7. PLANT CONSERVATION IN SINGAPORE II: PRACTICAL IMPLEMENTATION

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In Chapter 6, the historical and legislative framework for plant conservation in Singapore is discussed, along with a summary of the threats to Singapore's native plant diversity. In Chapter 7, the research that underpins conservation is introduced and NParks' species recovery and reintroduction programmes are discussed.

Conservation efforts in Singapore focus on the protection of native plants and their natural habitats through the Singapore Green Plan (Chew, 2016), Sustainable Singapore Blueprint (Ministry of the Environment and Water Resources (MEWR) & Ministry for National Development (MND), 2015), National Biodiversity Strategy and Action Plan (National Parks Board, 2009), and Nature Conservation Masterplan (National Parks Board, 2015b). That the plant diversity of Singapore has been subject to considerable pressure over a long period of time is not in doubt. This has led to very high numbers of species being presumed Nationally Extinct or assigned one of the IUCN threat categories (Vulnerable, Endangered or Critically Endangered) (Table 1). The initiatives mentioned above advocate action to halt biodiversity loss through research on rare and threatened species and through practical conservation measures. These include ex situ conservation actions to augment the populations of species under threat and potentially to reverse national extinctions through reintroductions of formerly native species from other countries.

Research

Effective conservation action relies on accurate data of which species are native in Singapore, where they occur, and whether they are under threat. For Singapore, International Union for the Conservation of Nature (IUCN) conservation assessments of plant species using the methodology set out in Davison et al. (2008) have almost entirely been under category D which is based on the number of mature individuals. The current status of each species will be included throughout the *Flora of Singapore* using the best available evidence. It must be acknowledged, however, that for most species the number of mature individuals in Singapore will have been estimated rather than precisely counted although programmes to tackle this lack of data have been initiated for some plant groups. A summary of the current (2019) conservation status of the native vascular plants of Singapore is given in Table 1. The bryophytes have not yet been assessed and are not included.

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The highest levels of plant diversity in Singapore are found in the Nature Reserves (Bukit Timah Nature Reserve, Central Catchment Nature Reserve, Labrador Nature Reserve and Sungei Buloh Wetland Reserve) Singapore Botanic Gardens' Rain Forest, other nature areas, and the Parks. Understanding what species occur in each of these areas better enables effective conservation measures to be afforded to those species most under threat. For plants, studies such as those that survey the plant diversity of specific areas, especially to assess the species with very restricted distributions and to highlight species not previously recorded, include Chong et al. (2018) for Nee Soon swamp and Ho et al. (2019) for Bukit Timah Nature Reserve. Within the last 10 years, continual survey work around Singapore has led to the discovery of new plant species (Yao, 2013; Sugumaran & Wong, 2014; Leong-Škorničková et al., 2014; Niissalo et al., 2014; Leong-Škorničková & Boyce, 2015; Seah & Wong, 2018a,b; Wong & Lua, 2018), over 80 new records of species presumed to be native and not previously known from Singapore (e.g. Niissalo et al., 2016; J. Chen et al., 2018; Chong et al., 2018; Ganesan et al., 2018a,b; Ho et al., 2018; Khoo et al., 2018; Lim et al., 2018a; Middleton et al., 2018; Turner, 2018a,b) and the rediscovery of around 140 species previously presumed to be Nationally Extinct (e.g. Chong et al., 2018; Ho et al., 2018; Leong et al., 2018; Lim et al., 2018a,b; Rodda & Lai, 2018). Around 16 non-native species have also recently been found to be newly naturalising in Singapore (e.g. L.M.J. Chen et al., 2018). The list of species recorded in Singapore, and the threat categories applied to the species, is ever-changing due to these new discoveries and due to the passage of time taking some species over the 30 year threshold since it was last recorded and, therefore, having its status changed to presumed Nationally Extinct (see below). In addition to the numbers presented in Table 1 for native species, over 400 exotic species have naturalised or are casual in Singapore (see Chapter 1 for definitions). This presents its own challenges as some of these species are invasive and may outcompete native species for available habitats (see Chapters 5 and 6).

An assessment of whether a species is to be presumed Nationally Extinct is based on whether the species has been collected or otherwise recorded (beyond doubt) from Singapore within the last 30 years. Currently, 561 species are recorded as Nationally Extinct, a lower figure than the 634 species given by Tan et al. (2008) due to the many rediscoveries but partly offset by additional species being added to the presumed extinct list since 2008 (see Table 1). Almost a quarter of the native vascular plant species in Singapore have not been recorded from the country in at least 30 years. It is perhaps surprising that the extinction level is not higher given that Singapore had already lost most of its primary forest in the nineteenth century. The resilience of Singapore's plant diversity has been discussed by Ngo et al. (2016) and Ho et al. (2019). However, Niissalo et al. (2017) warn that the very high number of species in one of the threat categories (Table 1) suggests that Singapore is still in a period of 'extinction debt', meaning that there are delayed yet anticipated extinctions due to past events. Identifying the species most at risk and what exactly the threats are, however, can also lead to active measures to mitigate the risks.

Knowledge of the reproductive biology of species can inform effective conservation policy. Field observations and the deployment of camera traps to gather information on pollinators and dispersers, accompanied by ex-situ experiments to find which species must be cross-pollinated or which will self-pollinate, can provide vital information on the success, or otherwise, of seed-set. These kinds of data are particularly important in the design of ex situ conservation measures. Comparing the nectar quality of native and non-native species, and consequent pollinator preferences, can also help us better understand why seed-set

Table 1. Estimate of current conservation status of native species of vascular plants in Singapore using the criteria of Davison et al. (2008). See also previous estimates of conservation status in Chapter 6, Table 2.

IUCN category	Current estimates
Globally Extinct	4
Nationally Extinct	561
Critically Endangered	722
Endangered	258
Vulnerable	287
Near Threatened and Least Concern (common)	361
Conservation status not yet assessed or Data Deficient	217
Total	**2410**

may differ across Singapore in response to different species assemblages. In particular, it is important to discover if non-native species are being preferred by pollinators to the detriment of native species. These experiments can then potentially lead to changes in the management of naturalised and cultivated species, particularly around the nature reserves.

A promising field of research to better effect conservation measures in threatened species is through the study of population genomics. Reduction and fragmentation of habitat area causes measurable changes in gene flow between populations and genetic diversity within them. Increased isolation makes the populations more susceptible to inbreeding, which may lead to loss of fitness in plants. Measures of population genetic diversity can direct conservation efforts to species and localities that are most affected by habitat alteration (Frankham et al., 2007). In some cases, changes to genetic diversity over time can be measured by sampling mature plants and seedlings. For example, in the large canopy tree, *Koompassia malaccensis* Maingay ex Benth., gene flow has decreased over time (Noreen et al., 2016), most likely due to fragmentation of Singapore's primary forest. In the case of the forest herb *Zingiber singapurense* Škorničk., population genomic work has shown that the plant has likely not reproduced sexually since forest fragmentation occurred (Niissalo et al., 2018). Identifying the barrier(s) to reproduction is a key conservation research question.

Population genomics tools have become far more affordable in recent years. Routine measurements of gene flow can help to highlight the species at the highest risk of inbreeding depression; to find populations within Singapore that have unique alleles that are beneficial for ex situ breeding; to identify plants that mostly reproduce asexually; and to detect wider patterns of gene flow at the landscape level. In some cases, highly inbred populations with a high genetic load may benefit from the introduction of plants from other areas, potentially from outside Singapore. Population genomics can also be used to estimate historic and current population sizes. It should be noted, however, that the translation of the findings of population genomic research into effective conservation practices is difficult (Shafer et al., 2015), although the existing infrastructure in Singapore is likely to help in the process. Findings from Singapore could also help predict the effects of habitat fragmentation and guide conservation practices in other, increasingly fragmented, tropical forests.

Species Recovery Programme

As part of the National Biodiversity Strategy and Action Plan and the Nature Conservation Masterplan, the following actions are highlighted: 1. rare plant species should be conserved in their natural habitats; 2. rare plants should be salvaged from areas undergoing development; and 3. the number of individuals of rare plants should be increased by propagation of originally wild collected seed and cuttings and through tissue culture followed by plantings in secure areas, potentially including back into the original wild populations (National Parks Board, 2009). Singapore Botanic Gardens (SBG) and NParks' Native Plant Centre (NPC) play a pivotal role in the collection, propagation and planting out of these rare species for the safeguarding of their future in the wild by conserving their germplasm and also introducing them to the urban landscape for ex situ conservation. While initially focused on orchids under the Orchid Conservation and Reintroduction Programme (Yam & Thame, 2005; Yam et al., 2011) from 1995, these efforts have been greatly expanded to include many other plant groups that have been identified as being vulnerable to extinction, both nationally and globally. In 2006, a project focusing on the conservation of gingers and other herbaceous monocots was initiated. Later, the Plant Conservation Project focused on the ex situ breeding of endangered plant species in nurseries, followed by planting in suitable natural sites so as to mitigate local threats to small and restricted populations (National Parks Board, 2010). These efforts then evolved into the current Species Recovery Programme (SRP), where threatened plant species are identified and prioritised based on endemism, conservation status and habitat range (National Parks Board, 2016a). The orchid and herbaceous monocot programmes have continued alongside the SRP, with some species also being taken under the umbrella of the SRP and jointly coordinated. Priority is given to threatened native species found in only one location, to rediscovered species previously thought to be extinct, and to newly discovered species which are endemic to Singapore. Field studies are conducted to understand the ecology of the species' habitats as well as their biology. Findings discussed in the Research section above can also be incorporated to build up a comprehensive picture of what actions will be most effective. The information gathered will serve as a guide to select suitable techniques and strategies for the introduction of species to existing and new localities or reintroduction to localities from where species were previously recorded but are now absent. The aim is to ensure that the reintroduced species can be self-sustaining and, therefore, will only be carried out when those managing the programme are confident that the local conditions are suitable for the species to thrive (and, if necessary, have evidence that the previous known threats or causes of decline have been removed or significantly ameliorated). Sites selected will be managed and monitored by NParks to ensure that suitable conditions are maintained and any future threats are identified in a timely manner.

In 2016, following the announcement of the Nature Conservation Masterplan in 2015 (National Parks Board, 2015b), 46 species were identified for the Species Recovery Programme (National Parks Board, 2016b; Yap, 2016). Of these, 31 were plant species. In 2017, a further 44 plant species were added (National Parks Board, 2017). With some additional changes (including some changes to the accepted scientific names), a consolidated list of the current 67 plant species in the Programme is provided in Table 2. A number of these species are being propagated from seeds, cuttings, air-layering, division or tissue culture at NPC and SBG. As well as being used for reintroductions and boosting natural populations in the nature reserves, some of the propagated plants are also being introduced into new localities such as parks to

promote public awareness and appreciation of native plants and to test their suitability for landscaping of public spaces (National Parks Board, 2016a). Some species have also been made available to the public for home and garden cultivation so that Singapore's native plant diversity is well-distributed across the country, both in natural habitats and in cultivation. The species in the Species Recovery Programme will inevitably change over time in response to the success, or otherwise, of the individual interventions and to the findings of further research on Singapore's native species.

We present here a selection of case studies from the current Species Recovery Programme.

1. *Cocculus orbiculatus* (L.) DC. (Menispermaceae)
Cocculus orbiculatus is a climber that was assessed as Nationally Extinct in Tan et al. (2008). It has since been rediscovered in a small area on Coney Island. Although it is known there from several individuals, it is a dioecious species and only male flowers have been observed. No fruiting has been observed. It was brought into cultivation from cuttings at the NPC where it flowers freely. Several female individuals grown from cuttings collected in Thailand are also being grown in NParks' Pasir Panjang Nursery (PPN) (which focuses primarily on growing exotic species), where they have been flowering for several years without producing fruit. Even when the native stock male and exotic stock female individuals flowered at the same time, albeit several hundred metres apart, there was no fruit development. A likely reason is that the small bees which visit the flowers do not travel far and did not cross pollinate them. Later, when two male plants were grown in close proximity to the female plants, fruits developed to maturity within a month on many of the female plants for the first time. Male and female plants grown from seed from individuals grown in cultivation have now been planted in conservation areas such as Labrador Nature Reserve and Pulau Ubin, as well as in SBG, Changi Beach Park and East Coast Park in conditions similar to those found on Coney Island. Seeds from the cultivated plants have also been collected for long-term storage and research at the Singapore Botanic Gardens Seed Bank. (Fig. 1).

2. *Fagraea splendens* Blume (Gentianaceae)
In Singapore this is a Critically Endangered species only known from a small population in Nee Soon freshwater swamp forest. In 2010, plants establishing as epiphytes were collected from fallen branches and propagated by the National University of Singapore before being transferred to NParks and the numbers increased through air-layering (Lim et al., 2018b) in the NPC. In 2018, they flowered for the first time. The flowers were hand-pollinated and fruit developed to maturity around three to four months later. Each fruit contained an average of 30 to 60 seeds. Germination levels were high but seedling growth has been slow because of the very small seed size (Naylor, 2003). The seedlings are currently about 5 cm tall, 12 months after sowing. Air-layered individuals have been planted in nature parks such as Springleaf Nature Park, as well as in SBG and Fort Canning Park.

3. *Kopsia singapurensis* Ridl. (Apocynaceae)
Found in southern Peninsular Malaysia and Singapore (Middleton, 2007), this species is now only known in the wild in Singapore from a small population in Nee Soon freshwater swamp forest and is assessed as Critically Endangered. Material was collected in the 1990s and grown by the National University of Singapore before being transferred to NParks for

Table 2. Plant species currently in the Species Recovery Programme with references to recent publications on their status and distribution, collection and propagation and other relevant information. Where there are no publications, voucher specimens are cited as evidence of their rediscovery.

No.	Species	Family	Publications or vouchers
1.	*Acriopsis liliifolia* (J.Koenig) Ormerod	Orchidaceae	Lok et al. (2009b)
2.	*Aeschynanthus albidus* (Blume) Steud.	Gesneriaceae	Lok & Tan (2008); Middleton (2016)
3.	*Aeschynanthus pulcher* (Blume) G.Don	Gesneriaceae	Williams (2014); Middleton (2016)
4.	*Alangium ridleyi* King	Cornaceae	Wijedasa et al. (2014); Chong et al. (2018)
5.	*Argyreia ridleyi* (Prain) Prain ex Ooststr.	Convolvulaceae	Staples (2015)
6.	*Barringtonia reticulata* (Blume) Miq.	Lecythidaceae	National Parks Board (2015c)
7.	*Bulbophyllum clandestinum* Lindl.	Orchidaceae	Yam (2013)
8.	*Bulbophyllum praetervisum* J.J.Verm.	Orchidaceae	Leong et al. (2014)
9.	*Calamus densiflorus* Becc.	Arecaceae	Loo et al. (2017)
10.	*Calamus javensis* Blume	Arecaceae	Loo et al. (2014)
11.	*Callostylis pulchella* (Lindl.) S.C.Chen & Z.H.Tsi	Orchidaceae	Lok et al. (2012)
12.	*Cheilocostus globosus* (Blume) C.D.Specht	Costaceae	Niissalo et al. (2017)
13.	*Cocculus orbiculatus* (L.) DC.	Menispermaceae	Lim et al. (2018a)
14.	*Dischidia acutifolia* Maingay ex Hook.f.	Apocynaceae	Rodda et al. (2015)
15.	*Etlingera maingayi* (Baker) R.M.Sm.	Zingiberaceae	Niissalo et al. (2017)
16.	*Fagraea splendens* Blume	Gentianaceae	Chong et al. (2018); Lim et al. (2018b)
17.	*Ficus delosyce* Corner	Moraceae	Ang et al. (2014); Chong et al. (2018)
18.	*Ficus stricta* (Miq.) Miq.	Moraceae	Yeo et al. (2012a)
19.	*Freycinetia javanica* Blume	Pandanaceae	Ang et al. (2012); Chong et al. (2018)
20.	*Globba leucantha* Miq.	Zingiberaceae	Niissalo et al. (2017)
21.	*Hanguana neglecta* Škorničk. & Niissalo	Hanguanaceae	Niissalo et al. (2014)
22.	*Hanguana nitens* Siti Nurfazilah et al.	Hanguanaceae	Leong-Škorničková & Boyce (2015)
23.	*Hanguana triangulata* Škorničk. & P.C.Boyce	Hanguanaceae	Leong-Škorničková & Boyce (2015), National Parks Board (2015a)
24.	*Hiptage sericea* Hook.f.	Malpighiaceae	Lim (2017)
25.	*Hopea ferruginea* Parijs	Dipterocarpaceae	Chong et al. (2018); Khoo et al. (2018)
26.	*Hopea sangal* Korth.	Dipterocarpaceae	Tan (2017)
27.	*Hornstedtia conica* Ridl.	Zingiberaceae	Niissalo et al. (2017)
28.	*Hoya caudata* Hook.f.	Apocynaceae	Rodda & Ang (2012)
29.	*Hoya obtusifolia* Wight	Apocynaceae	Rodda & Lai (2018)
30.	*Hydnophytum formicarum* Jack	Rubiaceae	Lok & Tan (2009)
31.	*Jasminanthes maingayi* (Hook.f.) Rodda (published as *Marsdenia maingayi* (Hook.f.) P.I.Forst.*)	Apocynaceae	*Yeoh et al. (2013); Rodda (2019)
32.	*Kopsia singapurensis* Ridl.	Apocynaceae	Middleton (2007)
33.	*Lecananthus erubescens* Jack	Rubiaceae	Lim et al. (2018a)
34.	*Lepironia articulata* (Retz.) Domin	Cyperaceae	Ooi & Ang (2015)
35.	*Lindsaea divergens* Hook. & Grev.	Lindsaeaceae	Tan & Yeo (2012)
36.	*Lophopetalum pallidum* M.A.Lawson	Celastraceae	Ganesan (2009)

Table 2. Continuation.

No.	Species	Family	Publications or vouchers
37.	*Mangifera magnifica* Kochummen	Anacardiaceae	Ganesan (2003); Hung et al. (2017)
38.	*Margaritaria indica* (Dalzell) Airy Shaw	Phyllanthaceae	Low et al. (2014)
39.	*Nageia wallichiana* (C.Presl) Kuntze	Podocarpaceae	Farjon (2010)
40.	*Neesia malayana* Bakh.	Malvaceae	Tan (2012); Chong et al. (2018)
41.	*Ormocarpum cochinchinense* (Lour.) Merr.	Fabaceae	Chong et al. (2012)
42.	*Pholidocarpus kingianus* (Becc.) Ridl.	Arecaceae	Loo et al. (2014); Loo et al. (2015)
43.	*Pinalia floribunda* (Lindl.) Kuntze	Orchidaceae	Leong et al. (2017)
44.	*Pinanga simplicifrons* (Miq.) Becc.	Arecaceae	Ang et al. (2010); Loo et al. (2014); Loo et al. (2015); Chong et al. (2018)
45.	*Piper porphyrophyllum* (Lindl.) N.E.Br.	Piperaceae	Lua (2013); Neo et al. (2013)
46.	*Piper ribesioides* Wall.	Piperaceae	*Lua SING2012-387* [SING0190194]; *Lua SING2012-388* [SING0190195]; *Lua SING2012-389* [SING0190196]
47.	*Planchonia grandis* Ridl.	Lecythidaceae	Nura & Md Fadli (2011); Prance & Kartawinata (2013)
48.	*Plectocomiopsis geminiflora* (Griff.) Becc.	Arecaceae	Tan et al. (2011); Loo et al. (2014); Loo et al. (2015)
49.	*Pomatocalpa diffusum* Breda	Orchidaceae	Lok et al. (2010); Yam (2013)
50.	*Portulaca pilosa* L. subsp. *pilosa*	Portulacaceae	Ng et al. (2011)
51.	*Pterisanthes cissioides* Blume	Vitaceae	Yeo et al. (2012b)
52.	*Pterospermum diversifolium* Blume	Malvaceae	Ganesan (2013)
53.	*Rhopaloblaste singaporensis* (Becc.) Hook.f.	Arecaceae	Loo et al. (2014); Loo et al. (2015)
54.	*Robiquetia spathulata* (Blume) J.J.Sm.	Orchidaceae	Yam (2013)
55.	*Salacca affinis* Griff.	Arecaceae	Loo (2011); Loo et al. (2014); Loo et al. (2015)
56.	*Scindapsus lucens* Bogner & P.C.Boyce	Araceae	Ho et al. (2018)
57.	*Scolopia macrophylla* (Wight & Arn.) Clos	Salicaceae	Lim et al. (2018a)
58.	*Spatholobus ridleyi* Prain	Fabaceae	*Ng SING2014-368* [SING0215121]
59.	*Stachyphrynium parvum* Ridl.	Marantaceae	Niissalo et al. (2016); Niissalo et al. (2017)
60.	*Sundamomum hastilabium* (Ridl.) A.D.Poulsen & M.F.Newman (published as *Amomum hastilabium* Ridl.*)	Zingiberaceae	*Niissalo et al. (2017)
61.	*Tetrastigma dichotomum* Planch.	Vitaceae	Yeo et al. (2012c)
62.	*Tetrastigma leucostaphylum* (Dennst.) Alston ex Mabb.	Vitaceae	Yeo et al. (2012c)
63.	*Thottea praetermissa* T.L.Yao	Aristolochiaceae	Yao (2013); Hassan (2014)
64.	*Thrixspermum amplexicaule* (Blume) Rchb.f.	Orchidaceae	Lok et al. (2008)
65.	*Thrixspermum trichoglottis* (Hook.f.) Kuntze	Orchidaceae	Yam (2013)
66.	*Utania nervosa* K.M.Wong & Sugumaran	Gentianaceae	Sugumaran & Wong (2014)
67.	*Zingiber singapurense* Škorničk.	Zingiberaceae	Leong-Škorničková et al. (2014); Niissalo et al. (2017)

further propagation. It flowers very freely in the wild but any fruits that develop do not fully mature. In cultivation, individuals are propagated from stem cuttings and air-layering, with higher success rates for air-layering. Air-layered individuals take up to two years to grow to a height of 1.5 m. Due to its beautiful flowers, this species is now a familiar sight in Singapore with large numbers of propagated plants successfully established in SBG, several parks, Singapore's streetscape and Pulau Ubin. However, as all of these cultivated plants have been produced vegetatively their genetic diversity is limited and work continues on this species to obtain mature fruit and seed.

4. *Mangifera magnifica* Kochummen (Anacardiaceae)
Once thought to have become extinct in Singapore, a single individual of *Mangifera magnifica* was rediscovered on St. John's Island in 2003 and was designated a Heritage Tree (HT2003-91) in the same year (Ganesan, 2003; National Parks Board, 2016c). No flowers or fruits were observed on this individual until 2018, when many *Mangifera* L. species in Singapore such as *Mangifera caesia* Jack*, Mangifera foetida* Lour. and *Mangifera pentandra* Hook.f. flowered and fruited (B. Phuah, pers. comm.). In 2015, a few more individuals of *Mangifera magnifica* were found on Pulau Tekong and in the Central Catchment Nature Reserve. During the fruiting event of 2018 seeds were collected from the Heritage Tree on St. John's Island and from the individuals in the Central Catchment Nature Reserve. There are now over a hundred saplings of *Mangifera magnifica* in the NPC representing stock from St John's Island and the Central Catchment Nature Reserve. Thirty young saplings have already been planted in the new Rifle Range Nature Park. (Fig. 2).

5. *Ormocarpum cochinchinense* (Lour.) Merr. (Fabaceae)
Once thought to have become extinct in Singapore, this coastal tree species was rediscovered in 1999 on Pulau Tekong and in 2004 on Pulau Ubin. Seeds and seedlings were collected from Pulau Tekong in 2017 and propagated in the NPC. The two individuals that were selected to be stock plants flowered and fruited after 6 months when they had reached a height of 1.5 m. Individuals grown from the seeds produced by these stock plants have now been planted in many coastal areas such as Jurong Lake Gardens, Labrador Nature Reserve, Pulau Ubin, Coney Island, Sungei Buloh Wetland Reserve, East Coast Park and Changi Beach Park. It is also being trialled as a streetscape tree due to its small leaflets, flowers and fruits, and tolerance of urban conditions. Seeds have also been collected for long-term storage and research at the Singapore Botanic Garden Seed Bank. (Fig. 3).

Orchid Conservation and Reintroduction Programme

Some 224 species of orchids have been recorded as native in Singapore, of which 154 are considered to be Nationally Extinct, 62 are Critically Endangered, and three are Vulnerable using the criteria of Davison et al. (2008). Only five species of native orchid in Singapore are considered to be of Least Concern, a quite staggeringly small percentage of the native orchid flora. Four of these five species are terrestrial, *Arundina graminifolia* (D.Don) Hochr., *Bromheadia finlaysoniana* (Lindl.) Miq., *Eulophia graminea* Lindl. and *Spathoglottis plicata* Blume, and only one is epiphytic, *Dendrobium crumenatum* Sw., also known as the pigeon

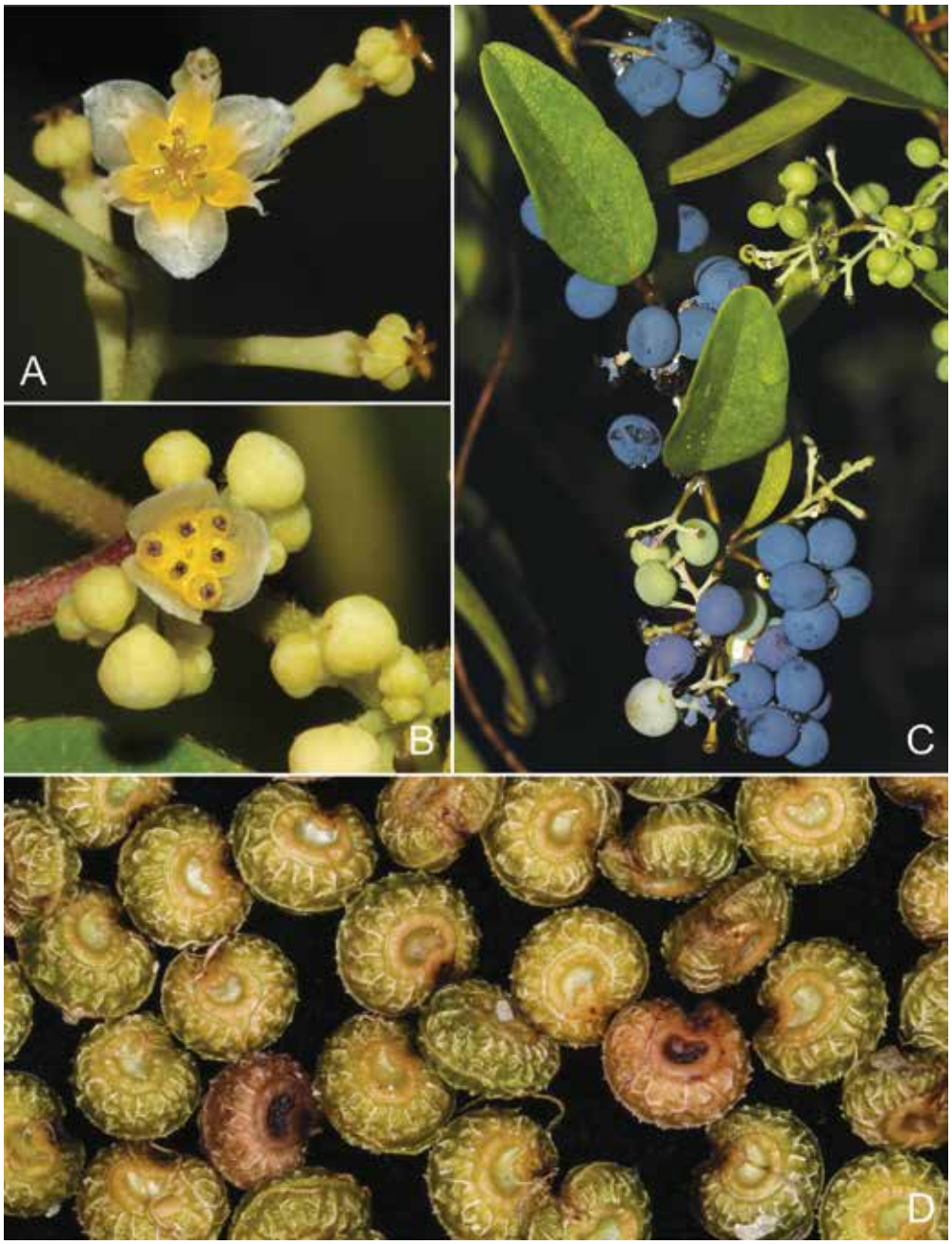

Figure 1. *Cocculus orbiculatus* (L.) DC. **A.** Female flowers of the plant from Thailand. **B.** Male flowers of the Singapore native plant. **C.** Ripe purple and unripe green fruits. **D.** Seeds with outer flesh removed. (Photos: X.Y. Ng).

Figure 2. *Mangifera magnifica* Kochummen. **A.** Conservation staff transplanting a sapling from under the parent tree. **B.** Fruits on an individual in the Central Catchment Nature Reserve. **C.** Fruits and exposed seeds. **D.** Seedlings two months after sowing. (Photos: R.C.J. Lim).

Figure 3. *Ormocarpum cochinchinense* (Lour.) Merr. **A.** Mature individual on Pulau Tekong. **B.** Fruits and seeds. **C.** Seedlings in the Native Plant Centre. **D.** Reproductively mature individuals in the Native Plant Centre. (Photos: R.C.J. Lim).

Table 3. Orchid species propagated from native stock and the year when they were first reintroduced into the wild. *Due to insufficient native stock in the early stages of the programme, some plants from Peninsular Malaysia were also introduced for planting only within urban areas.

Species	Country of origin	Year
Acriopsis liliifolia (J.Koenig) Ormerod	Singapore	2019
Bulbophyllum clandestinum Lindl.	Singapore	2013
Bulbophyllum membranaceum Teijsm. & Binn.	Singapore	1999
Bulbophyllum trigonopus (Rchb.f.) P.T.Ong	Singapore	2017
Bulbophyllum vaginatum (Lindl.) Rchb.f.	Singapore*	1999
Callostylis pulchella (Lindl.) S.C.Chen & Z.H.Tsi	Singapore	2017
Coelogyne rochussenii de Vriese	Singapore*	2009
Cymbidium bicolor Lindl. subsp. *pubescens* (Lindl.) Du Puy & P.J.Cribb	Singapore	2009
Cymbidium finlaysonianum Lindl.	Singapore*	1999
Dendrobium aloifolium (Blume) Rchb.f.	Singapore*	2011
Neuwiedia griffithii Rchb.f.	Singapore	2015
Pteroceras pallidum (Blume) Holttum	Singapore	2017
Renanthera elongata (Blume) Lindl.	Singapore*	2012
Robiquetia spathulata (Blume) J.J.Sm.	Singapore	2012
Thrixspermum amplexicaule (Blume) Rchb.f.	Singapore	2009
Vanilla griffithii Rchb.f.	Singapore	2015

orchid. Most of the Critically Endangered and Vulnerable species are in the nature reserves. Individuals of any of these species that are found outside of protected areas and which become threatened due to development activities are salvaged and relocated or used for further propagation. For example, *Liparis ferruginea* Lindl. was only known from a single locality in Tampines on a plot of land that was to be redeveloped. Seeds and mature plants were collected, seedlings were raised successfully from the collected seeds, and a reintroduction programme for the species into nature areas is ongoing.

The Orchid Conservation and Reintroduction Programme began in 1995 and includes the monitoring of extant species, the conservation of remaining germplasm so as to maximise genetic diversity, and the propagation of native species through the gathering of seed and other tissue in the wild to grow in controlled conditions in SBG's tissue culture laboratory and eventually reintroduce into the wild (Table 3). The propagation of plants in SBG greatly increases the number of individuals available for reintroductions into appropriate habitats, including onto roadside trees and in parks and nature areas (Yam, 2013).

There has also been a programme to reintroduce Nationally Extinct species back into Singapore from neighbouring countries, particularly from Peninsular Malaysia. To date, 24 orchid species that were originally native in Singapore have been reintroduced (Table 4). These orchids are being introduced into Singapore's streetscape, the parks and nature areas rather than into the nature reserves. It is hoped that these orchids will eventually form self-sustaining

Table 4. Reintroduction of 24 Nationally Extinct orchid species into Singapore and the year when they were first reintroduced.

Species	Country of origin	Year
Agrostophyllum majus Hook.f.	Peninsular Malaysia	2019
Agrostophyllum stipulatum (Griff.) Schltr. subsp. *bicuspidatum* (J.J.Sm.) Schuit.	Peninsular Malaysia	2019
Bulbophyllum gracillimum (Rolfe) Rolfe	Peninsular Malaysia	2016
Bulbophyllum maxillare (Lindl.) Rchb.f.	Peninsular Malaysia	1999
Bulbophyllum medusae (Lindl.) Rchb.f.	Peninsular Malaysia	2010
Bulbophyllum purpurascens Teijsm. & Binn.	Peninsular Malaysia	2011
Bulbophyllum restrepia (Ridl.) Ridl.	Peninsular Malaysia	2017
Cleisostoma scortechinii (Hook.f.) Garay	Peninsular Malaysia	2017
Cleisostoma subulatum Blume	Peninsular Malaysia	2017
Coelogyne mayeriana Rchb.f.	Peninsular Malaysia	2010
Dendrobium grande Hook.f.	Peninsular Malaysia	2013
Dendrobium hercoglossum Rchb.f.	Peninsular Malaysia	2018
Dendrobium indivisum (Blume) Miq.	Peninsular Malaysia	2017
Dendrobium leonis (Lindl.) Rchb.f.	Peninsular Malaysia	2010
Dendrobium pachyphyllum (Kuntze) Bakh.f.	Peninsular Malaysia	2015
Dendrobium pulchellum Roxb. ex Lindl.	Peninsular Malaysia	2019
Dendrobium secundum (Blume) Lindl.	Peninsular Malaysia	2017
Dendrobium singaporense A.D.Hawkes & A.H.Heller	Peninsular Malaysia	2016
Dendrochilum pallidiflavens Blume var. *pallidiflavens*	Peninsular Malaysia	2018
Eria javanica (Sw.) Blume	Peninsular Malaysia	2019
Grammatophyllum speciosum Blume	Peninsular Malaysia	1999
Phalaenopsis cornu-cervi (Breda) Blume & Rchb.f.	Peninsular Malaysia	2011
Pinalia bractescens (Lindl.) Kuntze	Peninsular Malaysia	2018
Rhynchostylis gigantea (Lindl.) Ridl.	Peninsular Malaysia	2019

populations and begin to spread on their own. As most of these species are epiphytes, one of the main challenges has been to select and plant species that require as little maintenance as possible by ensuring they are only planted in the correct microclimate so that they will thrive as well as any other epiphytes. In January and February of 2014, Singapore experienced one of its longest dry periods on record. During this period some intervention was taken to reduce the water stress of some reintroduced orchids but although the different species exhibited varying levels of damage, losses were remarkably small. It was found that the reintroduced epiphytic orchids did best on trees that already supported a large community of epiphytes, particularly of epiphytic fern species. These tend to be older trees and ones with rougher bark which is able to trap both water and humus.

We present here a selection of case studies from the orchid programme.

1. *Bulbophyllum membranaceum* Teijsm. & Binn.
Among the smallest of Singapore's native orchids, this species has very small flowers measuring about 6 mm in length. There is only a small natural population left in Singapore from which mature seed capsules were collected and seedlings raised in SBG. These seedlings were planted out on trees around Singapore and the survival rate has been high at more than 80%. Some re-introduced plants have flowered and formed seed capsules.

2. *Bulbophyllum trigonopus* (Rchb.f.) P.T.Ong
A Critically Endangered species, *Bulbophyllum trigonopus* (synonym: *Bulbophyllum pulchellum* Ridl.) was originally quite widespread in swampy areas of Singapore as an epiphyte on trees. Herbarium records show that it was known from Chan Chu Kang, Kranji, Seletar, Jurong and Mandai. In 1955, the species was collected by J. Sinclair on a 'road leading to Number 1 Rifle Range, in Nee Soon…as an epiphyte on *Knema malayana*' but was not seen again until 2010 in Nee Soon freshwater swamp forest. A few of these plants were collected and grown in the nursery of SBG's National Orchid Garden where they were bulked up from cuttings. Sibling crosses were also made between the different wild-collected genotypes. Fruits have been produced and seedlings from the seeds produced have been growing in the nursery for over two years. The species has been successfully reintroduced at Upper Peirce Reservoir, Bukit Timah Nature Reserve, Pasir Ris Park and Dairy Farm Nature Park. (Fig. 4).

3. *Cymbidium bicolor* Lindl. subsp. ***pubescens*** (Lindl.) Du Puy & P.J.Cribb
Once thought to have become extinct in Singapore, a single plant of *Cymbidium bicolor* subsp. *pubescens* was rediscovered in Sungei Buloh Wetland Reserve in 1999. Seeds were collected from this plant and seedlings propagated in SBG. The seedlings raised have been reintroduced successfully into parks and nature areas throughout Singapore. However, despite having been rediscovered in Sungei Buloh, the survival rate for seedlings in mangrove areas has been extremely low whereas seedlings grown in the more sheltered areas of the interior have fared much better. Some of these plants have flowered and produced seed capsules.

4. *Cymbidium finlaysonianum* Lindl.
Cymbidium finlaysonianum is a Critically Endangered species with small extant populations in Nee Soon freshwater swamp forest, Bukit Timah Nature Reserve and Pulau Pawai. To propagate the species, reciprocal crosses were made between two plants of native origin in SBG's nursery in 1998. Capsules were collected three months after pollination, the seeds planted and the seedlings grown in the laboratory before eventually being planted into pots until they were mature enough to be planted onto trees. From 2002, *Cymbidium finlaysonianum* has been planted on trees in SBG and later in Kent Ridge Park, Sembawang Park, Pulau Ubin, Woodland Town Garden, Telok Blangah Hill Park, Pulau Ubin, Pasir Ris Park and many other areas. The plants introduced to SBG began to flower 2 years after planting. Plants at Kent Ridge Park and Telok Blangah Hill Park both flowered in 2008. More than 90% of the plants are still alive and many of them have flowered and fruited. The formation of seed capsules indicates that the natural pollinators are present and spontaneous occurrence of seedlings has now been observed at Pasir Ris Park and on the roadside trees along East Coast Parkway.

Figure 4. *Bulbophyllum trigonopus* (Rchb.f.) P.T.Ong. Reintroduced from native stock, flowering at Upper Pierce Reservoir. (Photo: T.W. Yam).

5. *Grammatophyllum speciosum* Blume

Although Singapore is a small country, it is the home of the world's largest orchid species, *Grammatophyllum speciosum*, known as the tiger orchid in English. *Grammatophyllum speciosum* was last reported from the wild in Tuas and Pulau Ubin (Ridley, 1900a) but a large plant in SBG is likely of native stock. In late 1996, this plant flowered and was self-pollinated. The huge fruit was harvested 7 months later and plants were raised from seeds. As *Grammatophyllum speciosum* was known to have once been native on Pulau Ubin, the first batch of seedlings was reintroduced there in July 1999 when they were 26 months old and about 15–20 cm tall with 5–6 leaves. They were planted on trees of a number of different species. Seedlings were also planted on trees in the Botanic Gardens, around the Visitor Centre in the Bukit Timah Nature Reserve, and in the Orchard Boulevard area in the heart of the city (Yam, 2008). Over time, seedlings have also been introduced to many other areas around Singapore and as they are such large plants they have become a familiar sight on street trees and in the parks. The reintroduced orchids grow profusely, many have flowered and seed capsules have formed naturally. Spontaneous growth of new individuals has not yet been observed. (Fig. 5).

Figure 5. *Grammatophyllum speciosum* Blume. Flowering on a rain tree along Holland Road. (Photo: T.W. Yam).

Conservation of native gingers and other herbaceous monocots

The ginger order (Zingiberales) consists of eight plant families, of which three (Costaceae, Marantaceae and Zingiberaceae) are currently considered native to Singapore. About 26 species in these three families are native, of which 11 were listed as Nationally Extinct by Tan et al. (2008).

An informal programme on the conservation of native gingers began in 2006 and was formalised into an NParks' project in 2011. From 2012 the programme was widened to include other herbaceous monocot families, primarily the Hanguanaceae, Asparagaceae and Hypoxidaceae. Initial efforts focused on extensive surveys of forested areas to locate as many populations of surviving species as possible in order to understand distribution patterns and population sizes. In these surveys, most presumed Nationally Extinct species were rediscovered, leaving only three species still presumed to be Nationally Extinct (Niissalo et al., 2017). The surveys also led to the discovery of the new endemic species *Zingiber singapurense* Škorničk. (Leong-Škorničková et al., 2014) and new national records of *Phrynium hirtum* Ridl. (Niissalo et al., 2016) and *Etlingera maingayi* (Baker) R.M.Sm. Through analyses of historical records and distribution patterns, it was also concluded that several species previously recorded from Bukit Timah Nature Reserve and treated as native are in fact fairly recent introductions (see for example, Leong-Škorničková & Boyce, 2015; Niissalo et al., 2016). Detailed field and herbarium work on Hanguanaceae, previously thought to be represented by a single species in Singapore, resulted in the realisation that there are at least seven species in Singapore, of which five are native. Three of these species were described as new to science, two of which are endemic to Singapore, and the remaining two were new records for the country.

Almost all currently extant native species of gingers and of *Hanguana* Blume from multiple locations have been established in SBG for ex situ conservation and as stock plants for mass-propagation. Many native species are also exhibited in SBG, particularly in the Ginger Garden. Although a few species set seed regularly (e.g. *Alpinia aquatica* (Retz.) Roscoe, *Hornstedtia* Retz. species) and others are easy to propagate from cuttings or by division (Costaceae and some Marantaceae), several species are difficult to establish in ex situ cultivation. These are primarily the species which are known from only a single plant, or only very few, do not flower regularly, do not set seed, or are sensitive to transplanting. For several species, all attempts to establish them outside of their natural ranges have failed. Propagation by division when the available stock is very small is also extremely slow. Therefore, protocols have been optimised in SBG's tissue culture lab and some of the problematic species are being propagated using an in vitro approach (Fig. 6). However, hardening off of certain species is still proving to be an additional hurdle which requires further research (Fig. 7). Once these various protocols have been perfected, the keeping of such cultures over the long-term should ensure the availability of material if anything happen to the very few remaining individuals in the field. Many native herbaceous monocot species, including all *Hanguana* species, grow only in the remaining primary forest, often near streams and in places with higher humidity. Consequently, the availability of suitable habitats for these species to be reintroduced is very limited. However, some of the species which have been found to do well in cultivation have already been made available to the public.

Figure 6. Tissue culture lab at Singapore Botanic Gardens. **A.** Singapore Botanic Gardens' staff examining tissue cultures of native gingers. **B.** Plantlet of *Zingiber singapurense* Škorničk. **C.** Plantlet of *Hanguana podzolicola* Siti Nurfazilah et al. (Photos: J. Leong-Škorničková).

Figure 7. Tissue cultured plantlets of *Globba leucantha* Miq. being repotted by Singapore Botanic Gardens' staff after hardening off. (Photo: A.Thame)

We present here a selection of case studies of species that have also been included in the Species Recovery Programme.

1. *Cheilocostus globosus* (Blume) C.D.Specht (Costaceae)
This species was presumed Nationally Extinct until 2012 when two populations were rediscovered in Bukit Timah Nature Reserve. Although seed-set has not been observed, the species propagates extremely well from stem cuttings. It has been mass-propagated and successfully re-introduced into various reserves as well as into nature and public parks. Trials to also introduce this species along the Tengah Nature Way have proven successful. Due to the ease of mass-propagation and its tolerance of a range of habitats, this attractive clump-forming species could be employed more widely in Singapore and replace some of the non-native Costaceae species, especially those which are potentially invasive. (Fig. 8).

2. *Hornstedtia conica* Ridl. (Zingiberaceae)
This species is locally rare and there have been recent losses of mature individuals in the Dairy Farm Nature Park and the Bukit Timah Nature Reserve. It flowers and produces fruit regularly although the collection of ripe seeds has been difficult due to foraging by macaques, squirrels and other rodents, as captured on camera traps. This has been overcome by installing aluminium, steel or plastic protective netting around the ripening infructescences. The species has been propagated in SBG and the gardens of the Istana since 2012 and has recently been introduced into a number of Nature Parks and Nature Reserves. (Fig. 9).

Figure 8. *Cheilocostus globosus* (Blume) C.D.Specht. **A.** Habit in Bukit Timah Nature Reserve. **B.** Stem with branches; each branch can be easily propagated into a new individual. **C.** Flower (front view). **D.** Inflorescence. **E.** Plants successfully growing along Tengah Nature Way. (Photos: A–D, J. Leong-Škorničková; E, A. Thame)

Figure 9. *Hornstedtia conica* Ridl. **A.** Aluminium and plastic protective netting installed over ripening infructescences. **B.** Inflorescence. **C.** Fully ripe infructescences. **D.** Ripe fruits and seeds. **E.** Plants successfully growing along Tengah Nature Way. (Photos: A–D, J. Leong-Škorničková; E, A.Thame)

3. *Zingiber singapurense* Škorničk. (Zingiberaceae)
This small and iconic ginger species is endemic to Singapore. Genomic studies have revealed the existence of only 13 distinct genotypes with no evidence of any recent gene flow (see Research section above). The species flowers regularly, but fruit set has so far not been observed. The species is unusual in the Zingiberaceae in that it produces live plantlets on the old stems from which it can propagate vegetatively at a faster rate than from division of the rhizomes. In vitro cultures have been established in the SBG tissue culture lab and several hundred individuals have been propagated and hardened off. The species has potential in local horticulture and was made available to the public at NParks' events for the first time in 2019.

4. *Sundamomum hastilabium* (Ridl.) A.D.Poulsen & M.F.Newman (Zingiberaceae)
Once presumed to be Nationally Extinct, this species was rediscovered in 2012 in Bukit Timah Nature Reserve as a single clump consisting of three individuals, all badly damaged by squirrels. A few small off-shoots were carefully harvested and established in SBG and from these plants over 50 individuals have been propagated to date. No flowering and seed-set has been observed in either the natural or cultivated plants so far. Although this species is common across Peninsular Malaysia and extends into Sumatra, its great morphological variability across this range could suggest a complex of several cryptic species with narrower distribution ranges. It is, therefore, especially important to preserve the morphotype that occurs in Singapore.

5. *Hanguana neglecta* Škorničk. & Niissalo (Hanguanaceae)
Hanguana neglecta is the smallest of the native *Hanguana* species in Singapore and is locally rare. The initial stock was established from seeds and seedlings collected at the type locality in Bukit Timah Nature Reserve and the plants in SBG have fruited repeatedly since 2016. The species is easy to grow and suitable for shady areas in the Nature Parks, having been introduced, for example, into Yishun Park. The leaves with their finely checkered and velvety surfaces and the long-lasting sprays of black fruits makes this species suitable for horticultural use. (Fig. 10)

6. *Hanguana triangulata* Škorničk. & P.C.Boyce (Hanguanaceae)
Endemic to Singapore, this species has proven to be one of the most difficult species to conserve. There are only a few individuals left in the wild which has precluded any harvesting of the native stock. It is also very slow growing, producing only 1–2 leaves per year, and flowers irregularly with only one flowering event, in 2018, having been observed since 2015. Plants raised from the seeds produced have had a very low survival rate and it is estimated that it may take 5–10 years before the surviving plants reach maturity.

Other reintroductions

There have been a number of efforts to reintroduce plant species into Singapore which have become Nationally Extinct. To date, these reintroduction efforts have been primarily into Singapore's urban landscape rather than back into natural habitats, primarily through the Orchid Conservation and Reintroduction Programme (Yam, 1992; Yam & Thame, 2005;

Figure 10. *Hanguana neglecta* Škorničk. & Niissalo. **A.** Habit in its natural habitat in Bukit Timah Nature Reserve. **B.** Public planting of *Hanguana neglecta* and other native species in Yishun Park during the Bioblitz in May 2018. (Photo: J. Leong-Škorničková)

Yam et al., 2011). In addition, a number of other species have been reintroduced for their particular horticultural appeal. These efforts began in the 1990s, with the intention of restoring some of Singapore's lost natural heritage and to beautify Singapore's parks and streetscapes with species that are or were native. Species are selected based on availability of plant materials from neighbouring countries, their charismatic appeal, ease of cultivation, and other horticultural qualities such as being free flowering (Yam, 2013). Non-orchid examples include *Cyrtostachys renda* Blume (Loo et al., 2014; Loo et al., 2015), *Leea rubra* Blume ex Spreng. (Lok et al., 2011), *Syzygium myrtifolium* Walp. (Wong, 2015), *Hernandia nymphaeifolia* (C.Presl) Kubitzki (Keng, 1990), *Kleinhovia hospita* L. (Keng, 1990), *Macaranga caladiifolia* Becc., *Pteleocarpa lamponga* (Miq.) Bakh. ex K.Heyne and *Ochrosia oppositifolia* (Lam.) K.Schum. (Toh, 2017). There are also Nationally Extinct plant species that are commercially available from nurseries and specialist growers that are collected and grown by enthusiasts such as *Myrmecodia tuberosa* Jack (Lok & Tan, 2009), *Phlegmariurus squarrosus* (G.Forst.) Á.Löve & D.Löve and *Platycerium ridleyi* Christ.

Singapore Botanic Gardens Seed Bank

In July 2019, Singapore Botanic Gardens opened a new Seed Bank to conserve seed collections from Singapore and the surrounding region. Eventually the Seed Bank will be able to conserve a much greater proportion of the plant diversity of Singapore than at present by being able to 'bank' more of each species' genetic diversity than is feasible in ex situ living collections. These seed bank collections will be available for restoration projects if natural populations decline or suffer a catastrophic event. A limitation, however, is that a high percentage of species in everwet tropical countries, including Singapore, have recalcitrant seeds. These are seeds that do not survive the reduction in moisture content necessary to enable seeds to be frozen. Although there are algorithms to predict the success rate for species, i.e. to assess which species have orthodox seeds that can be dried and banked, very little research has yet been done on these species in the region. Although in its infancy, the Seed Bank has the potential to become a centre of research on seed biology and the optimum techniques for storing the seeds of tropical species, including techniques for conservation of germplasm from species with recalcitrant seeds.