2. TAXONOMIC OVERVIEW OF THE PLANTS OF SINGAPORE

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The *Flora of Singapore* will be published in 14 volumes with the taxonomic accounts systematically arranged in volumes 2–14 and the introductory chapters in volume 1. The account of each family is pre-assigned to a volume and each volume will be printed when all of the content intended for the volume is ready. The taxonomic hierarchy used, the assignment of families to orders, and the order of presentation of families follows Frey & Stech (2009) for bryophytes, PPG I (2016) for lycophytes and ferns, Christenhusz et al. (2011) for gymnosperms, and APG IV (2016) for angiosperms, each modified with minor updates from more recent studies when appropriate.

Traditionally, liverworts, mosses and hornworts were regarded as classes within a single plant division under Bryophyta sensu lato, i.e. Marchantiopsida/Hepaticae, Bryopsida/Musci and Anthocerotopsida/Anthocerotae, respectively. However, their interrelationships have long been a subject of debate and controversy among plant systematists (see review in Goffinet, 2000). Despite the availability of large genome-level studies from advances in sequencing technology, the phylogenetic relationships among the three bryophyte groups remain largely unresolved although there are two better-supported hypotheses (Cox, 2018). Nonetheless, the monophylies of each group are better established. As generally accepted today, the bryophytes for the *Flora of Singapore* will be treated as three separate divisions, namely Marchantiophyta, Bryophyta sensu stricto and Anthocerotophyta.

The classifications within each of the three bryophyte divisions have undergone constant modification and adjustment, particularly in light of modern molecular phylogenetic systematics (Crandall-Stotler et al., 2009a,b; Goffinet et al., 2009; Renzaglia et al., 2009; Vilnet et al., 2009). The arrangement of bryophyte taxa for the *Flora of Singapore* follows the framework proposed by Crandall-Stotler et al. (2009a) for liverworts, Goffinet et al. (2009) for mosses and Renzaglia et al. (2009) for hornworts, with minor updates from more recent studies. Worldwide there are 32 orders of liverworts and 89 families, of which 5 orders and 20 families are in Singapore. Worldwide there are 35 orders of mosses and 120 families, of which 10 orders and 23 families are in Singapore. Worldwide there are 5 orders of hornworts and 6 families, of which 2 orders and 2 families are in Singapore.

With approximately 13,000 species (Crosby et al., 1999), mosses are the largest group of bryophytes and second only to the angiosperms amongst the embryophytes (Goffinet et al., 2009). Hornworts are the smallest group of bryophytes with about 220 species (Villarreal et al., 2015; Söderström et al., 2016). There are an estimated 7500 species of liverworts (von Konrat et al., 2010; Söderström et al., 2016). Pending a full revision of the species in all three divisions of bryophytes in Singapore, the current estimates of the number of taxa are in Chapter 1, Table 1. They will be treated in volume 2 of the *Flora of Singapore*.

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The ferns and lycophytes have traditionally been treated together under the general term of pteridophytes, or have been referred to as the 'ferns and fern allies'. These terms have fallen out of favour as the ferns and lycophytes do not form a monophyletic group (see Smith et al., 2006 for a summary). Instead, it is now widely agreed that the ferns are sister to the gymnosperms + angiosperms and that all three groups together are sister to the lycophytes. The Psilotaceae and Equisetaceae, previously recognised as evolutionary lineages distinct from the lycophytes and ferns, are now included within the eusporangiate ferns. Beyond this generally agreed framework, however, there has been considerable debate about the delimitation of orders, families and genera within the pteridophytes, particularly within the ferns, often despite a degree of consensus on the major phylogenetic lineages.

In Southeast Asia, the classification of ferns has generally followed systems proposed by Copeland (1947), Holttum (1947) and Pichi Sermolli (1977) although different authors have often had widely differing generic delimitations. Compare, for example, the generic concepts within the Thelypteridaceae by Holttum (1981) and Tagawa & Iwatsuki (1988) where Holttum recognises 22 genera but Tagawa & Iwatsuki recognise only two genera.

In recent years there have been a number of new systems for the orders and families of ferns, particularly to incorporate the findings of molecular phylogenetic data. Smith et al. (2006) was the first major new classification system in this era which aimed to reflect the phylogeny of the ferns whilst maintaining as much stability in the names being used as possible. The classification system proposed by Christenhusz & Chase (2014), based on more or less the same overall phylogeny available to Smith et al. (2006), was a radical departure from existing classification systems for ferns and was consequently largely dismissed. The system to be adopted in the *Flora of Singapore* will follow that proposed in PPG I (2016), which largely returns to the system of Smith et al. (2006) but with the addition of the lycophytes and with a generic delimitation system based on the then best available evidence. The authors of PPG I (2016) note that they do not consider the system to be the last word on the matter and generic delimitations in particular are likely to change as more evidence becomes available. The system has already been the subject of criticism (Christenhusz & Chase, 2018), particularly for the large number of genera recognised in some fern families and in the Lycopodiaceae. The converse, however, is true for Davalliaceae and Dryopteridaceae where fewer genera are recognised in PPG I compared to other treatments. PPG I does, however, provide a standard and relatively stable framework for a project such as the *Flora of Singapore* where the focus is not on examining higher level relationships. It shall, therefore, be adopted for both family and genus delimitation except when contrary and compelling new evidence becomes available. Although PPG I (2016) does not present a linear sequence as formally as APG IV (2016) does for the angiosperms, the *Flora of Singapore* will nevertheless adopt the family numbering system used by PPG I as the linear sequence for presentation of the families. In PPG I, the ferns and lycophytes are formally referred to the classes Polypodiopsida and Lycopodiopsida respectively.

Of the 3 orders and 3 families of lycophytes listed in PPG I (2016), 2 orders and 2 families are in Singapore. Of the 11 orders and 48 families of ferns listed in PPG I (2016), 9 orders and 23 families are in Singapore, one of which is only represented by naturalised or casual species. Pending a full revision of the species of lycophytes and ferns in Singapore, the current estimates of the number of taxa are in Chapter 1, Table 1. They will be treated in volume 3 of the *Flora of Singapore*.

In contrast to the ferns and lycophytes, higher level classification of the gymnosperms is fairly uncontroversial. The *Flora of Singapore* will follow the system proposed by Christenhusz et al. (2011) which is largely unchanged from earlier traditional classification systems. There are only 8 species of gymnosperms in 3 families in Singapore.

The large majority of the plant species in Singapore are angiosperms. As noted for the bryophytes and pteridophytes above, angiosperm classification has been revolutionised through the incorporation of molecular phylogenetic data which has led to a series of papers by the Angiosperm Phylogeny Group progressively clarifying order and family delimitation (APG, 1998; APG II, 2003; APG III, 2009; APG IV, 2016). In these systems, the previous principal split into the monocotyledons and dicotyledons is dispensed with in favour of recognising a series of clades, culminating with the major orders and then families. In the form the phylogenetic tree is usually presented, the so-called basal dicots form a grade which is sister to the monocots plus the rest of the dicots. These non-basal dicots are referred to as the eudicots. The bulk of the eudicots are split between the Rosids and the Asterids, although there are many orders that do not belong to either major group. Altogether, APG IV (2016) recognises 64 orders and 416 families of which 46 orders and 186 families are present in Singapore, including 21 families known only from introduced species. APG IV also presents all families in a linear sequence which will be the sequence in which they will be presented in the *Flora of Singapore*. Pending a full revision of the species of gymnosperms and angiosperms in Singapore, the current estimates of the number of taxa are in Chapter 1, Table 1.

Due to the markedly different sizes of the major clades, orders and families for angiosperms, and the practicalities of assigning families to volumes to maintain a similar size for each volume, the volume contents cut across the major clades, particularly the Rosids and Asterids. The volumes will not, however, split up any orders (listed in bold below). Those families known in Singapore only from naturalised or casual species are marked with an asterisk*. It is possible that further collecting and research may uncover additional families not included here. It is also possible that further research on the families listed here as only known from introduced species will result in their exclusion from the *Flora of Singapore* if no evidence is found that they are casual or naturalising despite claims in previous literature that they were. There are a number of families where it is not yet certain if any of the species are native and it is hoped that the research undertaken for the *Flora of Singapore* will clarify their status. It is, however, quite possible that the native status of some species and, consequently, some families will remain forever uncertain. These are not marked with an asterisk below. The content of each volume will be thus.

Volume 2

This volume will include all families of liverworts, mosses and hornworts, specifically:

MARCHANTIOPHYTA (LIVERWORTS)

Marchantiales
Marchantiaceae, Cyathodiaceae, Ricciaceae, Wiesnerellaceae
Pallaviciniales
Pallaviciniaceae

Metzgeriales
Aneuraceae
Porellales
Radulaceae, Frullaniaceae, Lejeuneaceae
Jungermanniales
Schistochilaceae, Pseudolepicoleaceae, Trichocoleaceae, Lepidoziaceae, Lophocoleaceae, Plagiochilaceae, Adelanthaceae, Cephaloziellaceae, Jackiellaceae, Calypogeiaceae, Solenostomataceae

BRYOPHYTA (MOSSES):
Diphysciales
Diphysciaceae
Dicranales
Fissidentaceae, Ditrichaceae, Dicranaceae, Leucobryaceae, Calymperaceae
Pottiales
Pottiaceae
Bryales
Bryaceae, Mniaceae
Bartramiales
Bartramiaceae
Orthotrichales
Orthotrichaceae
Rhizogoniales
Rhizogoniaceae
Hypnodendrales
Hypnodendraceae
Hookeriales
Hypopterygiaceae, Daltoniaceae, Pilotrichaceae
Hypnales
Leskeaceae, Thuidiaceae, Hypnaceae, Pylaisiadelphaceae, Sematophyllaceae, Neckeraceae, Myuriaceae

ANTHOCEROTOPHYTA (HORNWORTS):
Anthocerotales
Anthocerotaceae
Notothyladales
Notothyladaceae

Volume 3

This volume will include all families of lycophytes and ferns, specifically:

LYCOPODIOPSIDA (CLUBMOSSES & SPIKEMOSSES):
Lycopodiales
Lycopodiaceae

Selaginellales
Selaginellaceae

POLYPODIOPSIDA (FERNS):
Psilotales
Psilotaceae
Ophioglossales
Ophioglossaceae
Marattiales
Marattiaceae
Hymenophyllales
Hymenophyllaceae
Gleicheniales
Dipteridaceae, Gleicheniaceae
Schizaeales
Lygodiaceae, Schizaeaceae
Salviniales
Salviniaceae*
Cyatheales
Cyatheaceae
Polypodiales
Lindsaeaceae, Pteridaceae, Dennstaedtiaceae, Aspleniaceae, Blechnaceae, Athyriaceae, Thelypteridaceae, Dryopteridaceae, Nephrolepidaceae, Lomariopsidaceae, Tectariaceae, Davalliaceae, Polypodiaceae,

Volume 4

This volume will include the gymnosperms and the basal angiosperms. The basal angiosperms in this volume include a particularly large number of trees found in the forest understorey in families such as Annonaceae and Lauraceae. There are many economically and locally important medicinal and culinary species in Lauraceae, Myristicaceae, Piperaceae and Schisandraceae. The volume will include:

Cycadales
Cycadaceae
Gnetales
Gnetaceae
Cupressales
Podocarpaceae
Nymphaeales
Nymphaeaceae
Austrobaileyales
Schisandraceae
Piperales
Piperaceae, Aristolochiaceae

Magnoliales
Myristicaceae, Magnoliaceae, Annonaceae
Laurales
Hernandiaceae, Monimiaceae, Lauraceae
Chloranthales
Chloranthaceae

Volume 5

This volume will include the monocot order Asparagales. Several of the families in this order, particularly the Orchidaceae, are of economic value, primarily in the horticultural trade. This volume will also undoubtedly contain the largest number of species that have become Nationally Extinct or are the focus of concerted conservation action. The volume will include:

Asparagales
Orchidaceae, Hypoxidaceae, Iridaceae*, Asphodelaceae, Amaryllidaceae, Asparagaceae

Volume 6

This volume will include a number of monocot orders that come both before and after the Asparagales in the linear sequence proposed by APG IV (2016). This is for purely practical reasons to ensure that the three volumes containing the monocots will all be of roughly equal size. The Asparagales and Poales are both large and can each fill their own volume, leaving volume 6 to contain all other monocot orders. The families in Volume 6 include many economically important species, particularly in the Arecaceae and Zingiberaceae. The sea grasses are in the Alismatales. The volume will include:

Alismatales
Araceae, Alismataceae*, Hydrocharitaceae, Cymodoceaceae
Dioscoreales
Burmanniaceae, Dioscoreaceae,
Pandanales
Triuridaceae, Stemonaceae, Pandanaceae
Liliales
Colchicaceae*, Smilacaceae
Arecales
Arecaceae
Commelinales
Hanguanaceae, Commelinaceae, Philydraceae, Pontederiaceae
Zingiberales
Heliconiaceae*, Musaceae, Cannaceae*, Marantaceae, Costaceae, Zingiberaceae

Volume 7

This volume will include the monocot order Poales. Two of the families, Typhaceae and Mayacaceae, are known only from naturalised exotic species, three native families are very small, and the remaining two families, Cyperaceae and Poaceae, are very large. The Poaceae is the world's most economically important plant family. Specifically, the volume will include:

Poales
Typhaceae*, Xyridaceae, Eriocaulaceae, Mayacaceae*, Cyperaceae, Flagellariaceae, Poaceae

Volume 8

From volume 8 onwards, the volumes do not well reflect the major clades of angiosperm phylogeny, except those that include only a single order (i.e. Volume 10 – the Malpighiales and Volume 13 – the Gentianales), due to a desire to keep the volumes of approximately equal size. This volume will include a number of orders that form a grade to the clade that includes both the Superrosids and Superasterids, plus the Dilleniales and some families of Rosids (see APG IV, 2016). The Fabaceae are the world's second most economically important plant family, containing very many edible species as well as species of widespread use in agriculture for fodder and soil improvement. Many are also important timber species, including several species that are now threatened due to over-exploitation. Vitaceae are also economically important, primarily due to grapes and the wine industry. Specifically, the volume will include:

Ranunculales
Menispermaceae
Proteales
Sabiaceae, Proteaceae
Dilleniales
Dilleniaceae
Saxifragales
Daphniphyllaceae, Crassulaceae*, Haloragaceae
Vitales
Vitaceae
Fabales
Fabaceae, Polygalaceae

Volume 9

This volume will include all of the so-called Fabid orders (see APG IV, 2016) within the Rosid clade except for the Fabaceae which will be in Volume 8. This includes a number of economically important families such as the Rosaceae with its many fruit species in temperate

regions, Moraceae, which is the source of figs and jackfruit, Juglandaceae, which is the source of walnuts and pecans in temperate regions, and Cucurbitaceae, which includes a wide range of edible squash and melon species. Specifically, the volume will include:

Rosales
Rosaceae, Rhamnaceae, Cannabaceae, Moraceae, Urticaceae
Fagales
Fagaceae, Myricaceae, Juglandaceae, Casuarinaceae
Cucurbitales
Anisophyllaceae, Cucurbitaceae
Celastrales
Celastraceae
Oxalidales
Connaraceae, Oxalidaceae, Elaeocarpaceae

Volume 10

This volume will include the Malpighiales which is the largest order in Singapore with respect to number of families and the second largest order of dicots in number of species in Singapore, after the Gentianales. The order includes mostly tree species which range from the understorey to large canopy trees in families such as the Chrysobalanaceae. The Rhizophoraceae has a number of mangrove species. At least in Singapore, the Passifloraceae and Linaceae are climbers. Most of the families in this order in Singapore are of limited economic importance, except for their role in the maintenance of ecosystem services (e.g. mangroves for coastal protection and seafood hatcheries), and limited provision of timber resources and fruits. Specifically, the volume will include:

Malpighiales
Pandaceae, Irvingiaceae, Ctenolophonaceae, Rhizophoraceae, Erythroxylaceae, Ochnaceae, Bonnetiaceae, Clusiaceae, Calophyllaceae, Hypericaceae, Putranjavaceae, Centroplacaceae, Malpighiaceae, Trigoniaceae, Dichapetalaceae, Chrysobalanaceae, Achariaceae, Violaceae, Passifloraceae, Salicaceae, Peraceae, Euphorbiaceae, Phyllanthaceae, Linaceae, Ixonanthaceae, Picrodendraceae

Volume 11

This volume will include a number of so-called Malvid orders (see APG IV, 2016) within the Rosid clade. These include some of the most economically important fruit species in Singapore, including mangoes, rambutans, oranges and limes. Specifically, the volume will include:

Myrtales
Combretaceae, Lythraceae, Onagraceae, Myrtaceae, Melastomataceae, Crypteroniaceae

Crossosomatales
Staphyleaceae
Sapindales
Burseraceae, Anacardiaceae, Sapindaceae, Rutaceae, Simaroubaceae, Meliaceae

Volume 12

This volume will include the remaining Rosid orders (see APG IV, 2016) plus the grade of orders at the base of the Superasterids and the true Asterid orders Cornales and Ericales. It is currently uncertain whether any of the species in Singapore of Polygonaceae, Nyctaginaceae and Molluginaceae are actually native. The families in this volume include the Dipterocarpaceae which dominate the structure of most Southeast Asian forests and are of enormous economic value. This value has also, of course, led to severe deforestation across much of Southeast Asia, including Singapore. This volume also includes the economically important family Brassicaceae, the source of cabbage and its innumerable different forms, and other edible species. Sapotaceae is also an economically important timber tree family as well as the source of gutta percha. Specifically, the volume will include:

Malvales
Muntingiaceae*, Malvaceae, Thymelaeaceae, Dipterocarpaceae
Brassicales
Caricaceae*, Capparaceae, Cleomaceae*, Brassicaceae*
Santalales
Olacaceae, Opiliaceae, Santalaceae, Loranthaceae
Caryophyllales
Plumbaginaceae*, Polygonaceae, Nepenthaceae, Ancistrocladaceae, Caryophyllaceae*, Amaranthaceae, Aizoaceae, Phytolaccaceae*, Petiveriaceae*, Nyctaginaceae, Molluginaceae, Talinaceae*, Portulacaceae, Cactaceae*
Cornales
Nyssaceae, Cornaceae
Ericales
Balsaminaceae*, Lecythidaceae, Pentaphylacaceae, Sapotaceae, Ebenaceae, Primulaceae, Theaceae, Symplocaceae, Styracaceae, Actinidiaceae, Ericaceae

Volume 13

This volume will have only the large order Gentianales which includes the Rubiaceae with a particularly large number of understorey shrubs and trees in Singapore. It also contains the Gentianaceae and Apocynaceae, also with many understorey shrubs and trees, the latter also with a number of emergent trees and large forest lianas. The Rubiaceae is economically important for the coffee trade and as the source of quinine but in Singapore is most important in the horticultural trade. The Loganiaceae and Apocynaceae also have many horticulturally

important species. The Apocynaceae is well-known for its many medicinal plants. Specifically, the volume will include:

Gentianales
Rubiaceae, Gentianaceae, Loganiaceae, Gelsemiaceae, Apocynaceae

Volume 14

This volume will include all remaining Asterid orders. The families do have many tree species but is perhaps most notable for the large number of herbaceous species, particularly in the Solanales, Lamiales and Asterales. The volume includes economically important families such as the Solanaceae, which includes edible species such as tomatoes, chillies, potatoes and aubergines, as well as many species with medicinal uses. The Lamiaceae is well-known for including species used as herbs such as mint, basil, thyme, rosemary and sage. Specifically, the volume will include:

Icacinales
Icacinaceae
Boraginales
Boraginaceae
Solanales
Convolvulaceae, Solanaceae, Hydroleaceae
Lamiales
Oleaceae, Gesneriaceae, Plantaginaceae, Scrophulariaceae*, Linderniaceae, Pedaliaceae*, Acanthaceae, Bignoniaceae, Lentibulariaceae, Verbenaceae, Lamiaceae, Mazaceae, Orobanchaceae
Aquifoliales
Stemonuraceae, Cardiopteridaceae, Aquifoliaceae
Asterales
Campanulaceae, Pentaphragmataceae, Menyanthaceae, Goodeniaceae, Asteraceae
Escalloniales
Escalloniaceae
Dipsacales
Adoxaceae
Apiales
Torricelliaceae, Pittosporaceae, Araliaceae, Apiaceae