlands usually occur as small forest fragments embedded in an urban matrix. These patches are usually awaiting future development.

The cleared lands are usually either previously cultivated lands, or graveyards. The top soil was likely to have been removed or buried, and the soil conditions were considerably altered when the land was cleared (Wee & Corlett, 1986; Corlett, 1992). Since the 1960s, Singapore has become more built-up with more buildings and roads (Savage, 1992). Trees were actively planted to green the urban areas, and many are exotic species (Wee & Corlett, 1986). Singapore's landscape after the 1960s is thus very different compared to that of the years before. This changed environment may have promoted initial succession by exotic species on recently cleared lands.

Wee & Corlett (1986) and Tan et al. (2010) have described wasteland vegetation dominated by herbaceous weeds and shrubs such as *Imperata cylindrica*, *Mimosa pigra*, *Panicum maximum*, and *Pennisetum purpureum*. Succession in wasteland vegetation can be patchy, and is affected by the underlying substrate. In areas where succession occurs, woody trees begin to form canopies that suppress the dominance of the herbs and shrubs. The term "waste-woodland" is thus used to describe the successional stage of a wasteland after trees have replaced scrub.

The tree species composition of waste-woodlands depends mainly on the seed sources available from the surroundings during the time of clearance, and succession. As such, trees that can commonly be found in waste-woodlands (Fig. 9) are *Acacia auriculiformis* and *Falcataria moluccana*, which were common wayside trees in the past, and which are capable of fixing their own nitrogen (Wee & Corlett, 1986). In these last 10 years, *Cecropia pachystachya* and *Leucaena leucocephala* have become dominant in some areas of waste-woodlands of Singapore (Lok et al., 2010a, 2010b). In our opinion, this likely reflects a switch in the seed rain reaching newly-regenerating wasteland. The four above-mentioned exotic species can also be found in abandoned-land forests and in some parts of the native-dominated secondary forest, but they are never the dominant tree species in these forest types. In the understorey, it is not uncommon to encounter seedlings and saplings of common wayside plants such as *Ardisia*

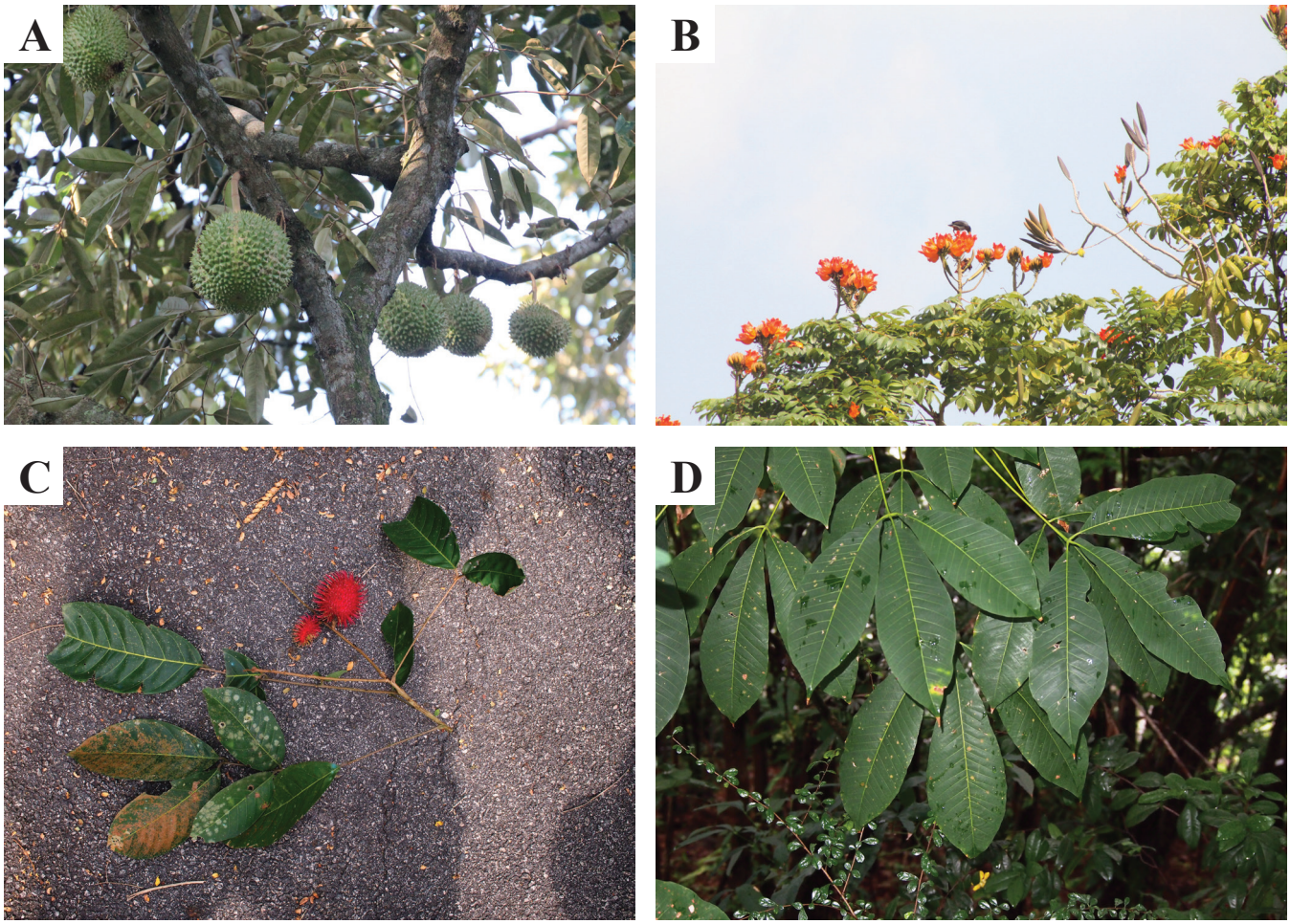

Fig. 7. Common tree species of abandoned-land forests A) *Durio zibethinus* B) *Spathodea campanulata* C) *Nephelium lappaceum* D) *Hevea brasiliensis*. The former three are usually associated with abandoned kampungs, while the latter is usually associated with abandoned rubber plantations.

Fig. 8. A patch of waste-woodlands near Tampines Drive 2. The canopy is made up of albizia trees (*Falcataria moluccana*).

elliptica, *Syzygium grande*, and *Syzygium polyanthum*.

A NOTE ON RECLAIMED-LAND FORESTS

Although succession on reclaimed land can be considered primary instead of secondary in nature, we include forests growing on reclaimed land as they tend to be structurally similar to waste-woodlands, and were mapped as young secondary forests by Yee et al. (2011). Newly-reclaimed sites are usually left untouched for a few years to allow the landfill to settle (Tan et al., 2010). Such reclaimed land is usually scheduled for future development.

The plant species composition found on reclaimed land is dependent on the fill material used (Tan et al., 2010). Land reclaimed using subsoil will have similar a vegetation composition to the waste-woodlands as described above. On the other hand, if marine sand is used, the species composition will have a higher affinity to coastal vegetation. In this latter case, *Casuarina equisetifolia* is usually the most abundant tree species, and it can form monospecific stands in reclaimed-land forests (Fig. 10). The understorey layer can sometimes be densely covered by herbs such as the exotic *Chromolaena odorata*. The exotic tree species, *Acacia auriculiformis* and *Leucaena leucocephala*, can also be found in reclaimed land sites, usually further inland (Lok et al., 2010a; Tan et al., 2010). Nearer to the coast, herbs such as *Ipomoea pes-caprae*, and trees such as *Cocos nucifera*, *Taliparititi tiliaceum*, and *Terminalia catappa*, can also be seen.

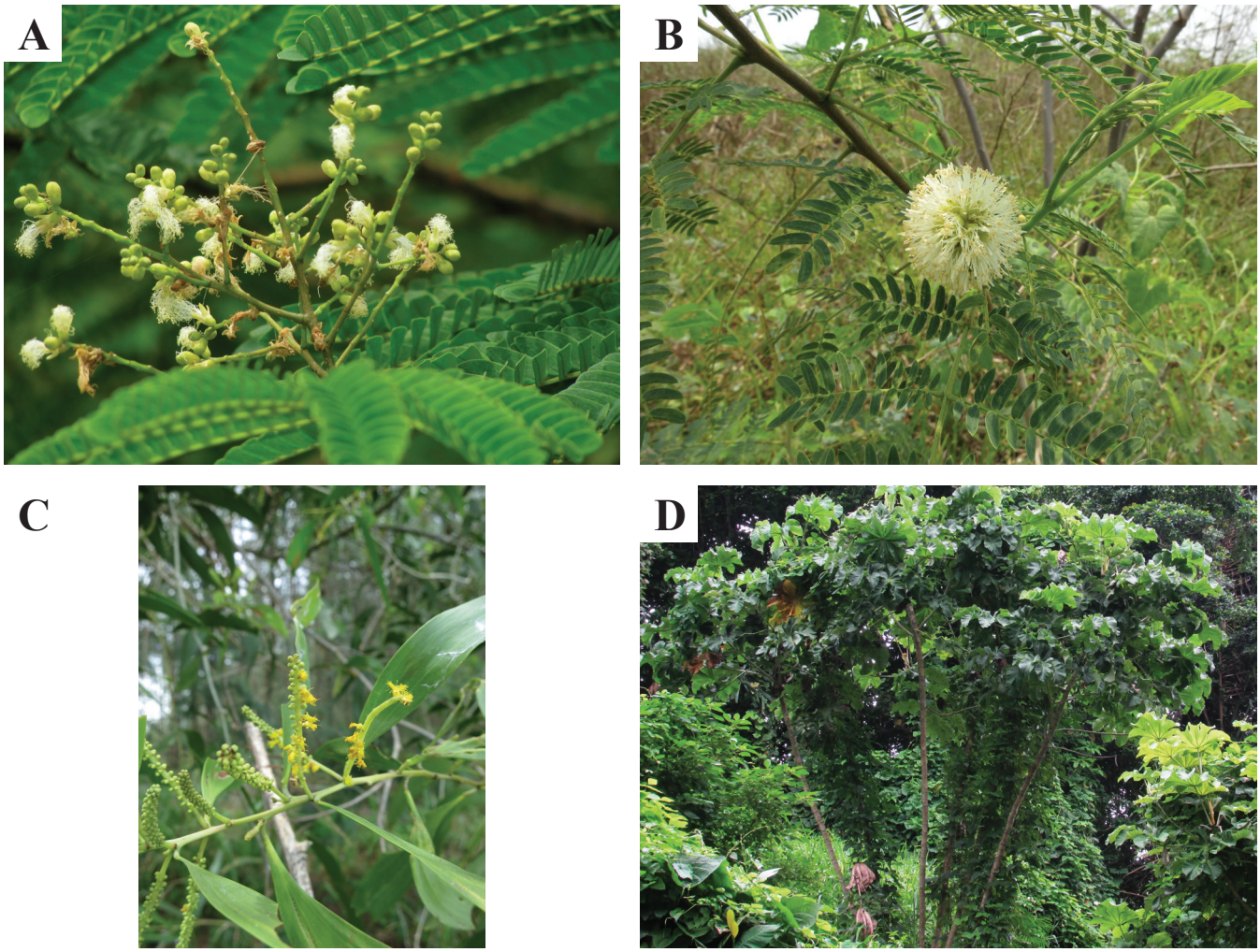

Fig. 9. Common tree species of waste-woodlands, A) *Falcataria moluccana* B) *Leucaena leucocephala* C) *Acacia auricuriformis* D) *Cecropia pachystachya* has become locally dominant along the Seletar Expressway.

Fig. 10. Reclaimed-land forest on Coney Island. Casuarina trees (*Casuarina equisetifolia*) usually form monospecific stands in this type of forest.

CONCLUSIONS

Here, we have classified the secondary forests of Singapore based on their land-use histories. The three main types that we have described are native-dominated secondary forest, abandoned-land forest, and waste-woodlands (Table 1). We have provided vegetation descriptions of these forest types, and briefly discussed reclaimed-land forest. We hope that this classification system can aid users in classifying vegetation that they observe in the field. Land-use history of a single patch of secondary forest can be heterogeneous, e.g., Admiralty forest, (Neo et al., 2013a). Therefore, it would be advisable to classify a single patch of forest as a mixture of the forest types observed. Although the data used from our field surveys are from Singapore Island sites, the classification scheme proposed here is also applicable to the offshore islands of Singapore.

It has been argued that secondary forests hold considerably less biodiversity than primary forests, and hence have little conservation value (Gibson et al., 2011). We agree that priority for conservation in Singapore should be given to the few remaining patches of primary forest in the BTNR and CCNR. However, given that most of the spontaneous vegetation that is found today in Singapore is secondary (Yee

Table 1. Summary of the updated secondary forest classification system for Singapore. Reclaimed-land forest is not secondary but is included for its similarity to the structure of waste-woodlands.

Secondary forest type	**Description**
Native-dominated	Developed on land cleared before the 1950s. Dominated by native plant species.
Early successional	Dominated by native pioneer tree genera such as *Adinandra*, *Macaranga*, *Mallotus*, and *Trema*.
Late successional	Developed from the early successional forest and contains higher plant species richness. *Alstonia*, *Calophyllum*, *Campnosperma*, *Elaeocarpus*, *Garcinia*, *Litsea*, *Rhodamnia,* and *Syzygium* are common genera found in the canopy layer. *Anisophyllea disticha* and *Agrostistachys borneensis* are common treelets found in the understorey.
Abandoned-land	Developed from abandoned plantations or kampung with mature trees largely left intact. Dominated by exotic plant species.
Abandoned plantation	Developed from abandoned plantation, usually dominated by rubber (*Hevea brasiliensis*).
Abandoned kampung or orchard	Developed from abandoned kampung or orchard, usually dominated by fruit trees (e.g., *Durio zibethinus*, *Nephelium lappaceum*) or ornamental plants (e.g., *Spathodea campanulata*, *Aglaonema commutatum*, *Dieffenbachia seguine*, *Heliconia* spp.).
Waste-woodland	Developed on land cleared after the 1960s. Dominated by exotic plant species with high propagule pressure in surrounding landscape (e.g., *Acacia auriculiformis*, *Falcataria moluccana*, *Leucaena leucocephala*).
Reclaimed-land	Developed on reclaimed land. Can be similar to waste-woodlands or dominated by *Casuarina equisetifolia*.

et al., 2011), it may be wise to also direct some attention to secondary forests, especially the native-dominated secondary forests. Native-dominated secondary forests are potential recruitment sites for the primary forest species in the nature reserves. They can also act as buffers for the primary forest patches against the effects of hard edges (e.g., an edge between forest and a road) surrounding the nature reserves., Moreover, these native-dominated secondary forests can provide habitats for many forest-dependant animal species (Corlett, 1997).

Abandoned-land forests and waste-woodlands are usually unprotected and are often slated for future clearance for the development of housing estates and transport infrastructure. Van Breugel (2013) questioned the conservation value of such ephemeral secondary forests, as they seldom contain native trees mature enough to act as seed sources. However, studies like those of Hassan Ibrahim et al. (2011) and Neo et al. (2012, 2013a, 2013b, 2014a, 2014b) have found some nationally-threatened species in the abandoned-land forests and waste-woodlands of Singapore. Even though the clearance of these two types of forests is mostly inevitable, such species can still be propagated or transplanted elsewhere for conservation. This thus highlights the need for proper and publicly-accessible environmental impact assessments to be conducted before the clearing of any forest patch.

It has been noted that the succession of native-dominated secondary forest to primary forest in Singapore is a very slow process, possibly impeded by the lack of seedling recruitment and the persistence of long-lived pioneer species (Goldsmith et al., 2011; Chua et al., 2013). It is also unknown whether or when the two exotic species-dominated secondary forest types will revert to native-dominated forest. Active reforestation and assisted natural regeneration may perhaps be needed to restore these types of secondary forest in Singapore (Shono et al., 2006, 2007a, 2007b). More long-term monitoring of plots similar to that of the 2-ha Bukit Timah Forest Dynamics Plot (Lum et al., 2004) is needed to better understand the succession of secondary forests in Singapore.

There has been increasing public concern over the disturbance and clearance of secondary forest patches in Singapore in recent years, for example, the case of residents living near the Petir Road forest and Pasir Ris woodlands (Chua, 2012, 2013). The recently proposed cross-island line that will cut through the secondary forest around MacRitchie Reservoir has also raised the attention of members of the public and nature groups (Nature Society (Singapore), 2013; Neo, 2013). Therefore it seems that spontaneous vegetation (including secondary forests), is appreciated by Singaporeans to be of conservation value. There is a need to better understand the ecosystem functions, services and values of these forests, so that conservation efforts can be geared towards the needs of future generations.

ACKNOWLEDGEMENTS

We thank the past and present members of the Botany Laboratory, Department of Biological Sciences, National University of Singapore, especially Carmen Kee Yingxin for her research on waste-woodlands. Eun Jung Min, Jeremy Yu King Yan, Galen Tiong Ji Liang, and Yeoh Yi Shuen from the NUS High School of Mathematics and Science, and their teacher mentor Lee Siak Cheong collected the plant community data from the forest around MacRitchie Reservoir. Yeo Chow Khoon and Lua Hock Keong provided useful inputs on the classification scheme. Ng Xin Yi kindly

provided her photo of *Durio zibethinus* (Fig. 7a). Access to the various forest patches was granted by the following permits from the National Parks Board, Singapore: NP/RP13-043, NP/RP13-030, NP/RP12-085, NP/RP11-095, NP/RP11-062, NP/RP11-039, and NP/RP11-021. The field surveys and data collection would not have been possible without the aid of numerous field assistants, and we are grateful too for the plant identification help provided by the staff of the Singapore Herbarium (SING), located in the Singapore Botanic Gardens. We also thank the National Archives of Singapore, and the National Library of Singapore for allowing us access to their collections of the topographic maps of Singapore.

LITERATURE CITED

Chazdon RL (2014) Secondary Growth: The Promise of Tropical Forest. The University of Chicago Press, Chicago, 20 + 449 pp.

Chief Surveyor, Singapore (1969) 1:63,360 Singapore Series I Edition I. 84 Survey Squadron RE, AD Survey Far East Land Forces.

Choong MF, Lucas PW, Ong JSY, Pereira B, Tan HTW & Turner IM (1992) Leaf fracture toughness and sclerophylly: their correlations and ecological implications. New Phytologist, 121(4): 597–610.

Chua G (2012) Protest over condo plan for forest site. Straits Times, 18 May 2012.

Chua G (2013) Pasir Ris Heights: Fight to save forest patch hots up. Straits Times, 9 Jan 2013.

Chua SC, Ramage BS, Ngo KM, Potts MD & Lum SKY (2013) Slow recovery of a secondary tropical forest in Southeast Asia. Forest Ecology and Management, 15: 153–160.

Corlett RT (1991a) Plant succession on degraded land in Singapore. Journal of Tropical Forest Science, 4(2): 151–161.

Corlett RT (1991b) Vegetation. In: Chia LS, Ausafur Rahman & Tay DBH (eds.) The Biophysical Environment of Singapore. Singapore University Press, Singapore. Pp. 134–154.

Corlett RT (1992) The ecological transformation of Singapore, 1819–1990. Journal of Biogeography, 19(4): 411–420.

Corlett RT (1994) What is secondary forest? Journal of Tropical Ecology, 10(3): 445–447.

Corlett RT (1997) The vegetation in nature reserves of Singapore. Gardens' Bulletin Singapore, 49: 147–159.

Eun JM, Yu JKY, Yeoh YS, Tiong GJL, Yee ATK, Lee SC & Tan HTW (2014) Tree and seedling communities in MacRitchie Forest, Singapore. In: Abstracts of the 2014 Biodiversity Research Symposium. National Parks and National University of Singapore, Singapore. http://brs-2014.blogspot.sg/p/abstracts.html. (Accessed 21 July 2015).

Gibson L, Lee TM, Koh LP, Brook BW, Gardner TA, Barlow J, Peres CA, Bradshaw CJA, Laurence WF, Lovejoy TE & Sodhi NS (2011) Primary forests are irreplaceable for sustaining tropical biodiversity. Nature, 478: 378–381.

Gilliland HB (1958) Plant communities on Singapore Island. The Gardens' Bulletin Singapore, 17(1): 82–92.

Goldsmith GR, Comita LS & Chua SC (2011) Evidence for arrested succession within a tropical forest fragment in Singapore. Journal of Tropical Ecology, 27(3): 323–326.

Hassan Ibrahim, Leong PKF, Yam TW & Lua HK (2011) The rediscovery of the ground orchid *Dienia ophrydis* (J. König) Seidenf. (Orchidaceae) in Singapore. Nature in Singapore, 4: 329–337.

Hill RD (1977) The vegetation map of Singapore: A first approximation. Journal of Tropical Geography, 45: 26–33.

Hobbs R, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Epstein PR, Ewel JJ, Klink CA, Lugo AE, Norton D, Ojima D, Richardson DM, Sanderson EW, Valladares F, Vilà M, Zamora R & Zobel M (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography, 15(1): 1–7.

Holttum RE (1954) Adinandra belukar. Malayan Journal of Tropical Geography, 3: 27–32.

Kee YC (2012) Factors Affecting Plant Species Richness and Composition in Singapore's Waste-woodlands. Unpublished Honours Thesis. National University of Singapore, Singapore, 48 pp.

Lok AFSL, Tan K-X, Ang WF & Tan HTW (2010a) The distribution and ecology of *Leucaena leucocephala* (Lam.) de Wit ssp. *leucocephala* (Fabaceae) in Singapore. COSMOS, 6(1): 45–55.

Lok AFSL, Tan K-X, Chong KY, Nghiem TPL & Tan HTW (2010b) The distribution and ecology of *Cecropia* species (Urticaceae) in Singapore. Nature in Singapore, 3: 199–209.

Lum SKY, Lee Sk & LaFrankie JV (2004). Bukit Timah Forest Dynamics Plot, Singapore. In: Logos EC & Leigh Jr EG (eds.) Tropical Forest Diversity and Dynamism: Findings from a Large-scale Plot Network. University of Chicago Press, Chicago, pp. 464–473.

Ministry of Defence, Singapore (1975) 1:25,000, R.S.O. Metric Grid, Singapore. Officer Commanding, Mapping Branch, Ministry of Defence, Singapore.

Nature Society (Singapore) (2013) NSS Discussion & Position Paper - Cross Island Line. Online Report. Nature Society (Singapore), Singapore. http://www.nss.org.sg/documents/(NSS)%20Cross-Island%20Line%20Position%20Paper.pdf. (Accessed 15 August 2014).

Neo CC (2013) NGOs move to extend nature's reach; Climate issues, human-wildlife conflicts could feature prominently in the year ahead. Today, 31 December 2013.

Neo L (2012) Plant Diversity of Abandoned Rubber Plantations in Singapore: A Novel Ecosystem. Unpublished Honours Thesis. National University of Singapore, Singapore, 61 pp.

Neo L, Yee ATK, Chong KY & Tan HTW (2012) The vascular plant flora of abandoned plantations in Singapore I: Clementi Forest. Nature in Singapore, 5: 275–283.

Neo L, Yee ATK, Chong KY, Kee CY & Tan HTW (2013a) The vascular plant flora of Admiralty Forest, Singapore. Nature in Singapore, 6: 61–72.

Neo L, Yee ATK, Chong KY, Kee CY & Tan HTW (2013b) The vascular plant flora of Bukit Batok, Singapore. Nature in Singapore, 6: 265–287.

Neo L, Yee ATK, Chong KY & Tan HTW (2014a) The vascular plant flora of Upper Thomson Forest. Nature in Singapore, 7: 55–68.

Neo L., Yee ATK, Chong KY, Yeoh YS & Tan HTW (2014b) The vascular plant flora of abandoned plantations in Singapore IV: Windsor Forest. Nature in Singapore, 7: 93–109.

O'Dempsey T (2014) Singapore's changing landscape since c. 1800. In: Barnard TP (ed.) Nature Contained: Environmental Histories of Singapore. NUS Press, Singapore. Pp. 17–48.

Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH & Wagner H (2013) vegan: Community Ecology Package. R Package Version 2.1-10. http://CRAN.R-project.org/package=vegan (Accessed 28 July 2014).

Pickett STA & Cadenasso ML (2005). Vegetation dynamics. In: van der Maarel E (ed.) Vegetation Ecology. Blackwell Publishing, Malden, Massachusetts, pp. 172–198.

R Development Core Team (2013) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org (Accessed 28 July 2014).

Savage VR (1992) Landscape change: from kampung to global city. In: Gupta A & Pitts J (eds.): Physical Adjustments in a Changing Landscape: The Singapore Story. Singapore University Press, Singapore, pp. 5–31.

Shono K, Davies SJ & Chua YK (2006) Regeneration of native plant species in restored forests on degraded lands in Singapore. Journal of Tropical Forest Science, 19(1): 25–34.

Shono K, Davies SJ & Chua YK (2007a) Performance of 45 native tree species on degraded lands in Singapore. Forest Ecology and Managment, 237(1–3): 574–582.

Shono K, Cadaweng EA & Durst PB (2007b) Application of assisted natural regeneration to restore degraded tropical forestlands. Restoration Ecology 15(4): 620–626.

Sim JWS, Tan HTW & Turner IM (1992) Adinandra belukar: an anthropogenic heath forest in Singapore. Vegetatio 102: 125–137.

Singapore Mapping Unit (1982) 1:25,000 Topographic Map. Mapping Unit, Ministry of Defence, Singapore.

Singapore Mapping Unit (1987) 1:25,000 Topographic Map. Mapping Unit, Ministry of Defence, Singapore.

Singapore Mapping Unit (1992) 1:25,000 Topographic Map. Mapping Unit, Ministry of Defence, Singapore.

Singapore Mapping Unit (2000) 1:25,000 Topographic Map. Mapping Unit, Ministry of Defence, Singapore.

Singapore Mapping Unit (2008) 1:25,000 Topographic Map. Mapping Unit, Ministry of Defence, Singapore.

Surveyor-General, Federated Malay States and Straits Settlements (1924) Singapore. Surveyor-General, Federated Malay States and Straits Settlements.

Surveyor-General, Malaya (1953) 1: 25,000 Singapore Provisional Issue. Survey Department Federation of Malaya, Malaya.

Survey Production Centre, South East Asia (1945) 1: 25,000 Topographic Map. Survey Department, Federation of Malaya.

Tan HTW, Tan K, Ali bin Ibrahim, Chew PT, Chua KS, Duistermaat H, Ganesan SK, Goh MWK, Gwee AT, Kiew R, Lee SML, Leong P, Lim J, Lok AFSL, Loo AHB, Lum SKY, Morgany T, Saifuddin Suran, S. Sim, Haji Samsuri bin Haji Ahmad, Wee YC, Yap KF, Yeo CK & Yong JWH (2008). Checklists of threatened species—seed plants. In: Davison GWH, Ng PKL & Ho HC (eds.) The Singapore Red Data Book. Second edition. The Nature Society (Singapore), Singapore, pp. 213–245.

Tan HTW, Chou LM, Yeo DCJ & Ng PKL (2010) The Natural Heritage of Singapore. Third Edition. Pearson Prentice Hall, Singapore, 9 + 323 pp.

Thomson J, Brokaw N, Zimmerman JK, Waide RB, Everhamm III EM, Lodge JD, Taylor CM, García-Montiel D & Fluet M (2002) Land use history, environment, and tree composition in a tropical forest. Ecological Applications, 12(5): 1344–1363.

Turnbull CM (2009) A History of Modern Singapore 1819–2006. Third Edition. NUS Press, Singapore, 19 + 468 pp.

Turner IM, Wong YK, Chew PT & Ali bin Ibrahim (1996) Rapid assessment of tropical rain forest successional status using aerial photographs. Biological Conservation, 77(2–3): 177–183.

Turner IM, Wong YK, Chew PT & Ali bin Ibrahim (1997) Tree species richness in primary and old secondary tropical forest in Singapore. Biodiversity and Conservation, 6: 537–543.

van Breugel M, Hall JS, Craven D, Bailon M, Hernandez A, Abbene M & van Breugel P (2013) Succession of ephemeral secondary forests and their limited role for the conservation of floristic diversity in a human-modified tropical landscape. PLoS ONE, 8(12): e82433.

Wee YC (1964) A note on the vegetation of Singapore Island. Malayan Forester, 27: 257–266.

Wee YC & Corlett RT (1986) The City and the Forest: Plant Life in Urban Singapore. Singapore University Press, Singapore, 8 + 186 pp.

Wong PP (1969) The changing landscapes of Singapore Island. In: Ooi J-B & Chiang HD (eds.) Modern Singapore. University of Singapore, Singapore, pp. 20–51.

Wong YK, Chew PT & Ali bin Ibrahim (1994) The tree communities of the Central Catchment Nature Reserve, Singapore. The Gardens' Bulletin Singapore, 46(2): 37–78.

Wyatt-Smith J & Panton WP (1995) Manual of Malayan Silviculture for Inland Forest. 2nd edition. Malayan Forest Records 23. Forest Research Institute Malaysia, Kuala Lumpur.

Yee ATK, Corlett RT, Liew SC & Tan HTW (2011) The vegetation of Singapore—an updated map. Gardens' Bulletin of Singapore, 63(1 & 2): 205–212.

Zdenka O & Milan C (2006) Effects of plot size on the ordination of vegetation samples. Journal of Vegetation Science, 17: 465–472.