Rain Forest in the City: Bukit Timah Nature Reserve Singapore

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Chapter 1

Introduction

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Bukit Timah Nature Reserve consists of 81 hectares, mostly covered in forest, on the slopes and summit of Singapore's highest hill, Bukit Timah (162.5m) (figs. 1 & 2; fig. 1, chap. 11). This small reserve supports an incredible diversity of plants and animals which cannot survive outside the forest, yet it is only 8 kilometres from the city centre and a few minutes' walk from several crowded shopping arcades. It is visited daily by hundreds of people - walkers, joggers, nature lovers, school groups and tourists. It provides a research area for many Singapore-based and visiting scientists, and has featured in numerous scientific publications: Bukit Timah may well be the best studied forest area in Southeast Asia. It is also probably the oldest rain forest reserve in the region, if not the world.

Bukit Timah Nature Reserve is an island on an island. The forest on Bukit Timah hill has been isolated from other forest areas since at least 1860, if not considerably earlier. Today it is surrounded by roads, buildings, ex-quarries, and other open areas, and cut off from the more extensive, mostly secondary, forest in the Central Catchment Nature Reserve to the east by the 8-lane Bukit Timah Expressway (fig.1, chap. 11). Access to the Reserve is along Hindhede Drive, at the end of which is a car park and the excellent new Visitor Centre. (fig.2). A metalled road serves the Telecoms Tower and the summit within the Reserve but is closed to private vehicles. A network of well-marked footpaths penetrates the forest and there are huts for rest and shelters at various points.

For Singaporeans, Bukit Timah Nature Reserve is a public park with a difference. In place of close-mown grass with neatly-arranged trees and shrubs, there is the full exuberance of untamed tropical nature. Bright sun is replaced by cool shade, the hum of traffic is almost obscured by the sounds of unseen insects and birds. Many people come just to climb Singapore's highest hill but, for an increasing number, it is the forest and its inhabitants which are the main attraction. School trips, extensive media coverage, and the efforts of the Nature Society (Singapore) have served to raise Singaporeans' awareness of nature to an extent which is probably unique in an Asian city.

For Singapore, Bukit Timah is also an historical monument: a substantial and accessible remnant of the forest which covered the whole island less than two centuries ago. Unlike many older capitals, Singapore has no great old buildings

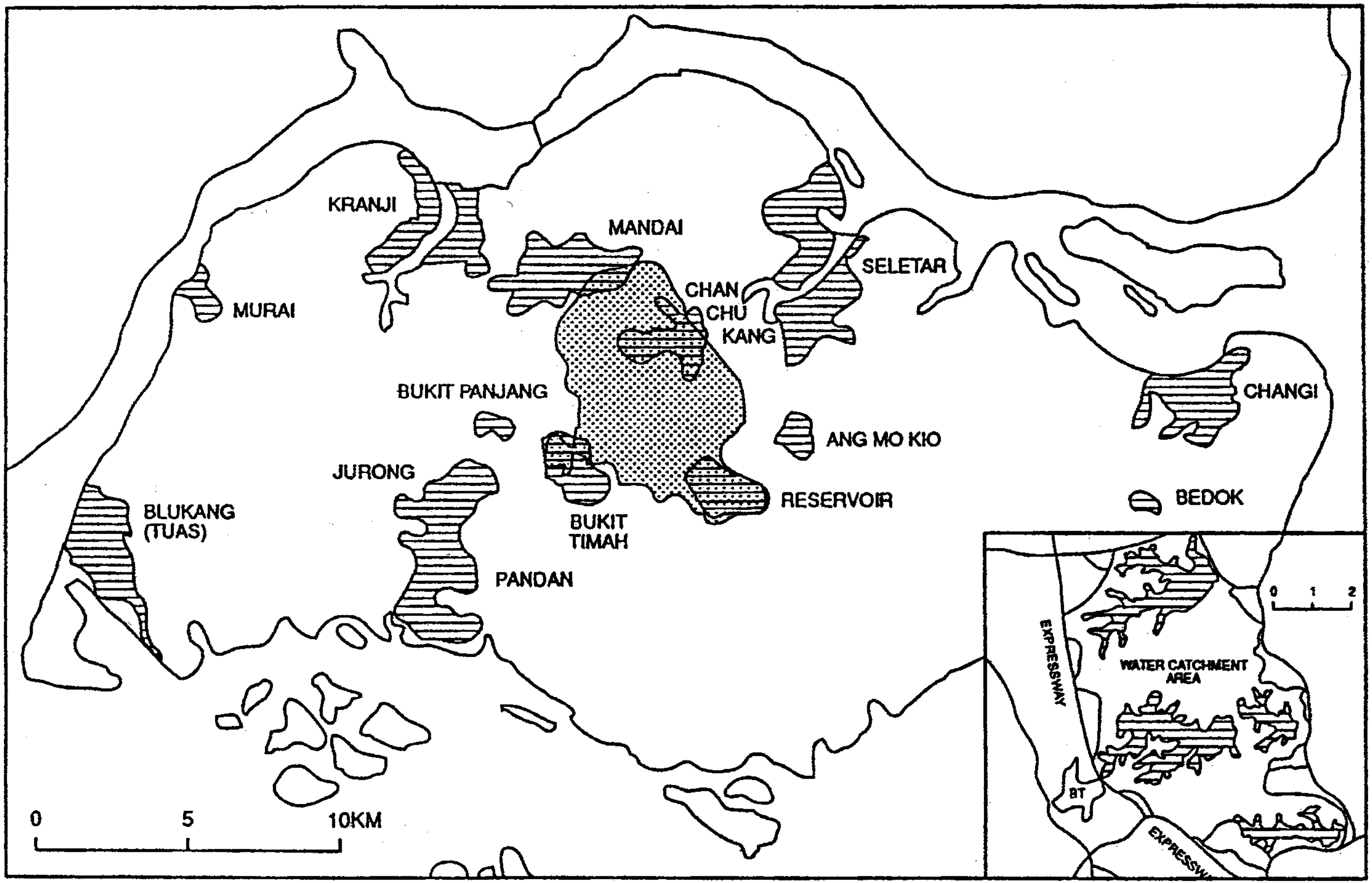


Figure 1. Map of Singapore showing Forest Reserves in 1897 (hatched) and Nature Reserves in 1994 (dotted). Inset map of the central part of the island showing the water catchment area and Bukit Timah Nature Reserve (BT).

or spectacular ruins, but what other city can boast a fragment of history as old and complex as the rain forest on Bukit Timah?

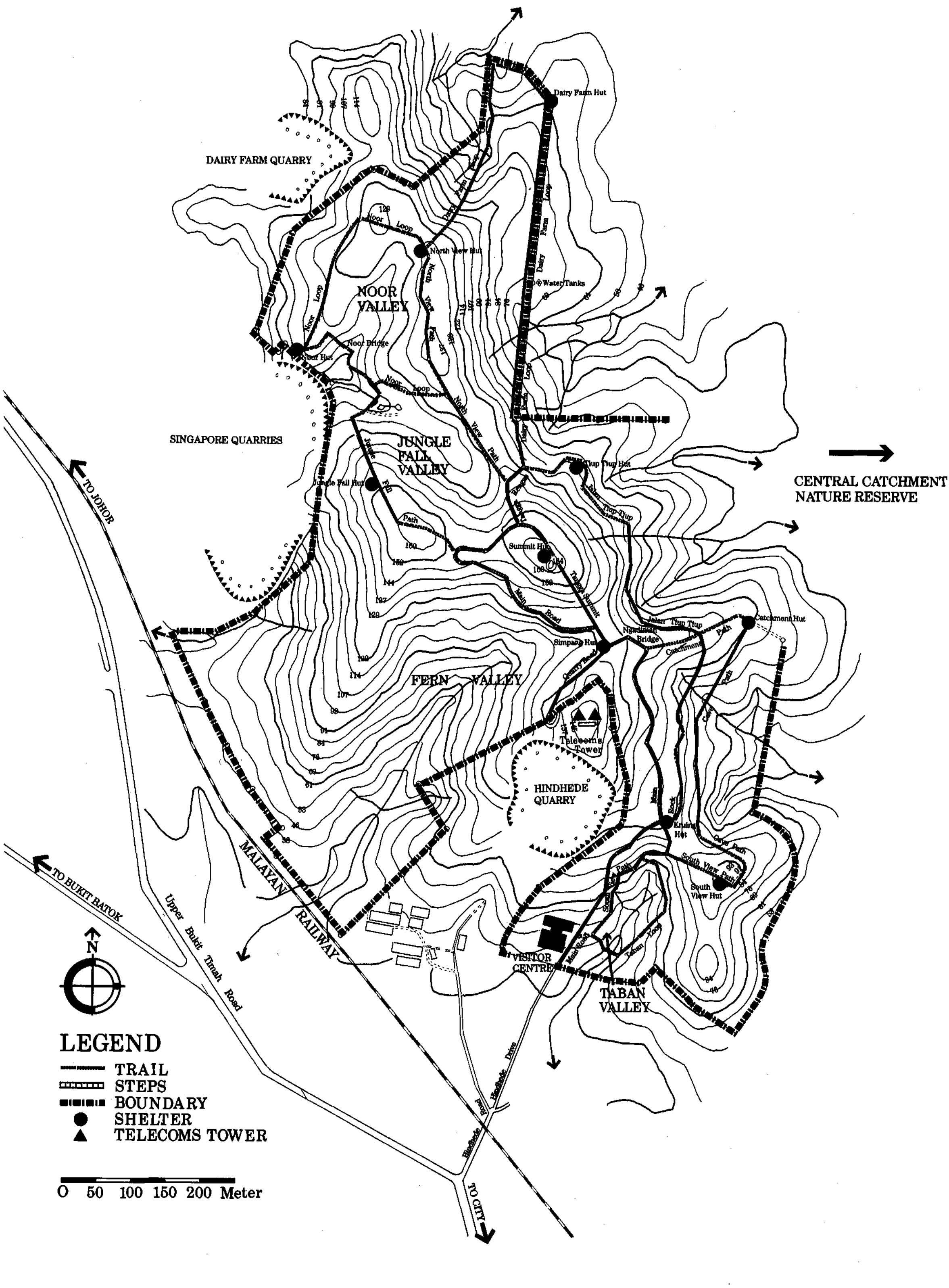
As this volume shows, Bukit Timah is a major research site for local scientists and for foreign researchers working in Singapore. Research at Bukit Timah is not just of local importance. For research projects which do not require the presence of the complete original rain forest biota, Bukit Timah offers an unrivalled proximity of primary dipterocarp forest and laboratory facilities equiped to the highest international standards. This permits studies requiring frequent monitoring or delicate equipment which would be difficult or impossible at more remote locations.

Perhaps the most important international role that Bukit Timah plays, however, is as an experiment - unplanned and incompletely documented - on the effects of fragmentation and isolation on a species-rich rain forest biota. Studies of extinction at Bukit Timah are hampered, however, by the variable quality of nineteenth century records and a major role of this volume is to act as a new "base line" against which future changes can be measured. The worldwide acceleration of tropical deforestation over the past decades has made an understanding of species survival in the forest fragments which remain an urgent task.

Nature recreation, education, and research, however important, are not the primary functions of a nature reserve. Bukit Timah Nature Reserve is, first and foremost, a store of biodiversity for future generations. We do not know the total number of species the reserve supports since many groups of organisms, including most of the invertebrates, are virtually unstudied, but the diversity of plants alone (chap. 3-7) justifies the reserve status. Bukit Timah has few known endemic species (species found nowhere else) but this number may rise as more invertebrates groups are studied in detail. Sadly, the number of endemic species will probably also rise as the increasing deforestation of southern Malaysia reduces the ranges of forest specialists. Morever, for plant and animal species with wide geographical ranges, Bukit Timah is often at the southern limit of distribution, so the local populations are likely to be genetically distinct from populations of the same species to the north.

The organisation of this volume is straightforward. After an account of the history of the reserve (chap. 2), there are separate chapters on those major groups for which we could find authors: in practice, the plants and the vertebrates. The flowering plants (Angiosperms: chap. 3), with at least 840 species, are the largest plant group at Bukit Timah. The ferns and their allies (Pteridophytes : chap. 5) have more recorded species (107) than the Bryophytes (53 species: chap. 6) and the Algae (19 species: chap. 7), but the latter two groups have been little studied at Bukit Timah and the totals given are undoubtedly underestimates. The birds are by far the most species-rich vertebrate group (c. 110 species: chap. 11), followed by the amphibia and reptiles (at least 37 species: chap. 12), the mammals

BUKIT TIMAH
NATURE RESERVE



(c. 15 species, excluding bats: chapter 9), and the fishes (10-12 spp.: chap. 14). Note the unfortunate absence of a chapter on by far the most species-rich group of organisms at Bukit Timah, the insects (30-50,000 species?). In addition, there are chapters on some smaller or less conspicuous groups on which detailed studies have been made: the mycorrhizal fungi (chap. 8), the freshwater decapod crustaceans (chap. 13), the Rubiaceae (the largest family of flowering plants at Bukit Timah: chapter 4), and the macaques (chap. 10).

To a large extent, the unevenness of coverage reflects unevenness in our knowledge of the Reserve, in turn a result of unequal research effort. We hope that this volume will spur efforts to fill some of the gaps. Obvious gaps include the bats (omitted from the mammal chapter because of inadequate data), the butterflies (for which there is fairly good historical information), and every other terrestrial invertebrate group. Moreover, for the great majority of species mentioned in this volume, the only information we have is the name and general habitat: detailed ecological studies of individual species (with the exception of the Long-tailed Macaque) have still to be carried out.

Bukit Timah is not the only rain forest reserve on the outskirts of a major city. In Brazil, several important remnants of the threatened Atlantic Rain Forest are near urban areas, including the 7900 ha Serra de Cantareira State Park, 12 km from the centre of Sao Paulo, a megapolis of over 15 million people, and Tijuca National Park, a secondary forest reserve on the margins of Rio de Janeiro (Por, 1992). These reserves suffer from similar problems to Bukit Timah, plus, in several cases, the additional one of severe air pollution. Yet all of them play important roles in conservatin and education. Such small reserves cannot substitute for national parks covering hundreds or thousands of square kilometres but they can save species and habitats which are not represented in larger protected areas. Moreover, in vast expanses of the humid tropics, Bukit-Timah-size fragments are all that remain. Too often, forest patches the size of Bukit Timah are dismissed as useless for conservation purposes and allowed to degrade until this prediction becomes self-fulfilling. Bukit Timah Nature Reserve is undoubtedly too small for the long-term maintenance of large vertebrate populations, but such vertebrates form a tiny percentage of the total biodiversity in lowland rain forest and some of their ecological roles, such as seed dispersal, may be possible to replace by careful management. Big is beautiful in reserve design but, as we hope this publication shows, small is far from useless!

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Chapter 2

The History of Bukit Timah Nature Reserve

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This account of the history of the reserve is updated from a previous, more detailed study published elsewhere (Corlett, 1988). The earliest reference to protection of the forest on Bukit Timah hill is in a paper published in 1848, which warned of the possible effects of the clearance of hill forest on the climate of Penang. The author contrasted the situation in Penang with that in Singapore where 'the present zealous Governor has absolutely prohibited the further destruction of forests on the summits of hills', including, presumably, Bukit Timah (Logan, 1848). Thirty years later, the Colonial Engineer, J.F.A. McNair, describing the state of the forests of the Malay Peninsula, mentioned that 'a reserve is kept round the principal hill [Bukit Timah] for climatic purposes'. Thus in 1882, when Nathaniel Cantley, the Superintendant of the Singapore Botanic Gardens, was commissioned to prepare a report on the forests of the Straits Settlements, Bukit Timah hill had already been under some kind of protection for more than three decades. Cantley, noting that only seven per cent of Singapore's forest remained and that there were 'absolutely no Forest Rules or Regulations, or Forest Law of any kind', recommended the establishment of forest reserves and the reafforestation of wasteland (Cantley, 1884). The proposed reserves were to supply timber and firewood, prevent soil erosion, protect the water supply and improve the climate.

Cantley's proposals were accepted. Bukit Timah had more good forest than any other of the proposed reserves so demarcation of its boundaries was given priority. A fire-break, 10 kilometres long and 5 metres wide, was cut around the margin of the reserve in 1884. However, less than a third (122 hectares) of the 343 hectare reserve was 'under timber'. The largest fraction (133 hectares) was 'grass and fern' and the rest (88 hectares) was 'brushwood'. Planting of the wasteland areas started in 1883 and by 1886 a total of 118 hectares had been planted with a mixture of native species and exotics, such as teak and mahogany. I can find no record of the success of these plantings but none of the exotics seem to have survived to the present day. Planting of waste areas continued under Cantley's successor, H.N. Ridley, until a great reduction in the Forest Department budget in 1893 made anything but minimal protection of the reserves impossible. Fires and timber thefts were a problem from the beginning but Bukit Timah seems to have been better protected than most of the other reserves.

The forest reserve system eventually incorporated 11 percent of Singapore's total land area (fig. 1, chap. 1), although only part of this was forested and much of the forest was mangrove. An additional area, partly covered in degraded primary forest, was protected in the 1890s as water catchment around the major reservoir (now called MacRitchie Reservoir). In 1894, the Annual Report of the Forest Department commented that, because of the small extent and poor quality of the reserves, 'their utility as a source of revenue was subordinated to their climatic and hygienic uses'.

There was never any legal logging at Bukit Timah Forest Reserve and the only income derived from the reserve was from a plantation of Gutta Percha trees (*Palaquium gutta*), later mixed with rubber, started on an area cleared of scrub on the lower slopes of the hill in 1898 and eventually covering 40 hectares. Gutta Percha is a non-elastic thermoplastic polymer, extracted from the latex which oozes from cut parts of the plant. At the time when the plantation was established, it was used for coating submarine telegraph cables. Part of this plantation can still be seen in the southern part of the reserve. Of the reserve's original area of 343 hectares, 52 hectares, much of it probably forested, were transferred to the control of the Municipality in 1909 as part of an expanded water catchment area to the east and north-east of Bukit Timah. Small areas were also taken out for granite quarries, for realignment of the railway and for a rifle range. Despite this, Bukit Timah survived while most of the other forest reserves were worked for timber, handed over to squatters for growing vegetables or otherwise developed. The only other of Cantley's original reserves to escape destruction was Chan Chu Kang (Nee Soon; not to be confused with Chua Chu Kang), which was saved from total clearance by incorporation into the extended water catchment in 1909.

In 1930, Bukit Timah Forest Reserve was reconstituted so as to include only forest land. By this time it was obvious that the remaining forest reserves would never serve their original purpose and a decision was made to abolish them. This action was put off, however, until 1936. At this point, the Director of the Botanic Gardens, Mr. Eric Holttum, asked that Bukit Timah should be preserved as the best remaining area of primary forest on the island. This request was approved and, when the reserves were revoked, Bukit Timah and parts of the mangrove reserves at Pandan and Kranji were taken over by the Gardens Department to be held as nature reserves. There was a great deal of illegal felling of timber at Bukit Timah, particularly in the north-west, between revocation and the start of regular patrols by Gardens staff in July 1937. Finally, in 1939, these three areas were re-gazetted as forest reserves (since there was no nature reserve legislation) and the Director of the Botanic Gardens was appointed Conservator of Forests.

Bukit Timah was now a nature reserve in all but name. Under the Gardens Department, new paths were cut and sign-posted, trees labelled, timber thefts stopped, devastated areas planted and a thorough botanical survey started. However, these changes were interrupted by the coming of the war and the Japanese occupation of Singapore from 1942 to 1945. Bukit Timah hill, itself, was on the front line of the battle for Singapore in February 1942, and must have suffered considerable damage. Corner (1981), on his first visit to Bukit Timah during the occupation, was 'astonished and appalled at the quantity of unexploded mortar shells which had fallen on the paths and among the trees'. During the occupation the Japanese felled some trees and made some defensive excavations but, on the whole, the reserves were protected (Corner, 1981). This was largely due to the efforts of Professor Kwan Koriba, who was sent out from Kyoto University to take charge of the Singapore Botanic Gardens.

After the war, the most obvious threat was from the continued activites of the granite quarries, five of which now removed vast quantities of rock from the sides of the hill and, in places, encroached into the reserve. In July 1949, Holttum, as Director of Gardens, wrote to the Colonial Secretary about Bukit Timah and the future of the reserve system. A copy of this letter is in the files of the Nature Reserves Board. He argued that it would be disastrous to allow the quarries to cut further into the hill and proposed various extensions to the reserve in order to protect the margins. He also suggested that the three forest reserves under the control of the Gardens Department should be made into Nature Reserves in name as well as function and that the entire water catchment area should be added to the reserve system.

The Government appointed a Select Committee to investigate the matter. The final report of the committee, in 1951, recommended the gradual closure of the quarries at Bukit Timah and the enactment of new legislation to protect the reserves (Burkill, 1961). Holttum's recommendations had been accepted in full. As a result, the Nature Reserves Act of 1951 was passed to provide for the designation and administration of nature reserves 'for the purposes of propagation, protection and preservation of the indigenous fauna and flora of Singapore and for the preservation of objects and places of aesthetic, historical or scientific interest'. A secondary purpose was to provide 'facilities for the study of and research into matters relating to the flora and fauna of Singapore and the physical conditions in which they live'.

Since June, 1990, the nature reserves, including Bukit Timah, have been administered by the Nature Reserves Committee under the National Parks Board, a statutory board which also manages the Singapore Botanic Gardens and Fort Canning Park. An additional five hectares have been added to the reserve in the south-west corner, but more than half this extra area was occupied by two villages. With other adjustments, the area of the reserve is now 81 hectares. The quarries have finally ceased operation but, unfortunately, the new Bukit Timah Expressway provides an effective barrier between most of the water catchment forest and Bukit Timah. An excellent Visitor Centre at the main entrance of the reserve was opened in 1991.

More than 130 years of isolation and disturbance have taken their toll of Bukit Timah's flora and fauna. Even with optimum protection, extinctions will no doubt continue because of the small size of the reserve. In many cases, a species lost from Bukit Timah is a species lost from Singapore, as the other surviving areas of primary forest (notably at MacRitchie and Nee Soon) are even smaller. The loss of species is one the unifying themes of the papers that follow. The major theme, however, is the fantastic diversity that still survives.

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Chapter 3

Flowering Plants at Bukit Timah

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Vegetation

There are several types of vegetation within Bukit Timah Nature Reserve but the most extensive and by far the most important is the primary rainforest which occupies about half the area. This can be classified as "coastal hill dipterocarp forest", because of the presence of *Shorea curtisii* and other typical species, but it lacks the understorey palm, *Eugeissona tristis*, which is characteristic of this forest type in Malaysia. Other vegetation types within the reserve include secondary forests of various ages which have developed on sites degraded by prolonged cultivation (Corlett, 1992b; Sim et al., 1992), abandoned fruit tree orchards, an abandoned gutta percha plantation (*Palaquium gutta* - around Taban Valley at the southern end of the reserve) and open areas dominated by ferns (mostly *Dicranopteris* species) or grasses. None of these habitats approach the species diversity and structural complexity of the primary rainforest and they are not considered further in this account.

Flora

Excluding weeds of open areas, more than 840 species of flowering plants have been recorded from Bukit Timah in the last hundred years (table 1, Corlett, 1990). Some may now be extinct but these losses are probably more than balanced by species not yet recorded. The majority of species are trees and it is these which largely determine the three-dimensional structure of the forest. The tree species vary greatly in their heights at maturity, from treelets which barely attain head height to the giants which emerge above the canopy formed by their lesser fellows (fig. 1).

Big trees make up a small proportion of the total number of trees at Bukit Timah and relatively few species ever attain this status. At Bukit Timah, as in most Southeast Asian rain forests, the dominant family in the uppermost layers is the Dipterocarpaceae. The commonest dipterocarp species are *Shorea curtisii* and *Dipterocarpus caudatus* ssp. *penangianus*. Both tend to be gregarious, with *Shorea curtisii* most prominent on the ridges. Several other species of *Shorea* are also common, as well as species in the genera *Dipterocarpus, Anisoptera, Hopea* and *Vatica*. Neither *Hopea* nor *Vatica,* however, attain the stature of the other dipterocarps.

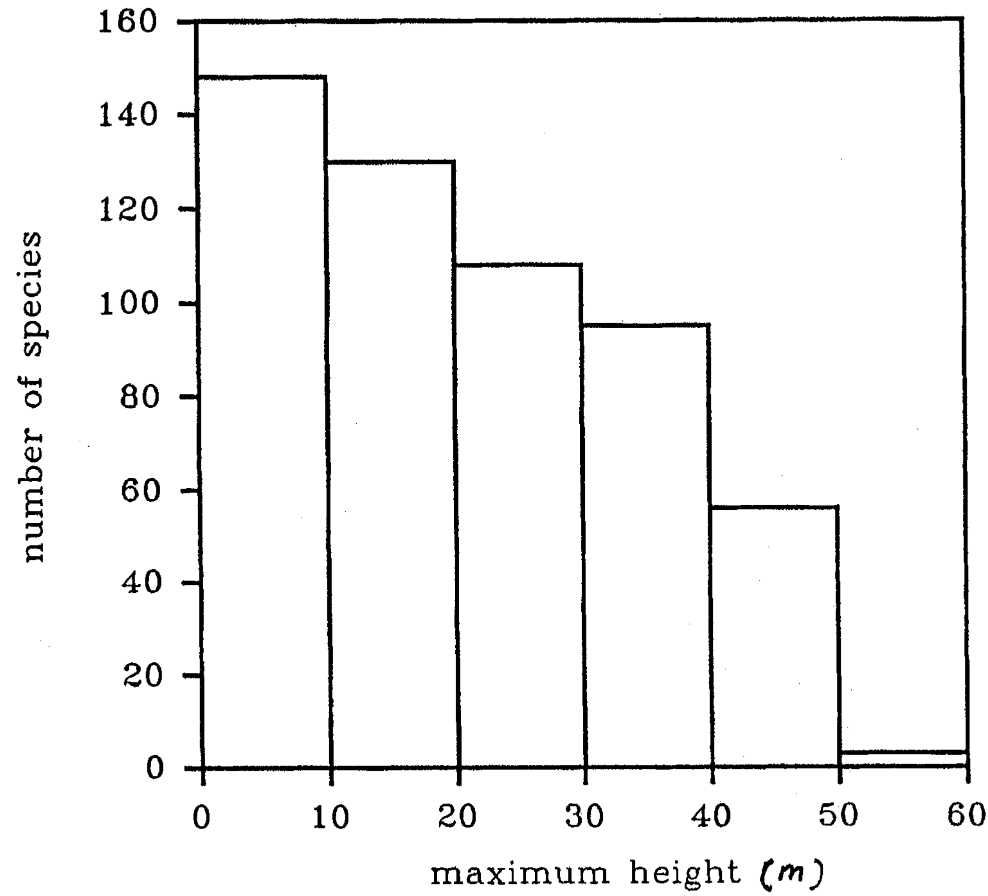

Figure 1. Distribution of maximum heights (excluding unusual extreme values, where possible) for the trees and shrub species of Bukit Timah Nature Reserve. Information from various literature sources.

The absence of species in *Shorea* Section *Shorea* at Bukit Timah, except for a single collection of *Shorea collina*, is surprising and a little suspicious. This is the section of the genus whose members produce the hard, heavy "balau" timber which was highly valued in the nineteenth century before the use of chemical preservatives made the lighter dipterocarps valuable. It is possible that the heavy hardwood species were selectively logged out before the hill was adequately protected, although some regeneration would have been expected.

After the dipterocarps, the most important families of big trees are the Anacardiaceae, Burseraceae and Leguminosae. The Anacardiaceae are represented in the upper canopy by two very common species, *Gluta wallichii* and *Campnosperma auriculatum,* and several rarer taxa (*Mangifera, Parishia*). *Gluta wallichii* is also very abundant as saplings in the understorey. In common with many other members of the Anacardiaceae, species of Gluta (called "Rengas" in

Malay) can cause severe, allergic contact dermatitis in sensitive individuals. *Campnosperma* has light-demanding saplings and its abundance near the margins of the reserve clearly reflects past disturbance. The Burseraceae are represented by a number of rather similar looking species in the genera *Canarium, Dacryodes,* and *Santiria,* all with pinnate leaves crowded at the tips of the twigs. The legumes are more diverse in appearance. The biggest of all is *Koompassia malaccensis,* an important timber tree in Peninsular Malaysia, where it attains heights of more than 50 metres. There are also a number of species of *Dialium* and *Sindora,* as well as the Petai, *Parkia speciosa,* which bears edible pods and seeds. Other families with some very large tree species include the Celastraceae (*Kokoona*), Sapotaceae (*Palaquium, Payena, Planchonella*), Myrtaceae (some species of *Eugenia*), Apocynaceae (*Dyera costulata, Alstonia angustiloba*), Magnoliaceae (*Magnolia elegans*), Sterculiaceae (*Heritiera, Scaphium*), Moraceae (*Artocarpus*), and Tiliaceae (*Pentace*). One palm species, the ferociously spiny *Oncosperma horridum,* reaches the canopy.

The space between and below the forest giants is filled with a bewildering array of smaller tree species, representing at least 60 families. The most important families, in both numbers of species and numbers of individuals, are the Rubiaceae and Euphorbiaceae. The Rubiaceae, most of which are small understorey trees and shrubs, are the largest family at Bukit Timah and are treated separately (chap. 4). Members of the Euphorbiaceae range in size from the understorey treelet, *Agrostistachys,* to the 30-40 m tall *Endospermum diadenum,* but most fall between these extremes. Other important families of medium-sized or small trees are the Myrtaceae (represented by at least 25 species of *Eugenia*), Annonaceae (*Cyathocalyx, Mezzettia, Polyalthia, Popowia, Xylopia*), Lauraceae (*Litsea* and other genera), Myristicaceae (*Horsfieldia, Knema, Myristica*), Guttiferae (*Calophyllum, Garcinia*), and Fagaceae (*Castanopsis, Lithocarpus* and one *Quercus*). Outside these families, two of the commonest small trees are *Gironniera parvifolia* (Ulmaceae) and *Pellacalyx saccardianus* (Rhizophoraceae). *Pellacalyx* is particularly common along major paths and roadsides. Two other small trees, *Pternandra echinata* (Melastomataceae) and *Adinandra dumosa* (Theaceae), are also very common along roadsides and in the disturbed fringes of the reserve, but rare or absent in the forest interior.

Many species of woody climber also contribute to the main canopy. Compared with trees of the same height and crown size, they have much more slender stems, consisting largely of conducting tissue. Support is provided by the host tree, which is harmed in several ways. The weight of the climber increases the mechanical stress on the tree and the climber canopy may compete with the host for light. In addition, at the point where a tendril or liane stem wraps round the host there is often a visible constriction, showing that radial expansion of the branch or twig has been prevented. It has been suggested that this constriction of the vascular system is the most damaging effect of woody climbers on their host trees (Stevens, 1987).

Table 1: Angiosperm flora of Bukit Timah (excluding non-forest weeds) by family and life-form. Rank order for each life-form indicated in parentheses. Updated from Corlett (1990). Rubiaceae from Tan, T.W. (chap. 4).

Family	Trees & Shrubs	Climbers	Herbs	Epiphytes & Hemi - parasites	Sapro-phytes	Parasites	Total
Rubiaceae	56 (2)	22 (1)	3	1	-	-	82
Euphorbiaceae	65 (1)	-	-	-	-	-	65
Orchidaceae	-	-	21 (1)	24 (1)	5	-	47
Moraceae	22	4	-	12 (2)	-	-	38
Annonaceae	26 (4)	11	-	-	-	-	37
Palmae	11	19 (2)	-	-	-	-	30
Myrtaceae	27 (3)	-	-	-	-	-	27
Leguminosae	13	10	-	-	-	-	23
Lauraceae	22	-	-	-	-	-	22
Malastomataceae	12	6	2	2	-	-	22
Araceae	-	9	12 (2)	-	-	-	21
Guttiferae	20	-	-	-	-	-	20
Dipterocarpaceae	18	-	-	-	-	-	18
Myristicaeae	18	-	-	-	-	-	18
Sterculiaceae	12	1	-	-	-	-	13
Anacardiaceae	12	-	-	-	-	-	12
Fagaceae	12	-	-	-	-	-	12
Meliaceae	12	-	-	-	-	-	12
Sapotaceae	12	-	-	-	-	-	12
Vitaceae	-	12 (3)	-	-	-	-	12
Apocynaceae	4	7	-	-	-	-	11
Burseraceae	11	-	-	-	-	-	11
Elaeocarpaceae	10	-	-	-	-	-	10
Myrsinaceae	5	5	-	-	-	-	10
Zingiberaceae	-	-	9 (3)	-	-	-	9
Asclepiadaceae	-	2	-	6 (3)	-	-	8
Cyperaceae	-	-	8	-	-	-	8
Ebenaceae	8	-	-	-	-	-	8
Theaceae	8	-	-	-	-	-	8
Celastraceae	4	3	-	-	-	-	7
Sapindaceae	7	-	-	-	-	-	7
Xanthophyllaceae	7	-	-	-	-	-	7
Connaraceae	1	5	-	-	-	-	6
Dilleniaceae	5	1	-	-	-	-	6
Loganiaceae	2	4	-	-	-	-	6
Pandanaceae	3	3	-	-	-	-	6
Piperaceae	-	6	-	-	-	-	6
Bombaceae	5	-	-	-	-	-	5

Table 1 (continued).

Family	Trees & Shrubs	Climbers	Herbs	Epiphytes & Hemi - parasites	Sapro-phytes	Parasites	Total
Flacourtiaceae	5	-	-	-	-	-	5
Loranthaceae	-	-	-	-	-	5	5
Rutaceae	5	-	-	-	-	-	5
Thymelaeaceae	3	2	-	-	-	-	5
Verbenaceae	3	2	-	-	-	-	5
66 more families	72	33	21	3	4	0	136
All angiosperms	540	165	76	48	9	5	843
Percentages	64.1	19.6	9.0	5.7	1.1	0.4	

The stem anatomy of woody climbers provides great flexibility which allows them to survive the fall of their host. The climbers at Bukit Timah show a variety of climbing mechanisms. Most of the larger species climb by twining around their support but others are aided by hooks or tendrils. Rattans - spiny, climbing palms in the genera *Calamus, Daemonorhops, Korthalsia* and *Plectocomia* - are abundant at Bukit Timah and climb by means of the reflexed spines that cause such problems for unwary botanists! Apart from the palms and the Rubiaceae (chap. 4), the commonest families of big woody climbers at Bukit Timah are the Annonaceae (*Artabotrys, Fissistigma*), Apocynaceae (*Willughbeia, Leuconotis*), Connaraceae (*Roure*a and other genera), and Leguminosae (*Dalbergia, Derris, Entada, Spatholobus* and others), but at least another dozen families are represented. Stem diameter growth in climbers is very slow compared with trees, so the presence of many large diameter climbers at Bukit Timah shows that the forest has not been badly disturbed for a long time. In additional to the big woody climbers there are smaller, often herbaceous, species, which grow straight up the trunks of trees, usually attached by adventitious roots. The most conspicuous species at Bukit Timah are in the family Araceae (*Anadendrum, Scindapsus*).

The forest floor herb flora of Bukit Timah is neither particularly rich nor very conspicuous, except in well-lit areas. In most places, the “herb layer” of the forest is dominated by seedlings of trees and climbers. The commonest true herbs are ferns, which are covered in chapter 5. Among the flowering plants, the orchid family has the most herb species, but most of these are inconspicuous and hard to find. More conspicuous are members of the families Araceae, Cyperaceae and Zingiberaceae.

Rain forest herbs typically have broad, thin leaves, as might be expected in an environment where the humidity is always high and the light intensity low. Other leaf characteristics are more difficult to explain. Several species have variegated leaves, others red or purple undersurfaces, and yet others a velvety sheen.

The forest floor is also home to a group of flowering plants that need no light at all, the saprophytes. These are plants which obtain nutrients from dead and decaying organic matter. Nine species have been collected from Bukit Timah, in the families Orchidaceae (*Aphyllorchis, Didymoplexis, Gastrodia, Lecanorchis, Stereosandra*), Burmanniaceae (*Burmannia, Gymnosiphon, Thismia*) and Triuridaceae (*Sciaphila*). Most of these have not been recorded recently but this does not necessarily mean they are extinct as they are very inconspicuous, except when in flower.

Epiphytes are plants which use other plants for support but are not parasitic on them. Some epiphytes are confined to the lower levels of the forest where accumulations of water-retaining humus provide habitats not very different from the forest floor. Others grow high in the canopy, exposed to intense solar radiation. Even in a wet climate like Singapore's, these plants suffer regular water stress because of the limited water-holding capacity of the bark on which they grow. Orchids, particularly in the genera *Appendicula, Bulbophyllum* and *Dendrobium*, are the dominant epiphytes of exposed microhabitats at Bukit Timah, although their presence is usually only revealed by examination of fallen trees and branches. Ferns are also important, although most are found in the more shaded positions. There are also several Asclepiadaceae (*Dischidia, Hoya*) and a few species in other families. An epiphytic species of *Rhododendron* was found on a *Shorea* near the summit in 1890 but has not been seen since.

Most of the exposure-tolerant epiphytes have thick, succulent leaves and many also exhibit a special type of photosynthesis, known as CAM (Crassulacean Acid Metabolism) (Winter *et al.*, 1983). Non-CAM plants, when subject to water stress, must either close their stomata and thus halt photosynthesis, or keep them open and lose more water. CAM plants, in contrast, can open their stomata at night to take in the necessary carbon dioxide, storing it in the form of malic acid in the cell vacuoles. During the day, the stomata are closed and the stored carbon dioxide released for photosynthetic fixation. Opening the stomata only at night minimizes water loss because of the lower temperatures and higher humidity at this time. Moreover, the night-time accumulation of malic acid ensures maximum osmotic pressure at dawn, which will facilitate uptake of water from the morning dew.

Hemi-parasites are often confused with epiphytes but differ in their attachment to the xylem of the host vascular system, from which they obtain water and nutrients, the resources in shortest supply for an epiphyte. In contrast to fully parasitic fungi and bacteria, they are not dependent on their hosts for organic compounds, as they have green leaves and photosynthesize normally. Most of the parasitic Angiosperms recorded at Bukit Timah are members of the mistletoe family, Loranthaceae. These attach to twigs and branches high up in the canopy and often have very wide host ranges. They are not conspicuous from ground level but easily detected by their fallen flowers. A root-parasitic member of the

Opiliaceae, *Cansjera rheedii*, has also been collected at Bukit Timah.

A final growth habit, the so-called "stranglers', is confined, at Bukit Timah, to several species of figs (*Ficus*, Moraceae). Strangling figs start off as epiphytic bushes which then send roots down the trunk of the supporting tree to the ground. These roots may branch and coalesce until they form a basket of roots around the host trunk, preventing further growth. The host tree eventually dies and is replaced by a free-standing fig tree. Only a few fig species seem to commonly kill their hosts but intermediate stages are common at Bukit Timah.

Biogeography

The forest at Bukit Timah is essentially an extension of the rapidly-disappearing lowland rain forest of Peninsula Malaysia. This, in turn, formed part of a large block of rain forest which, until very recently, covered the everwet lands of the Sunda Shelf: that is, Sumatra, Malaya, Borneo and western Java, plus a few smaller islands. The exposure of the entire Sunda Shelf during glacial low sea-levels has prevented much differentiation between the now-separated floras of the region. This is reflected in the modern distributions of the angiosperm species recorded from Bukit Timah and of Singapore's forest flora as a whole (Corlett, 1992b).

Reasonable data on the distributions of 570 species from Bukit Timah can be found in the taxonomic literature. Except for the mysterious and aptly named, *Sabia erratica*, the only known specimen of which was collected from the reserve in 1940 (if not mislabelled! (Van de Water, 1980)), none are confined to Singapore and only 15 percent are limited to the Malay Peninsula (including adjacent parts of peninsular Thailand to the north). A further 52 percent are endemic to the Sunda Shelf region, while the remaining third of the species are more widespread, extending north into continental Asia and/or east towards New Guinea and Australia. The apparent absence of narrow endemics presumably reflects the unexceptional nature of the physical environment of Bukit Timah, and Singapore's position near the centre of the Sunda Shelf. Future taxonomic revisions may change this picture somewhat but recent changes have more often resulted in an increase in the known range of species than a decrease. Deforestation, in contrast, is drastically reducing the ranges of all forest-dependent taxa, making Bukit Timah's once unexceptional flora an increasingly rare and valuable treasure.

Change

Regular trips to Bukit Timah reveal a dynamic aspect to the forest which is not obvious to the casual visitor. Changes are occurring on a variety of spatial and time scales. The study of recurrent phenomena, such as leafing, flowering and fruiting, is called phenology (e.g. Ng, 1988). The absence of climatic extremes in Singapore permits an incredible diversity of phenological patterns in plant species

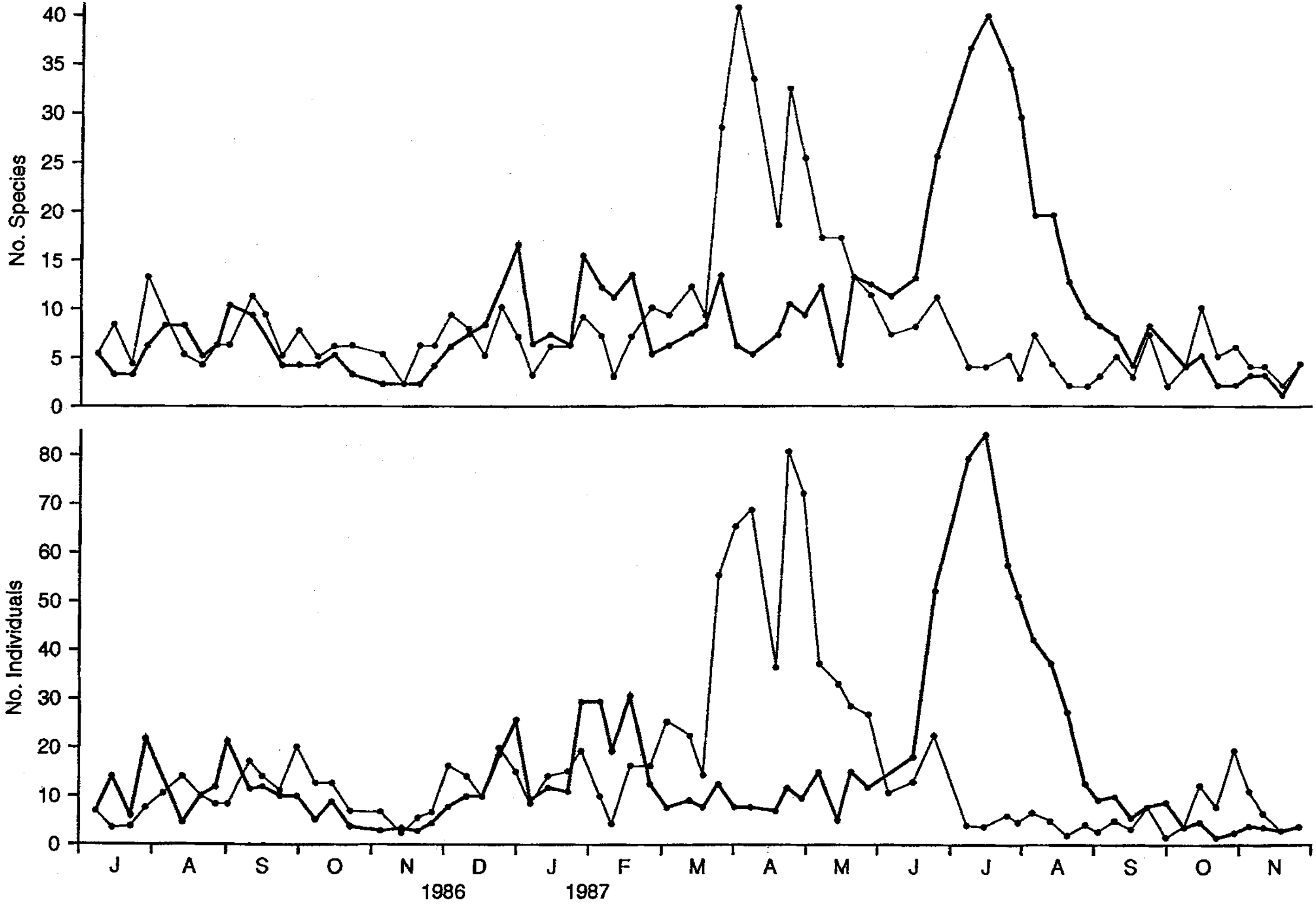

Figure 2. Species and individuals in flower (thin line) and fruit (thick line) along a 5.1 km route through the reserve between July 1986 and November 1987. (From Corlett, 1990).

so there is always something happening in the forest. The same lack of extremes is also presumably responsible for the frequent (but by no means universal) lack of synchronization between members of the same species and even between different branches on the same individual.

The great majority of plants at Bukit Timah are evergreen and the exceptions are only very briefly deciduous. Although no systematic study has been made in Singapore, informal observations over several years agree with studies in Malaysia that show two annual peaks of leaf production, centred around April and October (Ng, 1988). Leaf fall probably peaks at the same time because the old leaves are usually shed as the new leaves are produced. However, some plants can be found with new leaf flushes - often brightly coloured - at any time of the year.

Flowering phenology is less obviously seasonal at Bukit Timah. Most studies in Malaysia have suggested a single, annual flowering peak at the same time as the first peak of leaf production. These annual peaks are usually so low as to be barely detectable (Ng, 1988) but, at irregular intervals of 1-6 years, there are much higher peaks when many individuals of many species flower together. This phenomenon of supra-annual "gregarious flowering" is unique to Southeast Asian dipterocarp forests and has received a lot of attention in the recent ecological literature (Ashton *et al.*, 1988). Most of the attention has been focussed on the dipterocarps themselves but many other species in the forest show the same pattern.

There was an episode of gregarious flowering at Bukit Timah in 1987, following an exceptionally dry and sunny February (fig. 2) (Corlett, 1990). More than 150 species in 42 families flowered between late March and late May, including emergent, canopy, subcanopy and understorey trees and shrubs, as well as climbers. Gregarious flowering was followed by gregarious fruiting, peaking 13 weeks after flowering. This is an event of great significance to fruit-eating vertebrates, as discussed in chapter 10. There is evidence that mast-fruiting benefits the wind-dispersed dipterocarps through satiation of seed predators. Individual trees that fruit out of synchrony lose most of their seeds to predators (Burgess, 1972). The same benefit may apply to other wind-dispersed trees and climbers but it difficult to see any advantage in mast-fruiting for the animal-dispersed majority of species, where disperser satiation would seem as likely as predator satiation.

A similar, but less well documented, episode of gregarious flowering and fruiting took place in 1990, again following a dry period at the beginning of the year. In contrast to 1987, when few dipterocarps participated, dipterocarp fruits of many species littered the forest floor in August.

Many species at Bukit Timah have other reproductive periodicities, instead of or in addition to participation in the irregular community-level peaks. During two years of observations a few species flowered and fruited continuously, some many times, some annually, some once and some not at all.

The generally low levels of flowering and fruiting in the forest, except during the irregular bursts of activity every few years, have obvious implications for animals which feed on nectar, pollen or fruit. In particular, this community phenology makes it difficult for a long-lived animal to specialise on these resources. The flexible diet of the Long-tailed Macaques (*Macaca fascicularis*) in the reserve illustrates both the problem and a possible solution (Lucas and Corlett, 1991).

Changes in the forest on a longer time-scale result from the establishment, growth and death of individual trees. In all forests it is possible to recognize a forest growth cycle: a gap develops in the canopy, trees grow up in the gap, and the canopy is eventually restored. The gap phase is the crucial part of the cycle because what grows up in the gap determines the floristic composition of that patch of the forest for a century or more, until the cycle repeats itself. Gaps come in all shapes and sizes. At Bukit Timah, single canopy trees sometimes die and decompose without falling over, creating only a small hole in the canopy. More often, a tree falls full-length, smashing a hole through the canopy and understorey of a size determined by the crown diameter. The fall of a living tree is more destructive than that of a dead tree which has already lost much of its crown. Sometimes, a big tree brings down other trees which are in its path, or attached by climbers, and the gap eventually created extends over hundreds of square metres.

Regrowth in a newly created forest gap is typically dominated by species already present as seedlings and saplings. However, additional, light-demanding species may also establish from seed in the larger gaps. At Bukit Timah, these light-demanding "pioneer" species are particularly prominent in gaps formed at the forest margin and along roadsides, where the effective gap size and hence light availability is greatly increased. Moreover, the large areas of scrub and secondary forest in and around the reserve provide a massive and continuous supply of pioneer seeds to any newly-opened area. Which species eventually come to dominate the gap will depend on many factors, including gap size. Light-demanding tree species in the canopy, such as *Campnosperma auriculatum*, provide evidence of major canopy disturbances in the past. Whether or not large roadside or marginal gaps will ever regenerate the original forest structure and floristic composition is a question of great importance for the future of the reserve. It may be necessary to plant some of the more competitive large canopy species in such areas and weed out the more aggressive pioneers.

Plant-Animal Relationships

This chapter is concerned with flowering plants but the flora and fauna of the rain forest cannot be considered in isolation from each other. Few rain forest animals can survive outside the forest and few plant species would survive for long if all the animals were eliminated. At the most basic level, the flora controls the physical environment in which all the animals live: the microclimate, the soil structure, and the three-dimensional pathways along which animals move through the forest. For predatory animals, such as spiders and leopard cats, the architecture of the forest is probably its most important feature. Most animals are herbivores, however, directly dependent on plants for food. In general, invertebrate herbivores seem to specialize on one or a few closely related plant species, although some have much wider dietary tolerances. Millions of years of evolution has resulted in plants which are protected by physical or chemical means from most herbivores, yet all species are susceptible to specialists which have evolved means of overcoming or by-passing these defenses. Vertebrate herbivores, in contrast, are too large and long-lived to have the option of narrow specialization. They must either eat relatively unprotected plants or plant parts, as do the macaques at Bukit Timah (chap. 10), or, as the leaf-monkeys and forest deer, detoxify plant chemical defenses by bacterial fermentation in specialized digestive systems.

Not all relationships with animals are harmful to the plants involved. Most plant species at Bukit Timah are also involoved in mutualistic relationships with animals, in which both partners benefit. The most widespread of these relationships is pollination. Wind pollination is very rare in the rain forest, presumably because the low densities at which most plant species occur would make it very inefficient. Moreover, air movements, except in the canopy, are insufficient to disperse pollen far. The great majority of species are pollinated by insects which can, in theory, provide directed transport of pollen in still air between flowering individuals of the same species. Bees are probably the most important insect pollinators but butterflies, moths, beetles, and flies are also involved in some species. Some of the giant *Shorea* species are pollinated by minute thrips (Appanah and Chan, 1981). A few trees are pollinated by bats, notably *Parkia speciosa*, with its "shaving brush" flowers (Start and Marshall, 1976) but, as yet, no species at Bukit Timah has been shown to be pollinated by birds.

As in other rain forests, most plants at Bukit Timah are also dependent on animals for dispersal of their seeds. Large seeds are advantageous for seedling establishment in the deep shade of the rain forest floor and the wind is never strong enough below the canopy to move them. Wind dispersal is common, however, among the trees, climbers and epiphytes of the upper canopy, where the air movement is much greater. All the dipterocarps at Bukit Timah have winged fruits but, even for an emergent, the wind is rarely strong enough to disperse the large fruits far from the mother tree. Other common wind-dispersed species among the tallest trees are *Alstonia, Dyera, Gluta, Heritiera, Kokoona, Koompassia, Lophopetalum, Parishia, Pentace, Pterospermum, Scaphium*, and *Swintonia.* Wind-dispersed woody climbers of the canopy and forest edge include *Combretum, Derris, Spatholobus, Uncaria, Urceola,* and *Ventilago.* All the epiphytic ferns and orchids are also dispersed by wind.

Seed size is also a limiting factor in dispersal by animals. The typical animal-dispersed fruit consists of one or more hard, indigestible seeds (or seeds plus hard fruit tissues) surrounded by attractive, edible flesh. For the seed to be dispersed, it has to physically possible and energetically worthwhile for an animal to carry it away from the parent tree. Ecologists have tried to identify particular combinations of fruit characteristics with particular animal dispersal agents. However, detailed observations of one plant species usually show a broad spectrum of dispersal agents, suggesting that plant-disperser relationships are not very precise. For instance, the small fruits of *Campnosperma auriculatum* are eaten by macaques, fruit bats, squirrels and at least eight species of birds at Bukit Timah (Corlett and Lucas, 1989). In the extreme case of some fig species, the fruit may be consumed by virtually the entire frugivorous fauna as well as many animals which otherwise eat little fruit. The situation is further complicated at Bukit Timah by the extinction of many of the largest dispersal agents, including all hornbills, all but one barbet, and the three biggest deer species. It is very noticeable that certain tree species, for instance *Canarium littorale* and *Mezzettia leptopoda*, and the liane, *Strychnos ignatii,* produce large crops of large fruits that are barely touched by vertebrates, suggesting that they are no longer being dispersed. Careful investigation would probably reveal many more examples but it is becoming increasingly difficult, if not yet impossible, to find sites in the region with an intact vertebrate fauna for comparison.

Surviving dispersal agents at Bukit Timah include many smaller birds, fruit bats, macaques, civets, squirrels and other rodents, tree shrews, and perhaps the mouse deer. The commonest fruit-eating birds at Bukit Timah seem to be the Bulbuls, Flowerpeckers, Asian Fairy-bluebird, and Red-crowned Barbet. Flocks of White-vented and Common Mynas, and the Philippine Glossy Starling, and the occasional Black-naped Oriole, also visit fruiting canopy trees, although they are typically open-country birds and never enter the forest interior. None of these birds seem likely to be able to manage any of the larger fruits in the forest and they are most commonly seen feeding on smaller fruits, such as *Campnosperma* and *Endospermum.* The largest resident fruit-eating bird at Bukit Timah is probably the Hill Mynah but, although very conspicuous, only a few pairs are present. Pink-necked and Green-winged Pigeons, the Long-tailed Parakeet and the rare Blue-rumped Parrot also eat fruit but since they destroy and digest most seeds they probably play no role in seed dispersal.

The commonest fruit bat at Bukit Timah is the Lesser Dog-faced Fruit Bat (*Cynopterus brachyotis*). This species is an important dispersal agent in secondary forests in Singapore (Phua and Corlett, 1989) but its role in the rain forest is unknown. It almost certainly disperses the small green fruits of *Pellacalyx saccardianus,* a very common tree along roads in the reserve, and the similar fruits of *Adinandra dumosa*, which is common in the marginal areas. It very likely disperses many other species. The huge flying fox (*Pteropus vampyrus*) also visited the reserve in 1987, after an apparent absence of several years. They were only seen feeding on the small fruits of *Campnosperma*, but this bat could potentially carry off fruits as big as a mango (*Mangifera*).

The Long-tailed Macaque is the only species whose role in seed dispersal has been studied in detail at Bukit Timah (Corlett and Lucas, 1990; chap. 10). Although these monkeys swallow only the smallest seeds, large seeds may be transported away from the parent tree in the cheek pouches, mouth or hand. They may be the only current dispersal agents for fruits with an inedible rind that is most easily removed by hand (e.g. most species of *Garcinia*) as well as many other large-seeded species for which other potential dispersal agents are extinct. Their importance may be matched, however, by that of the civets. Nothing definite is known about civet ecology at Bukit Timah but the Common Palm Civet, at least, is still present. This species is arboreal and, apparently, largely frugivorous. Fruit are swallowed whole after little mastication and even very large seeds are passed intact (Bartels, 1964). Civets seem to prefer to defecate in the open, thus dispersing seeds to sites where they have most chance of establishment.

The two common squirrels at Bukit Timah seem to be largely seed predators. Some species of squirrel are important seed dispersal agents elsewhere by virtue of their habit of burying seeds for storage but Malayan tree squirrels do not bury seeds. Ridley (1895) describes acorns and chestnuts (the fruits of trees in the family Fagaceae) being dispersed by squirrels, which carry them off and then drop them accidentally, and goes on to suggest that the smooth coat of some acorns is an adaptation for this mode of dispersal. However, it seems rather unlikely that an important family of rainforest trees depends entirely on the mistakes of squirrels for its survival! Little is known about the ecology and behaviour of the ground dwelling rodents but, if they hoard seeds, they are potential dispersal agents for fruits without a fleshy covering, such as those of the Fagaceae.

The abundant Common Tree-shrew is another potential seed dispersal agent. Observations elsewhere (Emmons, 1991) have shown that tree-shrews eat considerable amounts of fruit and process them in much the same way as frugivorous bats, discarding the skin, fibres and seeds before swallowing the juice and pulp. This process is unlikely to disperse the seeds far and, since tree-shrews concentrate on small, soft fruits which are dispersed with greater efficiency by birds, their role as dispersal agents is probably not very significant. Finally, the elusive Lesser Mousedeer also eats some fruit but its role, if any, in seed dispersal is unknown.

In addition to the internal seed dispersal by frugivorous animals discussed above, two forest grasses at Bukit Timah, *Centotheca* and *Leptaspis*, have adhesive, burr-like fruits which are carried externally by animals, as well as on human clothing.

Mutualistic relationships in which an animal defends the plant against herbivores or competitors - protection mutualisms - are less common than pollination and dispersal mutualisms, but still important. Relationships involving ants have been most studied but there is increasing evidence that mite-plant relationships are even more widespread (Pemberton and Turner, 1989; O'Dowd and Willson, 1989). The mites inhabit "leaf domatia" : specialized chambers of very varied form which are usually located in the primary and secondary vein axils on the underside of the leaf. The mites occupying the domatia are largely predaceous or fungivorous. Although experimental evidence is currently lacking, it seems very probable that the mites benefit the host plant by preying on plant enemies, including pathogenic fungi, herbivorous insects and other mites. The mites, in turn, benefit by using the domatia as shelters for reproduction and development, and for protection from environmental extremes. The relationships seem to be much less specialized than those involving ants, described below. No definite feeding structures associated with mites have yet been reported and the abundance and taxonomic composition of the mite fauna varies between species, between individuals of the same species, and between leaves on the same individual. Apparently, no plant species that occurs at Bukit Timah has been investigated for mite-inhabited domatia. However, mite domatia have been investigated elsewhere in other species of several Bukit Timah genera (including *Canthium, Elaeocarpus, Cryptocarya* and *Timonius*) and domatia-like structures are obvious on some plants in the reserve.

The most conspicuous ant-defended plant at Bukit Timah is *Macaranga triloba*, a common small tree of large openings and the forest margin. In this species, the ants, *Crematogaster borneensis*, inhabit the hollow internodes and feed largely on the lipid-rich food bodies which the plant produces on the undersides of the down-turned stipules. The ants also consume the sugary secretions of scale insects which they "farm" inside the stems. It has recently been shown that the host plants benefit considerably from ant-occupation (Fiala *et al.*, 1989). The ants not only significantly reduce damage by herbivorous insects in comparison with both ant-free trees of the same species and non-ant-inhabited species of *Macaranga*, but also reduce climber growth by biting off any foreign plant parts which come into contact with their host tree. Reduced competition from climbers may be of particular importance in the well-lit sites that *Macaranga* prefers. Similar benefits have been shown for another ant-inhabited species found at Bukit Timah, *Macaranga hypoleuca.* This species also produces lipid-rich food bodies but, in contrast to *M. triloba,* they occur on the undersides of the young leaves.

Other *Macaranga* species and a wide range of other plants at Bukit Timah do not provide a home for ants but attract them to vulnerable plant parts by means of nectaries on the leaves. This relationship is less specialised than that described above but the benefit to the plant is also, apparently, defense against herbivores (Keeler, 1989; Fiala and Maschwitz, 1991).

Ants are also involved in another kind of mutualistic relationship, with epiphytes. At least two species of angiosperm recorded from Bukit Timah (*Myrmecodia armata* in the Rubiaceae and *Dischidia major* in the Asclepiadaceae) and one fern (*Lecanopteris*) provide a home for ants: in the tubers of *Myrmecodia,* the specialized, flask-shaped leaves of *Dischidia,* and the rhizomes of *Lecanopteris.* The benefit to the host seems to be largely nutritional, with the plant obtaining mineral nutrients from the decomposition of the organic debris which accumulates in the ant-inhabited cavities (Huxley, 1980).

Conclusions

Bukit Timah is not the only primary forest left in Singapore : there are other substantial and valuable areas around MacRitchie Reservoir and at Nee Soon (Corlett, 1991a, 1991b, 1991c, 1992a, 1992b). It is, however, the largest and best studied. Unfortunately, it is also the most isolated and the least well protected. The margins are unfenced and there is no buffer zone between the forest and the surrounding land uses. It is dissected by roads, pathways and clearings, favouring light-demanding weedy species. Recreational impact is heavy and increasing. Without more active management, the future of the reserve looks grim (chap. 15).

At fault, is the assumption that legal recognition of an area as a reserve and enforcement of reserve regulations is sufficient to preserve the plants and animals within. For small reserves - and Bukit Timah is about as small as a rain forest reserve could possibly be! – this assumption is far from valid. The majority of plant species in intact rain forest are present at very low densities and will have been represented by only a few individuals when the present reserve first became isolated more than 130 years ago (chap. 2). Species which require humid, shaded forest interior conditions will have become further restricted with time. These species are now liable to chance extinction even if the environment remains suitable. Many have probably already gone. The extinction of about half the forest vertebrates also threatens species which were dependant on them for seed dispersal.

The answer lies in active management of the reserve with the aim of preserving maximum biological diversity. Better protection of the margins and better control of visitors would be a good start. Weeding of exotic and non-forest species, and planting of tree-fall gaps have already been suggested. Human-assisted dispersal of species apparently lacking natural dispersal agents is another possibility, as is the reintroduction of natural dispersers. The success of any form of management will, however, depend ultimately on our knowledge of the ecology of the reserve.

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Chapter 4

Rubiaceae Of The Bukit Timah Nature Reserve

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Introduction

The Rubiaceae are the fourth largest flowering plant family in the world, after the Compositae, Orchidaceae and Leguminosae, and consist of 637 genera and approximately 10,700 species (Mabberley, 1987). In Singapore, it is the second largest family after the Orchidaceae with 46 genera and 147 species (Turner, Chua and Tan, 1990). In Bukit Timah Nature Reserve (BTNR), it is reported to be the largest, with 59 species (Corlett, 1990). They are also one of the most plentiful in numbers of individual plants. Swan (1988) found that they were the second and fifth most plentiful family in the two plots where plants with stem diameters of 2 cm or more were studied. Thus in the BTNR they are of considerable importance because of their high diversity and large number of individuals.

The species reported to occur in the reserve are mostly shrubs, treelets, trees or woody climbers and a few are herbs (Ridley 1923; Keng 1985; Corlett 1990). Large tree species are rare and thus in studies of trees with relatively large girth such as that of Wong (1987), their ecological importance is grossly underestimated.

The Rubiaceae are easily diagnosed by the possession of opposite leaves, inter- or intrapetiolar stipules, mostly inferior ovary and fused petals in its members. They are easy to recognize in the field; the difficulty is in distinguishing the genera and species as many taxa are similar in appearance and often are separated by technical and/or arbitrary characters.

No detailed survey of this important family in BTNR has been done. To facilitate identification of the various species found here, keys were composed for the identification of all species reported in the literature, as well as collected previously and in a recent survey. Some of the more common species were illustrated to aid further in identification.

Materials and Methods

Data for this study were collected through a series of three surveys. The first was conducted by making collections along all trails in the reserve. Collections of flowering, fruiting and sterile material of the members of the Rubiaceae in BTNR were made from November 1989 to April 1990. Specimens were identified from keys in Ridley (1923), Corner (1941), Backer and Bakhuizen van den Brink

(1965), van Beusekom (1967), Ridsdale (1978a, 1978b, 1979, 1989) and Wong (1982, 1984a, 1984b, 1988, 1989), Tirvengadum and Sastre (1986), Johansson (1988) and Puff (1991) as well as by comparison with annotated herbarium specimens at the Herbarium, Singapore Botanic Gardens (SING). Voucher specimens of the collected material were deposited in the Department of Botany Herbarium, the National University of Singapore (SINU).

The second was a survey of herbarium specimens in SING and SINU conducted to locate specimens previously collected from Bukit Timah. The third was a survey of species mentioned in the literature to occur in Bukit Timah. Sources included Ridley (1900, 1901, 1923), and Keng (1985, 1990) and revisions of the relevant taxa mentioned above.

A list of all species was compiled from the above three surveys. Keys to the identification of all these species were constructed. Photographs and line drawings were made of the more common species.

Results and Observations

Occurrence, distribution and life-forms

The total number of species previously and recently collected, as well as reported to occur in Bukit Timah Nature Reserve is 84 and the number recently collected is 35 (Table 1). The total figure is also larger than the 59 species estimated by Corlett (1990).

Aidia wallichiana, Gynochthodes sublanceolata and Psychotria cantleyi have not been previously collected or reported to occur in the reserve. *Gynochthodes sublanceolata* is a species commonly found in open disturbed areas but is still relatively rare in BTNR. The last two were probably overlooked by collectors in the past as they are fairly common in the reserve.

A number of species have been reported to be endemic to Singapore and South Johore or Peninsular Malaysia by Wong (1989) and these include *Chasalia pubescens, Lasianthus ellipticus, Lasianthus perakensis, Lasianthus ridleyi, Psychotria griffithii, Saprosma glomerulatum* and *Urophyllum trifurcum.* Van Beusekom (1967) has also indicated that *Gaertnera viminea* seems endemic to Singapore and Johore. If anything, the presence of such species indicates the importance of retaining this reserve if just to conserve these species. Considering the fact that large parts of Johore are being developed into plantations or housing estates, it is even more important to conserve what we have in Singapore of such species.

Some species have also been indicated to be rare throughout their range and include *Gardenia griffithii* (Wong, 1989), *Geophila pilosa* (Ridley, 1923), *Morinda ridleyi* (Wong, 1984), *Myrmecodia tuberosa* (Keng, 1985), *Coptosapelta tomentosa*

Table 1. The Rubiaceae of Bukit Timah Nature Reserve.

This table is compiled from collections made recently by us, those prior to 1990 (specimens from the Herbarium, Singapore Botanic Gardens and the Department of Botany Herbarium, the National University of Singapore) and from the literature (Ridley, 1900, 1901, 1923; Keng, 1985).

S/No	Species	Collected in 1990	Previously Collected	Reported
1	*Aidia wallichiana* Tirv.	+	-	-
2	*Coelospermum truncatum* (Wall.) K. & G.	-	+	+
3	*Canthium confertum* Korth.	+	+	-
4	*Canthium horridum* Bl.	+	-	+
5	*Chasalia chartacea* Craib	+	+	-
6	*Chasalia pubescens* Ridl.	-	-	+
7	*Chasalia curviflora* (Wall.) Thw.	-	+	+
8	*Coptosapelta parviflora* Ridl.	-	-	+
9	*Coptosapelta tomentosa* (Bl.) Val. ex K. Heyne	-	-	+
10	*Diplospora malaccensis* Hk.f.	-	+	+
11	*Gaertnera grisea* Hk.f. ex Clarke	+	+	+
12	*Gaertnera viminea* Hk.f. ex Clarke	+	+	-
13	*Gardenia griffithii* Hk.f.	-	-	+
14	*Gardenia tubifera* Wall.	+	+	+
15	*Gardeniopsis longiflora* Miq.	-	-	+
16	*Geophila pilosa* Pearson	-	+	+
17	*Gynochthodes sublanceolata* Miq.	+	-	-
18	*Hedyotis auricularia* L.	+	+	-
19	*Hedyotis capitellata* Wall. ex G. Don	-	-	+
20	*Hedyotis congesta* R.Br. ex G. Don	+	-	+
21	*Hedyotis vestita* R.Br.	-	-	+
22	*Ixora concinna* Hk.f.	-	+	+
23	*Ixora congesta* Roxb.	+	+	+
24	*Ixora pendula* Jack var. *pendula*	+	+	+
25	*Ixora umbellata* K. & V. var. *umbellata*	-	+	-
26	*Jackiopsis ornata* (Wall.) Ridsd.	-	+	+
27	*Lasianthus appressus* Hk.f.	-	-	+
28	*Lasianthus attenuatus* Jack	+	-	+
29	*Lasianthus densifolius* Miq.	+	-	+
30	*Lasianthus ellipticus* Wight	-	-	+
31	*Lasianthus griffithii* Wight	-	-	+
32	*Lasianthus maingayi* Hk.f.	-	+	+

Table 1 (continued).

S/No	Species	Collected in 1990	Previously Collected	Reported
33	*Lasianthus perakensis* K. & G.	+	+	-
34	*Lasianthus ridleyi* K. & G.	+	+	+
35	*Lasianthus stipularis* Bl. var. *hirtus* Ridl. var. *stipularis*	-	-	+
36	*Lasianthus tomentosus* Bl.	-	-	+
37	*Morinda ridleyi* (K. & G.) Ridl.	-	+	+
38	*Mycetia malayana* (Wall. ex Ridl.) Craib	-	+	+
39	*Myrmecodia tuberosa* Jack	-	-	+
40	*Nauclea officinalis* (Pierre ex Pitard) Merr. & Chun	+	+	+
41	*Nauclea subdita* (Korth.) Steud.	-	-	+
42	*Neonauclea pallida* (Reinw. ex Havil.) Bakh.f. ssp. *malaccensis* (Gand.) Ridsd.	-	-	+
43	*Ophiorrhiza singaporensis* Ridl.	+	+	+
44	*Oxyceros frangrantissima* (Ridl.) Wong	+	+	+
45	*Oxyceros longiflora* (Lam.) Yam	-	-	+
46	*Oxyceros penangiana* (K. & G.) Tirv.	-	-	+
47	*Oxyceros scandens* (Bl.) Tirv.	-	+	+
48	*Paederia verticillata* Bl.	-	-	+
49	*Pavetta* sp.	-	-	+
50	*Pertusadina eurhyncha* (Miq.) Ridsd.	+	+	+
51	*Porterandia anisophylla* (Jack ex Roxb.) Ridl.	+	+	+
52	*Prismatomeris glabra* (Korth.) Val.	+	+	-
53	*Psychotria cantleyi* Ridl.	+	-	-
54	*Psychotria griffithii* Hk.f.	-	+	+
55	*Psychotria helferiana* Kurz	+	+	+
56	*Psychotria malayana* Jack	-	-	+
57	*Psychotria ovoidea* Wall.	+	+	+
58	*Psychotria penangensis* Hk.f.	+	+	-
59	*Psychotria ridleyi* K. & G.	-	+	+
60	*Psychotria rostrata* Bl.	-	+	+
61	*Psydrax* sp. 10 of Tree Flora of Malaya 4	+	+	-
62	*Rothmannia macrophylla* (R.Br. ex Hk.f.) Bremek.	+	+	+
63	*Saprosma glomerulatum* K. & G.	-	+	-
64	*Tarenna adpressa* (King) Merr.	-	-	+
65	*Tarenna costata* (Miq.) Merr.	-	+	-
66	*Tarenna mollis* (Wall. ex Hk.f.) B.L. Robinson	-	+	-

Table 1 (continued).

S/No	Species	Collected in 1990	Previously Collected	Reported
67	*Tarenna odorata* (Roxb.) B.L. Robinson	-	+	+
68	*Timonius flavescens* (Jack) Baker	-	+	-
69	*Timonius wallichianus* (Korth.) Val.	+	+	+
70	*Uncaria attenuata* Korth.	-	-	+
71	*Uncaria callophylla* Bl. ex Korth.	-	+	-
72	*Uncaria cordata* (Lour.) Merr.	+	+	+
73	*Uncaria gambir* (Hunt) Roxb.	-	+	+
74	*Uncaria lanosa* Wall. var. *glabrata* (Bl.) Ridsd.	-	+	+
75	*Uncaria longiflora* (Poir.) Merr. var. *pteropoda* (Miq.) Ridsd.	+	+	+
76	*Uncaria roxburghiana* Korth.	-	+	+
77	*Urophyllum blumeanum* (Wight) Hk.f.	+	+	-
78	*Urophyllum corymbosum* (Bl.) Korth.	-	+	-
79	*Urophyllum glabrum* Wall.	+	+	+
80	*Urophyllum griffithianum* (Wight) Hk.f.	+	+	+
81	*Urophyllum hirsutum* (Wight) Hk.f.	+	+	-
82	*Urophyllum* sp. 2 of Tree Flora of Malaya 4	+	+	-
83	*Urophyllum streptopodium* Wall. ex Hk.f.	+	+	+
84	*Urophyllum trifurcum* Pearson ex K. & G.	-	-	+

(Keng, 1985) and *Prismatomeris glabra* (Wong, 1989). The last species however, seems locally abundant in the reserve at present and the rest appear to be extinct. The fact that only one has been collected recently is significant.

Evidence of disturbance in parts of the reserve comes from the presence of species that are weeds or those associated with open areas, forest fringes, secondary forest or regenerating forest. The weeds include *Hedyotis auricularia* and *Hedyotis vestita* (Ridley 1923). The fact that the latter was not collected recently may be because it is an annual and dies out in an area should conditions become unfavourable. Those species found in open areas or forest fringes include *Coelospermum scandens, Coptosapelta tomentosa, Gynochthodes sublanceolata, Uncaria cordata* and *Uncaria roxburghiana* (Ridley 1923; Ridsdale 1978; Sim, Tan and Turner, 1992). Species that are found in secondary forest or regenerating forest include *Porterandia anisophylla* and *Timonius wallichianus* (Wong 1989).

Urophyllum hirsutum is also a species associated with disturbance (K.M. Wong, pers. comm.; our personal observations) and the relative abundance of this species as well as *Porterandia anisophylla* and *Timonius wallichianus* are perhaps an indication that more stringent efforts to minimise disturbance in the reserve are due. One escape from cultivation *Uncaria gambir* which was previously cultivated extensively in Singapore (Wee, 1964; Burkill, 1966; Corlett, 1991a, 1991b, 1992a, 1992b) has been reported in the reserve (Ridley, 1923). No recent collection of this was made however.

Most of the Rubiaceae found in the reserve occur in lowland forest and/or hill forest and lower montane forest of this region. Some have a wider habitat range and also occur in swampy habitats, including *Jackiopsis ornata, Lasianthus griffithii, Nauclea officinalis, Nauclea subdita, Saprosma glomerulatum, Tarenna adpressa, Tarenna odorata* and *Urophyllim trifurcum* (Wong, 1989). *Tarenna adpressa* was reported by Wong (1989) to be exclusively restricted to swamp forest but was reported to occur in the reserve by Keng (1985, 1990). Unfortunately, the specimen cited by Keng (H.N. Ridley *s.n.*, 1986) could not be located in SING for verification. The species which also are found in riverine habitats include *Jackiopsis ornata, Nauclea subdita, Neonauclea pallida* and *Oxyceros fragrantissima* (tidal) (Ridley, 1923; Wong, 1989). Species also reported by Wong (1989) to occur in limestone areas include *Lasianthus stipularis, Mycetia malayana, Neonauclea pallida* and *Aidia wallichiana.*

In habit, the shrubs, treelets or trees are the most plentiful with 57 species (Table 2) and this is in agreement with observations of Ridley (1923), Keng (1985, 1990) and Corlett (1990). Only five species have maximum heights of 30 m or more. Nine species have maximum heights of greater than 10 to 25 m and ten species greater than 5 to 10 m. The remaining 33 are 5 m or less in height. *Myrmecodia tuberosa* is exceptional in that it is an epiphytic shrub unlike all the rest which are terrestrial plants. It is also a myrmecophyte or plant with an ant-association.

Climbers are next most plentiful, with 22 species and herbs are the smallest in number with five. The climbers include *Coelospermum truncatum*, two *Coptosapelta* species, *Gynocthodes sublanceolata, Hedyotis capitellata, Morinda ridleyi*, four *Oxyceros* species, *Paederia verticillata*, four *Psychotria* species and seven *Uncaria* species. These climb by twining except the species of *Oxyceros* and *Uncaria* climb by means of hooks and *Psychotria* which creep up boles by means of clasping adventitious roots. The five species of herbs include *Geophila pilosa*, three *Hedyotis* species and *Ophiorrhiza singaporensis*.

Keys to the identification of BTNR Rubiaceae

This section consists of a main key which can be used to identify genera which have two or more species in the reserve or species which are the only representatives

Table 2. Heights of shrubs, treelets and trees in the Rubiaceae of the Bukit Timah Nature Reserve.

The species are arranged in descending order of maximum height recorded. This list is based on Ridley (1923) or Wong (1988, 1989). This table lists 56 species but there is one more. *Pavetta indica* listed by Ridley (1923) consists of a number of different taxa (Wong, 1989). Both herbaria do not have the specimen(s) on which Ridley based his observation and thus the maximum height(s) cannot be listed because their identities cannot be confirmed.

S/No	Species	Maximum Height (m)
1	*Jackiopsis ornata*	35
2	*Gardenia tubifera*	30
3	*Nauclea officinalis*	30
4	*Pertusadina eurhyncha*	30
5	*Tarenna costata*	30
6	*Nauclea subdita*	25
7	*Psydrax* sp. 10 of Tree Flora of Malaya 4	23
8	*Canthium confertum*	18
9	*Diplospora malaccensis*	18
10	*Tarenna mollis*	16
11	*Aidia wallichiana*	15
12	*Urophyllum trifurcum*	15
13	*Porterandia anisophylla*	12
14	*Timonius flavescens*	12
15	*Ixora pendula*	10
16	*Urophyllum corymbosum*	9
17	*Gardeniopsis longiflora*	8
18	*Ixora concinna*	8
19	*Urophyllum blumeanum*	8
20	*Timonius wallichianus*	7
21	*Urophyllum streptopodium*	7
22	*Gardenia griffithii*	6
23	*Ixora congesta*	6
24	*Tarenna odorata*	6
25	*Gaertnera grisea*	5
26	*Lasianthus densifolius*	5
27	*Lasianthus tomentosus*	5
28	*Urophyllum glabrum*	5
29	*Urophyllum griffithianum*	5
30	*Urophyllum* sp. 2 of Tree Flora of Malaya 4	5
31	*Ixora umbellata*	4
32	*Lasianthus ellipticus*	4
33	*Lasianthus griffithii*	4
34	*Lasianthus perakensis*	4
35	*Mycetia malayana*	4

Table 2 (continued).

S/No	Species	Maximum Height (m)
36	*Prismatomeris glabra*	4
37	*Tarenna adpressa*	4
38	*Canthium horridum*	3
39	*Chasalia chartacea*	3
40	*Gaertnera viminea*	3
41	*Lasianthus appressus*	3
42	*Lasianthus maingayi*	3
43	*Psychotria malayana*	3
44	*Psychotria rostrata*	3
45	*Rothmannia macrophylla*	3
46	*Saprosma glomerulatum*	3
47	*Urophyllum hirsutum*	3
48	*Chasalia curviflora*	2
49	*Chasalia pubescens*	2
50	*Lasianthus ridleyi*	2
51	*Lasianthus stipularis*	2
52	*Neonauclea pallida*	2
53	*Lasianthus attenuatus*	1
54	*Myrmecodia tuberosa*	1
55	*Psychotria griffithii*	1
56	*Psychotria helferiana*	1

of their genus. The generic keys to the species are alphabetically arranged according to the generic names and placed after the main key.

The main key and most of the generic keys to species were largely based on Wong (1989) and an emphasis has been placed on field characters and sterile material as the main use envisaged for it will be ecological or floristic studies. Flower and fruit characters were used only when unavoidable. Technical language has been employed for precision and accuracy.

One family which is common in BTNR and easily confused with the Rubiaceae when sterile is the Rhizophoraceae. The genera *Gynotroches* and *Pellacalyx* also have opposite leaves and interpetiolar stipules but can be distinguished by their young plants which often have laminas with crenate, shallowly serrate or dentate margins whereas all members of the Rubiaceae have leaves with entire margins. Additionally, the twigs are hollow in the Rhizophoraceae but usually solid in the Rubiaceae.

To use these keys, obtain at least a fairly large portion of the plant, a branch and the main branch/stem to which it is attached as many genera are diagnosed by the architecture of branches or, where collection is prohibited, make sketches in a notebook and collect fallen leaves. There are insufficient characters for use in identification with only small scraps. Drying the material also helps as some characters are based on dried specimen characteristics. This also facilitates the identification of specimens by comparison with herbarium specimens. However, note the fresh characters in particular, fleshiness, scent of crushed leaves, shape of stipules, etc. which are also used in the keys. It is important that stipules are collected as this feature is important for distinguishing certain taxa.

Once the identity of the specimen has been determined by use of the key, compare the specimen with herbarium sheet specimens to verify its identity. Genera in urgent need of revision are *Lasianthus, Psychotria* and *Urophyllum.*

Rubiaceae

Important references: Ridley, Flora of the Malay Peninsula 2 (1923) 3-177, 5 (1925) 313-318; Corner, Wayside Trees of Malaya 3rd ed. (1988); Wong, Tree Flora of Malaya 4 (1989) 324-425.

Habit: Herbs, shrubs, treelets, trees or climbers. *Stems* or trunks unarmed or rarely spiny (*Canthium horridum, Oxyceros, Uncaria*), with a swollen base containing ant-inhabiting channels (*Myrmecodia*). *Inner bark* without milky latex. *Branches* paired or rarely solitary (*Lasianthus*). *Leaves* opposite, distichous, decussate or whorled, sometimes with one leaf reduced at alternate nodes (*Aidia*, Fig. 1f) or at the node just below the inflorescence (*Porterandia*); occasionally with acarodomatia in the axils of secondary veins of the lower leaf surface (*Canthium, Psydrax*); occasionally with wart-like bacterial nodules in leaf tissue (*Pavetta*). *Stipules* interpetiolar, rarely intrapetiolar (*Myrmecodia*), free or fused at the base or along the entire margin to form cup or cylinder. *Inflorescence* various, terminal, axillary or in cup-like cavities of the stem (*Myrmecodia*). *Flowers* bisexual or unisexual, homostylous or heterostylous (*Hedoytis capitellata),* mostly 4-5 merous; calyces variously shaped, base fused into a tube or cup, lobes free to absent, abscising early or persistent, occasionally developing into wings (*Jackiopsis*); corollas variously shaped, based fused into a tube, lobes free, valvate or contorted in bud; stamens as many and alternate with corolla lobes, inserted on the inner side of the corolla tube; disc present; ovary inferior, rarely half-inferior or superior (*Gaertnera*), 1-many loculate, 1-many ovules per locule. *Fruit* various, simple (from a single ovary of one flower) or multiple (from an inflorescence) (*Morinda,*), dehiscent or indehiscent, dry or fleshy. *Seeds* 1-many per fruit, rarely winged (*Uncaria*), endospermous or not (*Timonius*).

Key to the Genera and Species

1a Epiphytic shrubs with swollen ant-inhabited stem base bearing long-straight spines. Stipules intrapetiolar .... *Myrmecodia tuberosa.*

1b Herbs, shrubs, treelets, trees or climbers without swollen ant-inhabited stem base. Stipules interpetiolar or, fused into a cup-like or cylindrical sheath 2

2a Herbs 3

2b Shrubs, treelets, trees, climbers or scrambling shrubs 5

3a Ground creeper, rooting at nodes. Laminas cordate-reniform .... *Geophila pilosa.*

3b Erect plants, if rooting at the nodes, then only at the base of mainly erect stems. Laminas narrowly elliptic to elliptic or oblong 4

4a Capsules laterally compressed, obcordate. Flowers in bifurcating branched terminal cymes .... *Ophiorrhiza singaporensis.*

4b Capsules globose to subglobose or drupes ellipsoid to oblong containing two pyrenes. Flowers in dense axillary clusters .... *Hedyotis* (in part) (See key to species.)

5a Climbers or scrambling shrubs 6

5b Shrubs, treelets or trees 15

6a Mature stems and branches bearing thorns at the axils (modified axillary buds) 7

6b Mature stems and branches unarmed 9

7a Woody climbers with paired strongly recurved (G-shaped) spines. Inflorescences in terminal heads. Corolla lobes valvate in bud .... *Uncaria* (See key to species.)

7b Scrambling shrubs or woody climbers with paired straight to recurved (J-shaped) spines. Inflorescences in terminal or axillary cymes. Corolla lobes contorted or valvate in bud 8

8a Laminas less than 4 cm long, hairy below at least on veins. Inflorescences axillary. Corolla lobes valvate in bud .... *Canthium horridum* (in part).

8b Laminas more than 4 cm long, glabrous below. Inflorescences terminal. Corolla lobes contorted in bud .... *Oxyceros* (See key to species.)

9a Leaves of main stem sessile, 1-3 cm long, linear-lanceolate to lanceolate; leaves of the side branches petiolate, 2-15 cm long, laminas lanceolate to ovate, narrowly elliptic to elliptic. Fruit a loculicidal and septicidal capsule .... *Hedyotis capitellata*

9b Leaves only of one form. Fruit a drupe containing pyrenes, loculicidal capsule or syncarp (developed from a head inflorescence) 10

10a Laminas below short-hairy on the intercostal regions and long appressed-hairy on veins; stipules fused along one side, 10-15 mm long. Inflorescence a terminal pseudo-umbel consisting of stalked heads. Ovaries connate........ .... *Morinda ridleyi.*

10b Not this combination of characters 11

11a Fresh laminas foetid when crushed. Corolla lobes valvate in bud. Fruit dry, exocarp splitting into two valves; pyrenes winged .... *Paederia verticillata.*

11b Not this combination of characters 12

12a Dried laminas black above and dark grey with black veins below. Flowers in axillary heads. .... *Gynochthodes sublanceolata*

12b Not this combination of characters 13

13a Stems rooting at nodes and internodes, climbing by creeping upwards on trunks of trees, fleshy and usually hairy, like the leaves. Inflorescences terminal. Fruit baccate with two seeds. ....
.... *Psychotria* (in part) (See key to species.)

13b Not this combination of characters, ... 14

14a Laminas glabrous beneath; stipules free, entire. Corolla lobes contorted in bud. Fruit a loculicidal capsule. No raphides present. ....
.... *Coptosapelta* (See key to species.)

14b Laminas hairy beneath; stipules connate at base, bifid or entire. Fruit a drupe with 2-4 pyrenes. Raphides present. .... *Coelospermum truncatum.*

15a Laminas with dark, wart-like bacterial nodules .... *Pavetta.*

15b Laminas without bacterial nodules 16

16a Stipules with many long (>1 cm long) linear teeth .... *Jackiopsis ornata.*

16b Not so 17

17a Alternate nodes along lateral branches with one leaf highly reduced or absent .... *Aidia wallichiana* (Fig. 1f).

17b Nodes along lateral branches with more or less equal-sized leaves or without one undeveloped 18

18a Twigs with 1-4 closely set annular stipular scars marking leafless flowering nodes immediately above most nodes .... *Gardeniopsis longifolia.*

18b Twigs not so, if closely set leafless nodes occur, they are always associated with branching points, ... 19

19a Twigs and stem bark corky or spongy, pale brown to white 20

19b Twigs not so 21

20a Tertiary veins of the lamina ladder-like between secondary veins. Stem bark smooth. .... *Mycetia malayana.*

20b Tertiary veins of the lamina reticulate. Stem bark fissured or smooth. .... *Urophyllum* (in part) (See key to species.)

21a Stipules falling away to reveal persistent stiff bristles along the base on the inner side. Laminas foetid when crushed .... *Saprosma glomerulatum.*

21b Stipules not so. Laminas not foetid except in some *Lasianthus* species ... 22

22a Stipules fused along more than half their length from the base, along one or both edges, into a cylinder or cup 23

22b Stipules free or fused for less than half the length or stipular sheath not cylindric 25

23a Stipular cylinder or cup with 4 marginal teeth... .... *Gaertnera* (See key to species.)

23b Stipular cylinder or cup with entire margin or at most a cleft margin 24

24a Vegetative buds resinous. Stipules glabrous outside. .... *Gardenia* (See key to species.)

24b Vegetative buds non-resinous. Stipules hairy outside.................................. .... *Porterandia anisophylla* (in part).

25a Stipules with bifid tips, incised or jagged margins 26

25b Stipules with entire margins 28

26a Internodes with prominent median longitudinal interpetiolar ridge running the entire length (more distinct in dried twigs.) .... *Prismatomeris glabra* .

26b Internodes not so 27

27a Stipules with jagged margins. Adult trees without trunk slits ....*Psychotria* (in part) (See key to species.)

27b Stipules bifid. Adult trees developing slits in trunk, giving the impression that a strangler fig's roots have completely surrounded the trunk .... *Pertusadina eurhyncha*

28a Vegetative terminal bud flattened. Stipules ovate, elliptic or obovate, tightly appressed into a flat structure at shoot tips, the edges not overlapping 29

28b Vegetative terminal bud more or less conical. Stipules triangular, ovate or linear, either mutually overlapping around the bud or loosely surrounding it 32

29a Laminas apex abruptly narrowed to a slender tip; tertiary veins close together (to only 2-3 mm apart) and subparallel, prominent on lower surface; secondary veins more than 7 pairs. Inflorescence axillary .... *Urophyllum* (in part) (See key to species.)

29b Laminas not so. Inflorescence terminal 30

30a Flowers not in heads. Stipules triangular to ovate (rarely elliptic). Secondary veins flat or raised above, not distinctly looping toward the leaf margin. Twigs drying black .... *Psychotria* (in part) (See key to species.)

30b Flowers in heads 31

31a Secondary veins of lamina depressed above or else not conspicuously looping near the margin. Flower calyces not fused ..... *Nauclea* (See key to species.)

31b Secondary veins of lamina flat above and conspicuously looping near the margin. Flower calyces free .... *Neonauclea pallida* ssp. *malaccensis.*

32a Stipules on upper side of branches developing a narrow apical lobe. .... *Psydrax* sp. 10 of Tree Flora of Malaya 4 (in part)

32b Stipules not so 33

33a Plants with straight paired spines .... *Canthium horridum* (in part)

33b Unarmed plants 34

34a Stipules broadly triangular, hairy inside and outside, fused at the base or more, on 1 or 2 sides, the bases usually persistent. Corollas drying silvery hairy. .... *Porterandia anisophylla* (in part)

34b Not this combination of characters 35

35a Main branches rather straight, horizontal or ascending, sometimes with drooping tips. Laminas along branches mostly in one plane 36

35b Main branches ascending, repeatedly forking or composed of a series of branches of higher orders each upturned and bearing closely set pairs of leaves. Laminas along branches mostly decussate 41

36a Branches solitary along stem or trunk .... *Lasianthus* (See key to species.)

36b Branches mostly in pairs 37

37a Stipule apex drawn out into a linear tail at least as long as the basal part. Corollas 8-15 cm long .... *Rothmannia macrophylla.*

37b Stipule apex acute or ending in a stiff cusp, or the whole stipule linear. Corollas shorter than 8 cm 38

38a Smaller branch pairs along main branches mostly in one plane. Stipules ovate, triangular, acute, blunt or linear, without a stiff apical cusp .... *Urophyllum* (in part) (See key to species.)

38b Smaller branch pairs along main branches with alternate pairs with one branch horizontal and the other deflexed (or reduced), the adjacent pair with one branch horizontal on the opposite side and the other deflexed (or reduced) and so on. Stipules triangular, distinctly cusped 39

39a Laminas without domatia in axils of secondary veins, mostly longer than 4 cm; midrib depressed above .... *Diplospora malaccensis**.

39b Laminas frequently with domatia in secondary vein axils, otherwise longer than 4 cm; midrib raised or flat above 40

40a Stigma long exserted from the corolla, cylindric with a conspicuous basal recess. Laminas with a wavy margin; drying dull to shiny, reddish to greenish brown or black above and green to brown below. .... *Psydrax* sp. 10 of Tree Flora of Malaya 4 (in part).

40b Stigma only slightly protruding from the corolla, globose without a conspicuous basal recess. Laminas with a plane margin; drying dull green above and below. .... *Canthium confertum*

41a Lamina base cordate or auriculate 42

41b Lamina base acute or rounded 43

42a Laminas broadly ovate, elliptic or obovate*Ixora* (in part) (See key to species.)

42b Laminas oblanceolate .... *Psychotria* (in part) (See key to species.)

43a Lower leaf surface densely silvery hairy .... *Timonius wallichianus* (Fig. 2)

43b Lower lamina surface if hairy, not silver, ... 44

44a Points of branching mostly with closely set series of leafless nodes. Stipules cusped. .... *Ixora* (in part) (See key to species.)

44b Points of branching without closely set series of leafless nodes. Stipules not cusped. 45

45a Stipules falling to leave a papery-thin pale basal portion at branch nodes. Twigs terete, smooth 46

45b Stipules falling clean, or remains of its basal portion dark-coloured or leathery. Twigs terete or angular, smooth, ridged or wrinkled 47

46a Tertiary veins very fine and immersed in lamina below. Inflorescence branches fleshy or swollen, white or pink .... *Chasalia* (See key to species.)

46b Tertiary veins prominent in the lamina below. Inflorescence branches not so. .... *Psychotria* (in part) (See key to species.)

47a Stipules ovate, drying with a pale margin. .... *Tarenna* (in part) (See key to species.)

47b Stipules not so 48

48a Tertiary veins of lamina close together and subparallel, running almost perpendicular to the midrib. Inflorescence axillary, cymose. .... *Timonius flavescens*

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* - Ali and Robbrecht (1991) have indicated that this species rightly belongs to the tribe Hypobathreae and not the Gardenieae, its traditional position. They have not, as yet determined its generic position.

48b Tertiary veins of lamina reticulate, scalariform or obscure. Inflorescence terminal, or if axillary then heads or cymes 49

49a Leaf stalk base nearly encircled by a narrow ridge ...... *Psychotria malayana*

49b Leaf stalk base not so 50

50a Twig internodes conspicuously 4-grooved, along the petiolar and interpetiolar medians .... *Tarenna* (in part) (See key to species.)

50b Twig internodes only 2-grooved or irregularly grooved or not 51

51a Lower leaf surface uniformly velvety or rough hairy 52

51b Lower leaf surface if hairy, only on the veins or very scantily so, never or rough 53

52a Laminas drying reddish brown, tertiary veins obscure below ....*Psychotria* (in part) (See key to species.)

52b Laminas drying medium to greenish brown, tertiary veins faint to distinct... .... *Tarenna* (in part) (See key to species.)

53a Tertiary veins on lower lamina surface obscure 54

53b Tertiary veins on lower lamina surface distinct 57

54a Stipules cusped or narrowly triangular with a linear tail 55

54b Stipules ovate, acute, without a cusp or tail 56

55a Secondary veins of lamina 14 pairs or more; otherwise lamina margin recurved and young internodes with a median ridge on each side ....*Psychotria* (in part) (See key to species.)

55b Secondary veins of lamina less than 14 pairs; if lamina margin recurved then young internodes with a median groove on each side .... *Tarenna* (in part) (See key to species.)

56a Laminas with acute to attenuate tips; otherwise secondary veins greater than 10 pairs ....*Psychotria* (in part) (See key to species.)

56b Laminas with blunt apices and less than 10 pairs of secondary veins .... *Tarenna* (in part) (See key to species.)

57a Tertiary veins ladder-like between secondary veins on lower lamina surface .... *Tarenna* (in part) (See key to species.)

57b Tertiary veins reticulate on lower lamina surface 58

58a Secondary veins of lamina looping near margin 59

58b Secondary veins of lamina not looping near margin, fading towards the tips of the veins .... *Tarenna* (in part) (See key to species.)

59a Marginal vein loops of lamina very distinct, uninterrupted and as thick the secondary veins; otherwise stipules cusped and twigs terete .... *Psychotria* (in part) (See key to species.)

59b Marginal vein loops of lamina more faint than secondary veins, often interrupted by smaller vein points; stipules narrowly triangular to ovate, or if cusped, then twigs distinctly 4-angled .... *Tarenna* (in part) (See key to species.)

Key to the Species of *Chasalia*

1a Leaves completely glabrous .... *C. chartacea.*

1b Leaves hairy below, at least on veins 2

2a Leaves hairy on veins below .... *C. curviflora.*

2b Leaves hairy all over below .... *C. pubescens.*

Key to the Species of *Coptosapelta*

1a Corolla green, c. 1 cm long .... *C. parviflora.*

1b Corolla white, c. 2.5 cm long .... *C. tomentosa.*

Key to the Species of *Gaertnera*

1a Laminas hairy below, velvety to the touch; 9-27 cm long; coriaceous; stipules densely hairy. Twigs about 5 mm in diameter or more, densely hairy especially when young .... *G. grisea* (Fig. 3).

1b Laminas glabrous below, smooth to the touch; 4-10 cm long; chartaceous to subcoriaceous; stipules glabrous or with minute hairs at the top. Twigs 1.5-2 mm in diameter; glabrous .... *G. viminea.*

Key to the Species of *Gardenia*

1a Midrib above hairy and veins below hairy .... *G. griffithii.*

1b Midrib above glabrous and veins below glabrous or hairy .... *G. tubifera.*

Key to the Species of *Hedyotis*

1a Stem and leaves hairy. Corollas white, lilac or purple 2

1b Stem and leaves glabrous. Corollas white to light yellow or yellow to greenish yellow 3

2a Flowers in dense axillary clusters without distinct branches; corollas white, tube glabrous outside. Stem covered with white hairs .... *H. auricularia.*

2b Flowers in dense axillary clusters with distinct branches; corollas lilac or purple, tube hairy outside. Stem covered in yellowish brown hairs .... *H. vestita.*

3a Twining climber. Leaves of the main twining stem sessile, 1-3 cm long, linear-lanceolate to lanceolate; leaves of the side branches petiolate, 2-15 cm long, lanceolate to ovate, narrowly elliptic to elliptic. Fruit a loculicidal and septicidal capsule, purple and thin-walled when ripe and fresh .... *H. capitellata.*

3b Erect shrub-like herb. Leaves of only one form; petiolate, (4-)10-15(-18) cm long, lanceolate to ovate, narrowly elliptic to elliptic. Fruit indehiscent, white and fleshy when ripe and fresh .... *H. congesta.*

Key to the Species of *Ixora*

1a Inflorescence bracts and calyx lobes ovate to narrowly elliptic or lanceolate, at least twice as long as calyx tube. .... *I. umbellata* var. *umbellata.*

1b Inflorescence bracts and calyx lobes not as conspicuous, not longer than the calyx tube, or if longer, then linear in form 2

2a Corolla lobes narrowly to broadly elliptic to obovate or rounded, wider than 2 mm .... *I. congesta.*

2b Corolla lobes narrowly elliptic to lanceolate or linear, not wider than 2 mm3

3a Corolla tube c. 1 mm at the middle. .... *I. concinna.*

3b Corolla tube very narrow, not wider than 0.5 mm at the middle .... *I. pendula* var. *pendula.*

Key to the Species of *Lasianthus*

1a Laminas narrowly lanceolate, narrower than 1.5 cm 2

1b Laminas of various shapes, broader than 1.5 cm 4

2a Upper lamina surface (less midrib) glabrous .... *L. attenuatus* (in part).

2b Upper lamina surface (less midrib) hairy 3

3a Upper lamina surface sparsely covered with appressed hairs. Calyx lobes at least as long as fruit ....L. *attenuatus* (in part).

3b Upper lamina surface densely covered with suberect hairs. Calyx lobes shorter than fruit .... *L. densifolius* (in part) (Fig. 4).

4a Lower lamina surface glabrous (without magnification) 5

4b Lower lamina surface hairy, at least on the veins (without magnification) . 6

5a Stipules, if conspicuous, triangular and not covering the leaf stalk. Inflorescence bracts none or inconspicuous, or triangular ovate ....*L. maingayi.*

5b Stipules large, ovate and covering at least half the leaf stalks. Inflorescence bracts linear, hairy and as long as the leaf stalks *L. stipularis* var. *stipularis.*

6a Upper lamina surface (less midrib) hairy 7

6b Upper lamina surface (less midrib) glabrous 9

7a Leaf stalks 0.5 cm or more long ....*L. stipularis* var. *hirtus.*

7b Leaf stalks less than 0.5 cm long, ... 8

8a Upper lamina surface sparsely covered with appressed hairs. Calyx lobes at least as long as fruit ....*L. attenuatus* (in part).

8b Upper lamina surface densely covered with suberect hairs. Calyx lobes shorter than the fruit .... *L. densifolius* (in part) (Fig. 4).

9a Twigs with erect or suberect hairs 10

9b Twigs glabrous or with appressed hairs 17

10a Hairs along midrib on lower leaf surface appressed 11

10b Hairs along midrib on lower leaf surface erect or semierect 12

11a Laminas ovate, frequently bullate between the veins ... *L. appressus* (in part).

11b Laminas elliptic to obovate, never bullate between the veins .... *L. tomentosus* (in part).

12a Midrib on upper leaf surface hairy 13

12b Midrib on upper leaf surface glabrous 14

13a Stipules narrowly triangular to linear ....*L. attenuatus* (in part).

13b Stipules broadly ovate (lamina base acute and quite symmetric) ....*L. stipularis* var. *hirtus.*

14a Secondary veins more than15 pairs .... *L. griffithii.*

14b Secondary veins less than 12 pairs 15

15a Laminas ovate ....*L. ridleyi* (in part).

15b Laminas elliptic to ovate 16

16a Laminas broader than 4 cm. Inflorescence bracts filiform, c. 5 mm long and conspicuous .... *L. ridleyi* (in part).

16b Laminas generally narrower than 4 cm. Inflorescence bractstriangular to ovate, less than 3 mm long and inconspicuous .... *L. tomentosus* (in part).

17a Lower lamina surface velvety to touch 18

17b Lower lamina surface not velvety to touch 20

18a Twigs yellow-hairy. Leaves not broader than 3 cm . *L. appressus.* (in part).

18b Twigs brown-hairy. Leaves broader than 3 cm 19

19a Tertiary veins distinctly hairy below. Calyx silky long-hairy .... *L. ellipticus*

19b Tertiary veins minutely hairy below (with magnification). Calyx short hairy .... *L. perakensis* (in part).

20a Midrib raised above. .... *L. maingayi* (in part).

20b Midrib flat or sunken above .... *L. perakensis* (in part).

Key to the Species of *Nauclea*

1a Laminas usually drying bright yellowish brown (rarely dull brown); stipules flat. Twigs drying dark brown. Flowering and fruiting heads in groups of 2-5 (rarely singly) .... *N. officinalis*

1b Laminas usually drying dark purplish brown (rarely greenish brown); stipules with a central keel. Twigs drying white to pale brown. Flowering and fruiting heads solitary .... *N. subdita*

Key to the Species of *Oxyceros*

1a Branches descending, bearing recurved spines only at the proximal first nodes of branches 2

1b Branches horizontal or ascending, bearing recurved spines in pairs at usually two or more nodes of branches 3

2a Laminas chartaceous to coriaceous with margins flat in dried specimens. Corolla lobes narrow, less than 4 mm wide; calyx tube 4-5 mm long; stigma lobes appressed. Mature fruit less than 10 mm across .... *O. fragrantissima.*

2b Laminas thickly coriaceous with margins recurved in dried specimens. Corolla lobes broad, 7-13 mm wide; calyx tube 7-12 mm long; stigma lobes spreading apart. Mature fruit 15-20 mm across .... *O. scandens.*

3a Laminas apex acute; tertiary veins indistinct. Stigma lobes appressed. .... *O. longiflora.*

3b Laminas apex caudate; tertiary veins distinct. Stigma lobes parted .... *O. penangiana.*

Key to the Species of *Psychotria*

1a Shrubs or treelets 2

1b Climbers 6

2a Upper lamina surface hairy .... *P. helferiana.*

2b Upper lamina surface glabrous 3

3a Lower lamina surface hairy at least on the midrib and secondary veins (without magnification). .... *P. rostrata* (in part).

3b Lower lamina surface glabrous (without magnification) 4

4a Base of leaf stalk fringed by a narrow ridge running around its lower side .. .. *P. malayana.*

4b Base of leaf stalk not fringed by a ridge 5

5a Secondary veins inarching strongly to form distinct marginal loops 2-3 mm from the leaf margin .... *P. rostrata* (in part).

5b Secondary veins not looping at the margin, or fading with indistinct loops .. .. *P. griffithii.*

6a Laminas generally 7.5-17 cm long 7

6b Laminas generally 3-6 cm long 8

7a Laminas coriaceous, 1-2 times longer than broad, dull green when fresh, brown to dark brown when dry, with hairy petioles and midrib and secondary veins below. Inflorescence and young stems hairy .... *P. penangensis.*

7b Laminas membranous, 2-3 times longer than broad, bright green when fresh, light yellow to brownish yellow when dry. Whole plant glabrous. *P. ridleyi.*

8a Plant entirely glabrous .... *P. cantleyi.*

8b Stem, petioles, midrib and secondary veins of the lamina below and inflorescence hairy .... *P. ovoidea* (Fig. 5).

Key to the Species of *Tarenna*

1a Stipules triangular to ovate, with acute apex, drying with a pale margin .... *T. mollis.*

1b Stipules triangular, sometimes with lateral wings, with cuspidate to caudate apex, drying completely brown 2

2a Upper lamina surface hairy .... *T. costata.*

2b Upper lamina surface glabrous, or hairy only on the midrib 3

3a Lower surface of mature laminas uniformly short-hairy .... *T. adpressa.*

3b Lower surface of mature laminas glabrous to the naked eye, or hairs visible only with magnification .... *T. odorata.*

Key to the Species of *Uncaria*

1a Laminas glabrous above and below, or at most hairy at the angle between secondary veins and the midrib 2

1b Laminas hairy above and/or below, especially at the veins 3

2a Underside of lamina glaucous; petiole winged; lamina (including petiole) 13.5-19 cm long by 8-16 cm wide .... *U. longiflora* var. *pteropoda.*

2b Underside of lamina not glaucous; petiole wingless; lamina (including petiole) 4.5-13.5 cm long by 2-6 cm wide 3

3a Angle between the secondary veins and midrib of the lamina hairy .... *U. gambir.*

3b Angle between the secondary veins and midrib of the lamina glabrous .... *U. calophylla.*

4a Lamina base cordate 5

4b Lamina base obtuse to acute 6

5a Laminas of mature leaves 11-20 cm lng by 6-14 cm wide; stipules bifid .... *U. cordata.*

5b Laminas of mature leaves 4.5-6.5 cm long by 2-5 cm wide; stipules entire .... *U. roxburghiana.*

6a Corolla glabrous on the outside; flowers usually distinctly pedicellate .... *U. lanosa* var. *glabrata.*

6b Corolla hairy on the outside; flowers usually sessile .... *U. attenuata.*

Key to the Species of *Urophyllum*

1a Tertiary veins generally more or less perpendicular to the midrib of the lamina 2

1b Tertiary veins generally distinctly reticulate and/or ladder-like between (and perpendicular to) the secondary veins, not perpendicular to the midrib of the lamina 6

2a Laminas glabrous below 3

2b Laminas hairy below, at least on the midrib 4

3a Intermediate veins not developed or not conspicuous between secondary veins of the lamina. Corolla throat scantily hairy. Stipules strap-shaped, slightly waisted, fairly persistent such that most shoot tips possess them .... *U. blumeanum* (in part) (Fig. 1a).

3b Intermediate veins well-developed, distinct and reaching halfway to the leaf margin. Corolla throat densely hairy. Stipules linear, abscising early such that only a few young shoots possess them .... *U.* sp. 2 of Tree Flora of Malaya 4 (Fig. 1e).

4a Hairs on twigs and leaf veins dark-coloured, reddish or brownish .... *U. blumeanum* (in part) (Fig. 1a).

4b Hairs on twigs and leaf veins pale yellowish or white 5

5a Inflorescence sessile, resembling a fascicle. (Very similar to *U. blumeanum* which is distinguished only by its pedunculate inflorescences.) .... *U. streptopodium* (Fig. 1a).

5b Inflorescence always distinctly pedunculate. (Very similar to *U. streptopodium* which is distinguished only by its sessile inflorescences.) .... *U. blumeanum* (in part) (Fig. 1a).

6a Midrib on upper leaf surface densely hairy throughout .... *U. trifurcum* (in part).

6b Midrib on upper leaf surface glabrous or hairy near the leaf base only (less than halfway to the leaf tip) 7

7a Leaves hairy to the naked eye (at least the midrib on the lower surface) 8

7b Leaves glabrous to the naked eye 10

8a Laminas narrower than 5 cm .... *U. hirsutum* (Figs. 1d, 6).

8b Laminas on twigs mostly wider than 5 cm 9

9a Hairs on midrib below appressed .... *U. corymbosum* (in part).

9b Hairs on midrib below spreading to erect .... *U. trifurcum* (in part).

10a Stipules with a prominently thickened ridge-like base encircling the twig, rhomboidal. Inflorescence a shortly stalked umbel .... *U. griffithianum* (Fig. 1c).

10b Stipules without a thickened ridge-like base encircling the twig, strap-shaped, rhomboidal or broadly triangular. Inflorescence a shortly stalked umbel, fascicle, branched corymb or solitary flower 11

11a Inflorescence a condensed corymb with very short (less than 0.5 cm long) stalk and branches, sometimes reduced to 1-2 flowers ....
.... *U. glabrum* (in part) (Fig. 1b).

11b Inflorescence a distinctly branched corymb or pedunculate and umbel-like with 1-2 groups of flowers 12

12a Inflorescence umbel-like with 1-2 groups of flowers ....
.... *U. glabrum* (in part) (Fig. 1b).

12b Inflorescence a distinctly branched corymb 13

13a Calyx cups 4-5 mm wide .... *U. trifurcum* (in part).

13b Calyx cups narrower than 3 mm .... *U. corymbosum* (in part).

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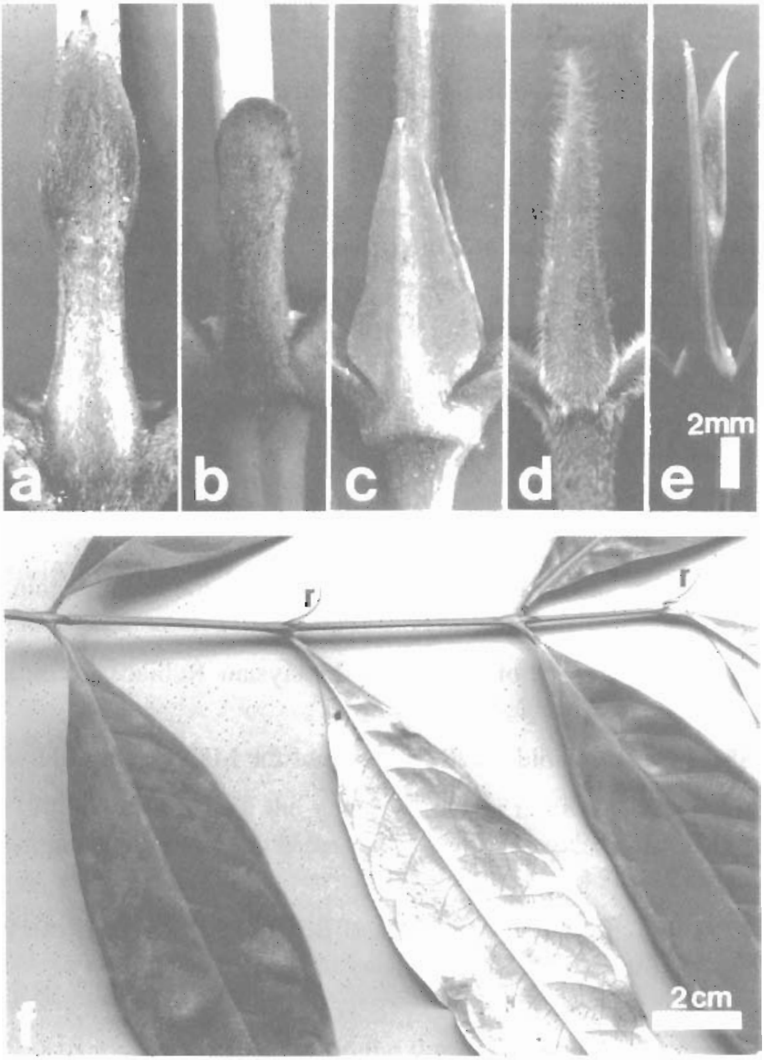

Figure 1. a.-e. Stipules in *Urophyllum*; a. *U. blumeanum* or *U. streptopodium*; b. *U. glabrum*; c. *U. griffithianum*; d. *U. hirsutum*; e. *U.* sp. 2 of Tree Flora of Malaya 4; f. Branch of *Aidia wallichiana* with one leaf reduced (r) at alternate nodes.

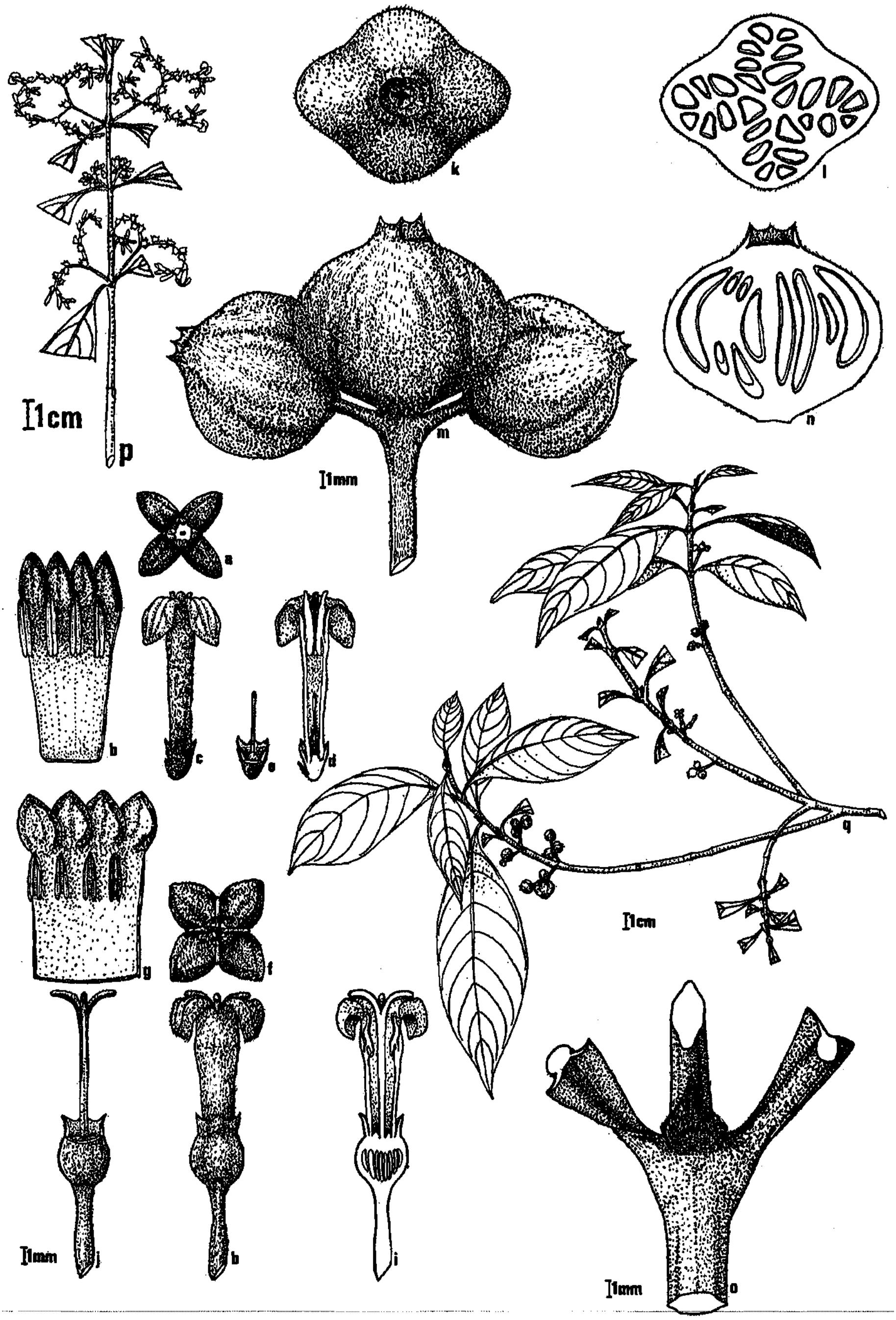

Figure 2. *Timonius wallichianus* (Korth.) Val. a.-e. Male flower; f.-j. Female flower; k.-n. Fruit; o. Stipule; p. Male inflorescences on branch; q. Female inflorescences on branch.

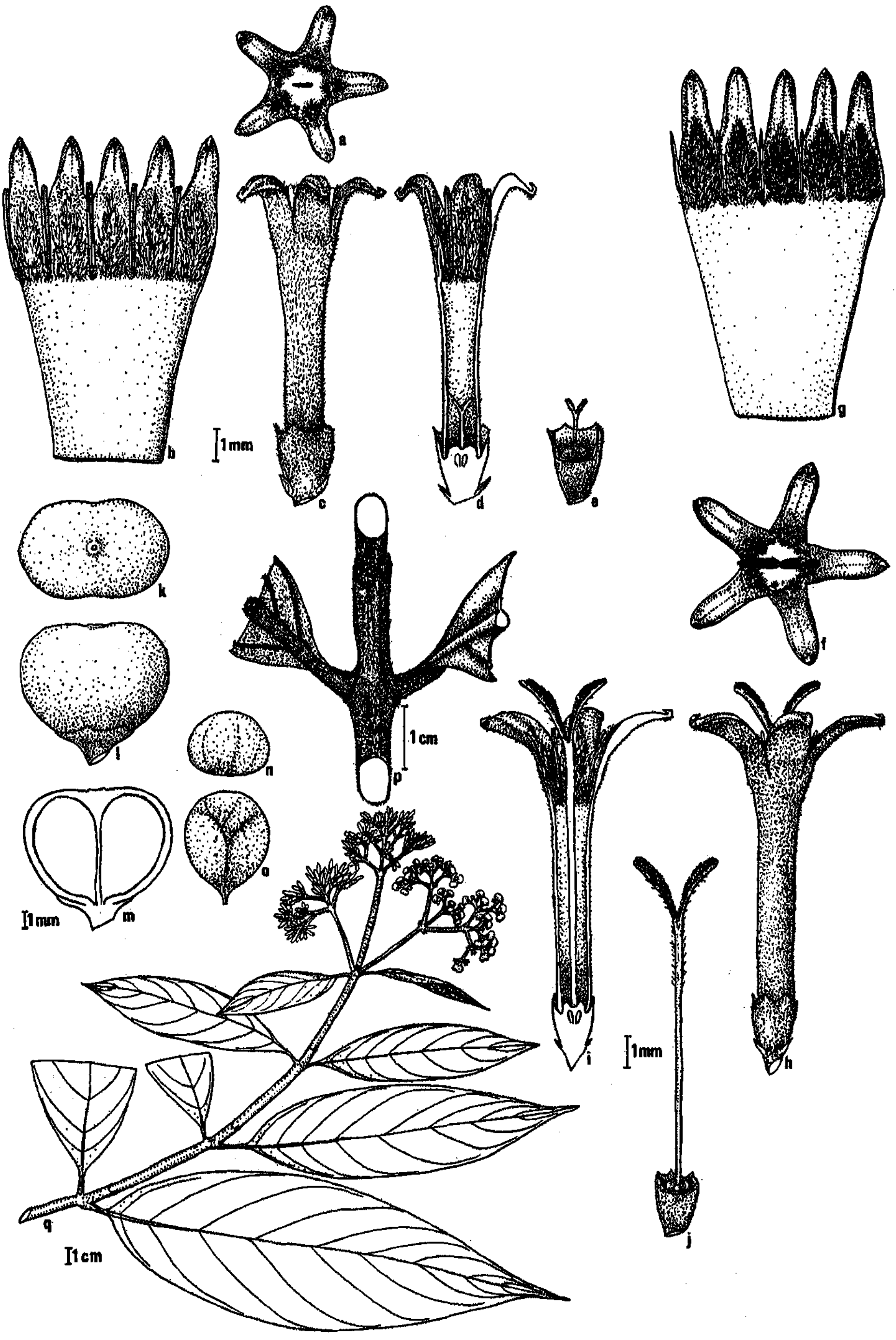

Figure 3. *Gaertnera grisea* Hk.f. ex Clarke. a.-e. Male flower; f.-j. Female flower; k.-m. Fruit; n.-o. Seed; p. Stipules; q. Female inflorescences and fruits on branch.

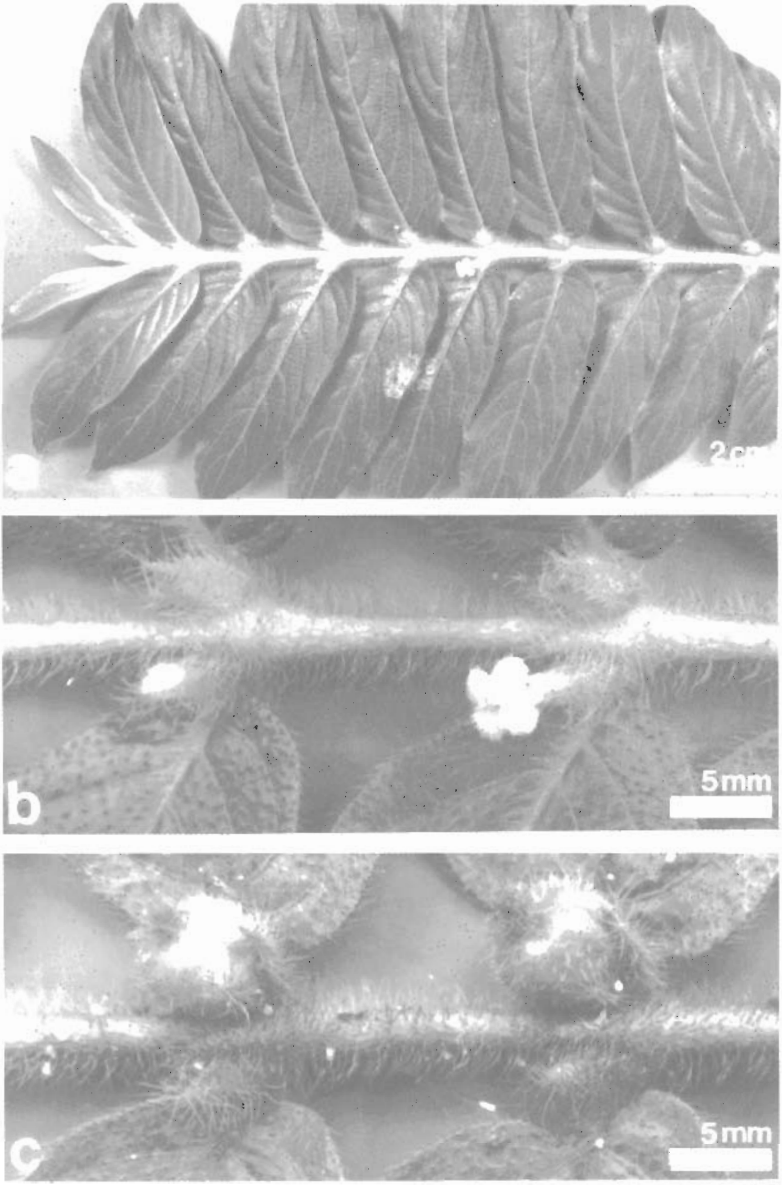

Figure 4. *Lasianthus densifolius* Miq. a. Branch portion; b. Buds and flower; c. Fruits.

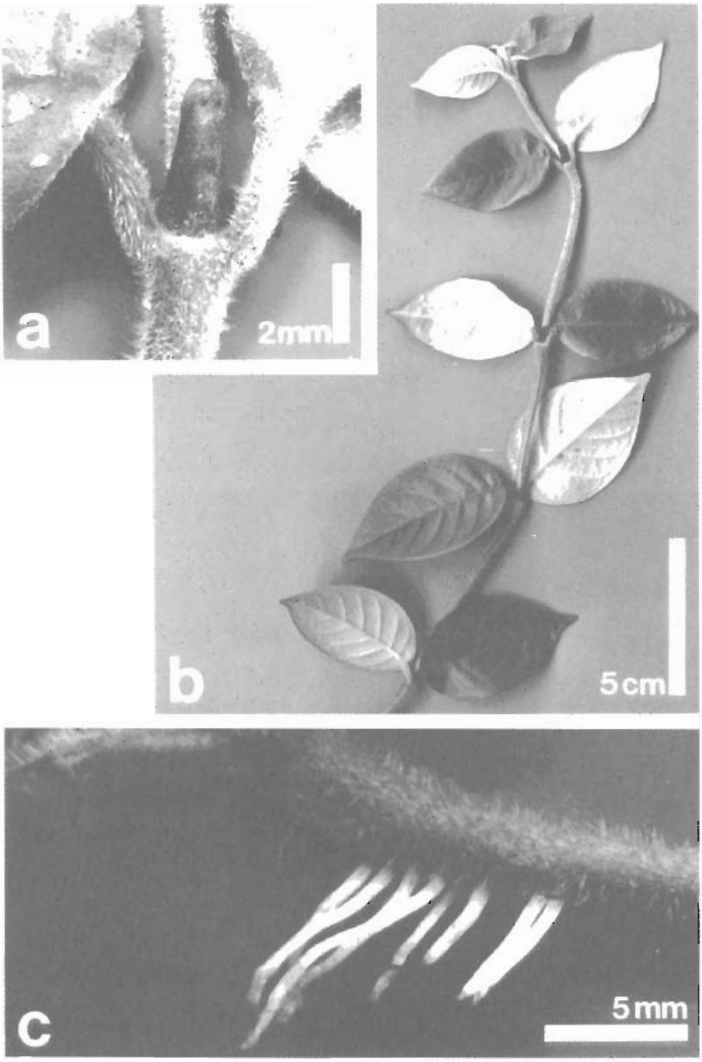

Figure 5. *Psychotria ovoidea* Wall. a. Stipule; b. Vegetative branch; c. Adventitious roots.

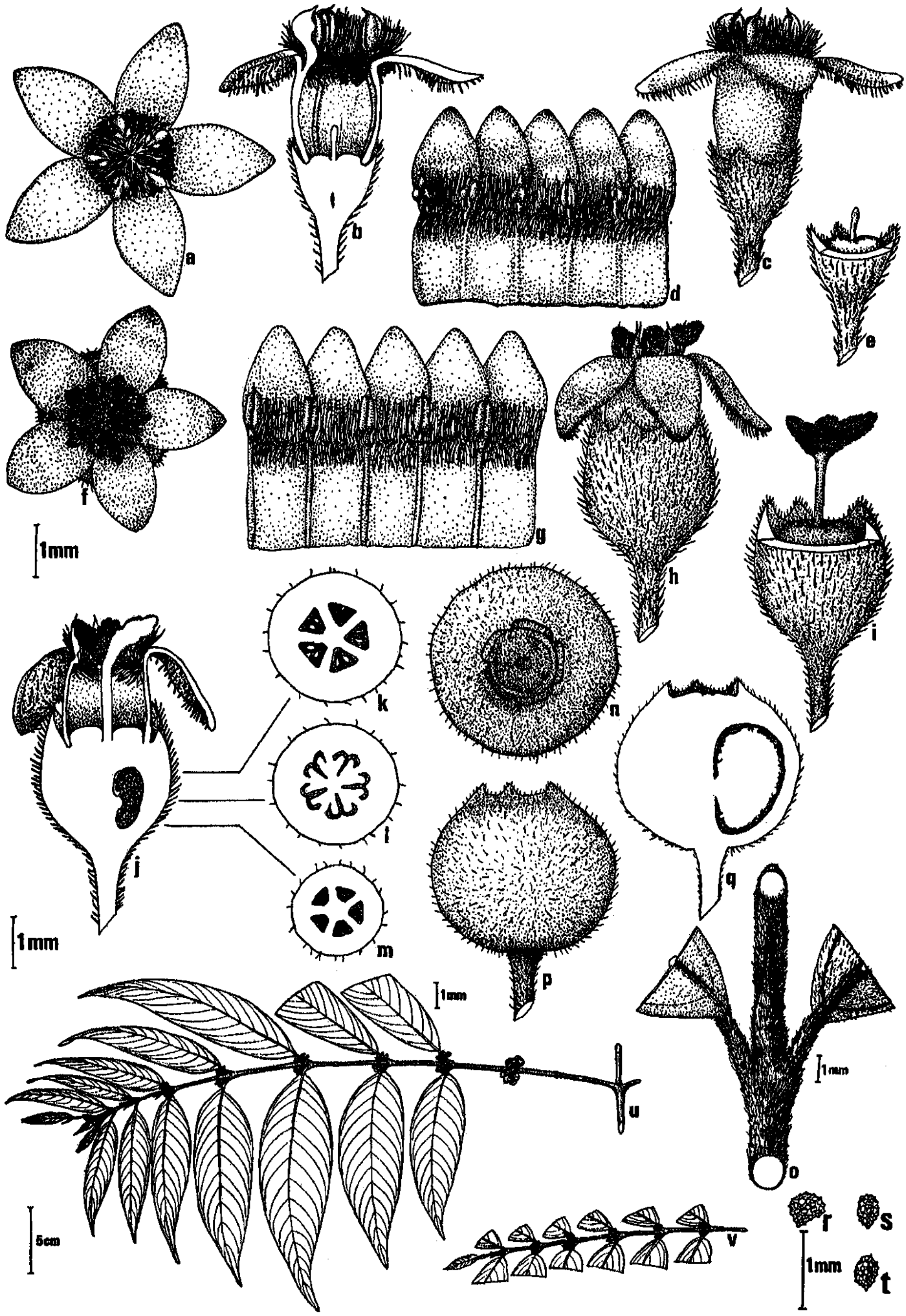

Figure 6. *Urophyllum hirsutum* (Wight) Hk.f. a.-e. Male flower; f.-m. Female flower; n., p., q. Fruit; o. Stipule; r.-t. Seed; u. Branch bearing female inflorescences and fruits; v. Branch bearing male inflorescences.

Chapter 5

Pteridophytes

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Introduction

It has been estimated that there are well over 12,000 species of ferns, in at least 400 genera (Crabbe *et al.*, 1975; Page, 1979). The inclusion of the clubmosses (*Lycopodium*), spikemosses (*Selaginella*) and horsetails (*Equisetum*), which, together with true ferns, make up the pteridophytes, would not increase this number very much. Of the 12,000 species, approximately 85% are believed to be found within the tropics (Tyron, 1964). In Peninsular Malaysia there are slightly more than 500 species (Holttum, 1988), of which Singapore's share is about 170 species or 34% (Wee, 1985, 1987). This is surprisingly high, considering that Singapore's land area is only about 0.43% that of Peninsular Malaysia. The small area of primary forest at Bukit Timah has about 107 species to its credit, reported since the last century (Holttum, 1966; Johnson, 1977; Wee, 1985; Wee & Rao, 1977). Of these, Johnson (1977) reports that 19 species have not been recorded elsewhere in Singapore. The 170 species recorded for Singapore since the early part of the nineteenth century has been slowly reduced to slightly more than 100 species today, a result of rapid urbanisation (Wee, 1985).

Because of the closed canopy, tropical rainforests are characterised by high humidity and low light intensity. These factors, in turn, are favourable for the proliferation of ferns, mainly because the sexual phase of the pteridophyte's life cycle, the gametophyte, requires a constantly moist environment to be able to survive and produce sporophytes. With increasing elevation to about 1,200 m, when the tropical lowland rainforest gives way to the lower montane rainforest (Whitmore, 1984), growth of pteridophytes becomes more luxuriant, especially epiphytic species. Their abundance further increases as the lower montane rainforest gives way to the upper montane rainforest at elevations of 1,500 to 3,000 m. This increase can be accounted for by the increased humidity further above ground level and decreased temperature together with increased light intensity as the trees become dwarfed and the canopy more open.

Although the fern flora at Bukit Timah is rich by Singapore standards, it is far from luxuriant. After all, the area is only 81 ha and the highest point only 162.5 m above sea level. With the forest criss-crossed with paths and a metalled road running up to the summit, it is obvious that the environment has been significantly modified. There are signs that the forest is slowly drying and true high forest species are slowly disappearing. Unfortunately there has been no research to support this claim. However, the increased presence of gaps seen during the last ten years as a result of tree falls and the presence of weedy species are disturbing signs.

Terrestrial Shade Ferns

The largest group of pteridophytes is still the shade species, growing from the forest floor, rock surfaces, stream banks and the lower portions of tree trunks. The presence of species with relatively large and much divided fronds like *Angiopteris evecta* and the tree fern, *Cyathea latebrosa,* can be attributed to the low light intensity and high humidity of the forest floor. These species are by no means confined to the primary forest as they are also found in secondary forests and among disturbed vegetation where there is sufficient shade. *Blechnum finlaysonianum* is another shade fern, common in parts of Taban Valley (fig. 2, chap.1)

Tectaria singaporeana, sometimes forming semi-pure stands along paths and by streams, is the common forest floor fern. Its simple fronds arising in clumps can easily be mistaken for a herbaceous angiosperm. Dimorphism in frond forms, as is evident in quite a number of species, is seen here where the inner fertile fronds are smaller and have longer stipes which are held more erect than the outer sterile fronds. According to Holttum (1938), this allows the spores to be more efficiently dispersed in the still air of the forest floor. The smallish *Schizaea digitata* has also been recorded, together with the bifurcating *S. dichotoma,* but they are seldom seen. *Taenitis blechnoides* is commonly seen as isolated plants along paths together with *Lindsaea ensifolia,* which prefers locations with a little more light.

The group of climbing ferns, *Teratophyllum aculeatum, T. ludens* and *T. rotundifoiliatum* as well as *Lomariopsis lineata* are similarly shade species. These are creepers, starting life on the ground until they come into contact with the base of a tree, whereupon the shoots climb upwards. Their highly dissected fronds are commonly seen on earth banks and the base of trunks. Fertile fronds, develop only high up the trees, where the air is drier for the effective dispersal of the spores (Holttum, 1938), are seldom seen. *Lindsaea doryphora* is another low climber of the rainforest, common also in Peninsular Malaysia.

In all, there are a total of 44 terrestrial shade species (table 1).

Table 1. Terrestrial ferns of shaded locations.

Angiopteris evecta (Forst.) Hoffm.
Blechnum finlaysonianum Hk. & Grev.
Bolbitis sinuata (Pr.) Henn. (*B. diversifolia* (Bl.) Schott.)
Cyathea glabra (Bl.) Copel.
Cyathea latebrosa (Wall.) Copel.
Cyathea squamulata (Bl.) Copel.
Diplazium asperum Bl. (*Athyrium asperum* (Bl.) Milde)
Diplazium cordifolium Bl. (*A. cordifolium* (Bl.) Copel.)
Diplazium crennatoserratum (Bl.) Moore (*Athyrium crennatoserratum* (Bl.) Milde)
Diplazium tomentosum Bl. (*A. tomentosum* (Bl.) Milde)
Heterogonium sagenoides (Mett.) Holtt.
Lygodium circinattum (Burm.f.) Sw.
Lindsaea cultrata (Willd.) Sw. (*Lindsaya decomposita* Willd.)
Lindsaea divergens Hk. & Grev. (*Isoloma divergens* (Hk. & Grev.) J.Sm.)
Lindsaea doryphora Kramer (*L. scandens* Hk. var. *terrestris* Holtt.)
Lindsaea parallelogramma v.A.v.R.
Lomariopsis lineata (Pr.) Holtt. (*L. cochinchinensis* Fee)
Mesophlebion chlamydophorum (Rosenst.) Holtt. (*Thelypteris chlamydophora* (Rosenst.) Ching)
Mesophlebion motleyanum (Hk.) Holtt. (*T. motleyana* (Hk.) Holtt.)
Microlepia speluncae (L.) Moore
Pleocnemia irregularis (C.Presl) Holtt. (*Arcypteris irregularis* (Pr.) Holtt.)
Pneumatopteris truncata (Poir.) Holtt. (*Cyclosorus truncatus* (Poir.) Farw.)
Pronephrium repandum (Fee) Holtt. (*Abacopteris urophyllus* (Wall.) Ching)
Pronephrium triphyllum (Sw.) Holtt. (*A. triphylla* (Sw.) Ching)
Pteris mertensioides Willd.
Schizaea dichotoma (L.) Sm .
Schizaea digitata (L.) Sw.
Selaginella intermedia (Bl.) Spring (*S. atroviridis* (Wall.) Spring)
Selaginella roxburghii (Hk. & Grev.) Spring
Selaginella willdenowii (Desv.) Bak.
Sphaerostephanos heterocarpus (Bl.) Holtt. (*Cyclosorus heterocarpus* (Bl.) Ching)
Syngramma alismifolia (Pr.) J. Sm.
Taenitis blechnoides (Willd.) Sw.
Taenitis interrupta Hk. & Grev.
Tectaria barberi (Hk.) Copel.
Tectaria griffithii (Bak.) C.Chr. (*T. multicaudata* (Wall.) Ching)
Tectaria semipinnata (Roxb.) Morton (*T. maingayi* (Bak.) C. Chr.)
Tectaria singaporeana (Wall.) Ching
Teratophyllum aculeatum (Bl.) Mett.
Teratophyllum ludens (Fee) Holtt.
Teratophyllum rotundifoliatum (R. Bonap.) Holtt.
Trichomanes javanicum Bl.
Trichomanes obscurum Bl.
Trichomanes singaporeanum (Bosch) v.A.v.R.

Synonyms are between parentheses

Epiphytes

Epiphytes are most abundant in the tropical lower montane rainforest where it is more humid, and less so in the lowland rainforest (Whitmore, 1984). At the lower montane forests at Cameron Highlands, Fraser's Hill and Maxwell Hill, low level epiphytic pteridophytes abound, growing from the trunks and branches of the low trees and shrubs. The most common are the filmy ferns, members of the family Hymenophyllaceae, with fronds of a single layer of cells, enabling them to absorb moisture from the humid air but at the same time resulting in rapid water loss when the air is dry. But then in the cloud zone of mountain forests, where the air is constantly saturated with moisture, periods of water stress are not common. In the lowland forests these filmy ferns are more frequently subjected to the drying air and it is common to see the fronds rolling up in an effort to reduce water loss. These delicate ferns, of which at least six species are recorded from Bukit Timah, are commonly seen by streams and on earth banks where there is sufficient shade to maintain a high humidity most of the time.

Low-epiphytes are classified by Tyron (1964) as belonging to the tropical mesic environment, unlike the high-epiphytes which belong to the tropical xeric epiphytic environment. A common low-epiphyte, *Asplenium tenerum,* seems to be confined to Fern Valley (fig. 2, chap. 1), where the high humidity, due to the presence of a stream, no doubt encourages its presence. These smallish epiphytes grow from the lower trunks of the smaller trees, collecting falling leaves rather inefficiently as the pinnate compound fronds do not form an efficient nest. They are also found growing from the bryophyte-covered rocks piled above the stream.

High-epiphytes are adapted to life high up in the canopy of tall trees, on the trunks and larger branches, where conditions are more extreme than within the forest (Page, 1979). The most spectacular high-epiphyte seen at Bukit Timah is *Platycerium coronarium,* commonly associated with the forest tree, *Campnosperma auriculata.* Along the Lower Path near Taban Valley, where the forest is not strictly primary in nature, a number of such trees bear many huge *P. coronarium. Asplenium nidus* is another high-epiphyte, growing from the forks of the taller trees but it is not a common fern as in other forests in the region. Growing within the nests of these ferns is *Ophioglossum pendulum,* with its conspicuous, ribbon-like fronds hanging down in bunches. The smallish *Vittaria ensiformis* often grows below or even within the huge nests of these ferns, benefitting from their large reservoir of nutrients and moisture. Another group of humus-collecting epiphytes is *Drynaria quercifolia* and *D. sparsisora,* which grow along the branches of trees under light shade.

Associated with these epiphytes are *Davallia solida* and *D. triphylla.* These are commonly seen, especially when branches fall as a result of age. *Pyrrosia piloselloides* and *P. longifolia* grow from branches of trees, especially along the periphery of the forest.

Tables 2 and 3 list the epiphytes of shaded and semi-open locations respectively. Most of the latter group of epiphytes are also found on wayside trees, but not members of the former group. Epiphytic shade ferns are mostly low epiphytes, the exception being *Platycerium ridleyi*. They grow mainly within the deep shade of the forest and many are also rock ferns, found especially in humid valleys and around streams, like *Trichomanes* spp. (table 2).

Table 2. Epiphytic ferns of shaded locations.

Asplenium batuense v.A.v.R.
**Asplenium phyllitidis* Don.
Asplenium tenerum Forst.
Davallia triphylla Hk.
Humata repens (L.f.) Diels
**Hymenophyllum denticulatum* Sw.
Lycopodium phlegmaria L.
Lindsaea repens (Bory) Thw. var. *pectinata* (Bl.) Mett. (*Lindsaya macraeana* (Hk. & Arn.) Copel.)
Monogramma dareicarpa Hk.
Platycerium ridleyi Christ.
**Trichomanes bimarginatum* Bosch
**Trichomanes humile* Forster
Trichomanes motleyi Bosch
**Trichomanes saxifragoides Presl (T. minutum* Bl.)
**Trichomanes sublimbatum* C.Muell.

* Also on rocks
Synonyms are between parentheses

Table 3. Epiphytic ferns of semi-open locations.

Asplenium glaucophyllum v.A.v.R.
Asplenium nidus L.
Davallia solida (Forst.) Sw.
Drynaria quercifolia (L.) J.Sm.
Drynaria sparsisora (Desv.) Moore
Goniophlebium verrucosum (Hook.) J. Sm.
Humata heterophylla (Sm.) Desv.
Nephrolepis acutifolia (Desv.) Chr.
Ophioglossum pendulum L.
Phymatosorus scolopendria (Burm.) Pichi Serm. (*Phymatodes scolopendria* (Burm.) Ching)
Platycerium coronarium (Koenig) Desv.
Pyrrosia angustata (Sw.) Ching
Pyrrosia lanceolata (L.) Farwell (*P. adnascens* (Sw.) Ching)
Pyrrosia longifolia (Burm.) Morton
Pyrrosia piloselloides (L.) Price (*Drymoglossum piloselloides* (L.) Presl)
Vittaria ensiformis Sw.

Synonyms are between parentheses

Rock Ferns

Under deep shade, as in Fern Valley, rock ferns are common, growing from huge boulders which are piled high over the stream. These include *Bolbitis appendiculata* and *B. sinuata,* which have apparently given rise to a natural hybrid, *Bolbitis* x *singaporensis,* endemic to Singapore and only reported on boulders in Fern Valley (Holttum, 1966; Johnson, 1977). *Antrophyum callifolium* was collected by me in Fern Valley back in 1981; while Johnson (1977) reports the very similar *A. parvulum* in the area, this species is usually found only on limestone rocks (Holttum, 1966). Both species are presumably uncommon. Like low epiphytes of shaded locations, rock ferns sometimes also grow on the lower trunk of trees (table 4).

Table 4. Rock ferns of shaded and semi-shaded locations.

**Antrophyum callifolium* Bl.
Antrophyum parvulum Bl.
**Asplenium macrophyllum* Sw.
Bolbitis x singaporensis Holtt. (*B. singaporensis* Holtt.)
Bolbitis appendiculata (Willd.) Iwatsuki (*Egenolfia appendiculata* (Willd.) J.Sm.)
**Monogramma trichoidea* J.Sm.
**Nephrolepis falcata* (Cav.) C.Chr.
**Phymatosorus nigrescens* (Bl.) Pichi Serm. (*Phymatodes nigrescens* (Bl.) J. Sm.)
Pleocnemia olivacea (Copel.) Holtt.

* Also epiphytic
Synonyms are between parentheses

Terrestrial Sun Species

Terrestrial sun species (table 5), strictly speaking, do not truly belong to the primeval forest. They are aggressive pioneers, common along the forest periphery and where the forest is exposed as a result of tree fall. These ferns are fast growing, to be able to compete successfully with a wide range of other plants. The more aggressive and fast growing include *Dicranopteris linearis* and *D. curranii,* forming pure stands in clayey soils of low fertility, and maintaining their dominance for decades. *Gleichenia truncata,* which grows in pure stands in the hill stations of Peninsular Malaysia, occurs sporadically here. Along the forest edge *D. linearis* var. *subpectinata* scrambles up trees. The thicket-forming, temperate *Pteridium caudatum* var. *yarrabense*, found also in open spaces at high altitudes in the tropics, is sparsely present here.

The more light requiring species, *B. orientale,* is seen at the forest edge and along portions of forest paths where there is more light. Growing along the fringe of the forest are juvenile plants of *Lygodium* spp. A more coarse climber is *Stenochlaena palustris,* also found towards the forest edge.

Table 5. Terrestrial ferns of open locations.

Amphineuron opulentum (Kaulf.) Holtt. (*Cyclosorus impressus* (Desv.) Alston)
Asplenium longissimum Bl.
Blechnum orientale L.
Christella arida (Don) Holtt. (*Cyclosorus aridus* (Don) Ching)
Christella subpubescens (Bl.) Holtt. (*Cyclosorus sumatranus* v.A.v.R.)
Dicranopteris curranii Copel.
Dicranopteris linearis (Burm.f.) Underw.
Dicranopteris linearis var. *subpectinata* (Christ) Holtt.
Gleichenia truncata (Willd.) Spr.
Lygodium flexuosum (L.) Sw.
Lygodium longifolium (Willd.) Sw.
Lygodium microphyllum (Cav.) R. Br.
Lygodium salicifolium Presl
Lindsaea ensifolia Sw. (*Schizoloma ensifolium* (Sw.) J.Sm.)
Nephrolepis biserrata (Sw.) Schott
Nephrolepis multiflora (Roxb.) Jarrett (*N. hirsutula* (Forst.) Pr.)
Nephrolepis radicans (Burm.) Kuhn
Pteridium caudatum (L.) Maxon var. *yarrabense* Domin
Pteris multifida Poir.
Pteris vittata L.
Stenochlaena palustris (Burm.) Bedd.

Synonyms are between parentheses

Rare And Endangered Species

Wee & Corlett (1986) have discussed the long term future of Bukit Timah and concluded that loss of a considerable number of species seems inevitable with time. Thus the loss of fern species, especially those growing in deep shade can be expected. *Platycerium ridleyi* has not been seen since it was first reported growing on tall trees from this forest decades ago (Holttum, 1966). Similarly, the hybrid *Bolbitis* x *singaporensis* discovered in the Fern Valley, and endemic to the reserve, has not been seen for the last three decades. Other species not seen for years now include *Monogramma dareicarpa* and *M. trichoidea.* The latter was thought to be extinct (Holttum, 1966) but was collected in 1960 (Johnson, 1961). Most of the rock ferns (table 4) can be considered endangered, especially *Antrophyum callifolium, A. parvulum, Asplenium macrophyllum* and *Bolbitis appendiculata.* Similarly, epiphytes of shaded locations (table 2) are also endangered, the danger coming from the disappearance of the habitat. Also, with the slow drying of the forest, these moist valleys, ideal locations for shade ferns, will in time be moist no more. Not at all endangered are epiphytic ferns of semi-open locations (table 3) and terrestrial sun ferns (table 5). There will always be an abundance of open habitats for such species in urban Singapore.

Exotic Species

Pityrogramma calomelanos, the tropical American silver fern, has been observed growing along the periphery of the reserve where there is more light. This is less worrying than the other exotic fern, *Adiantum latifolium,* introduced from Central America and northern South America (Piggott 1988). Not seen during the 1960s (Wee & Rao 1977), its presence was reported in the late 1970s as *A. flabellulatum* (Wee 1984; 1985; 1987). This exotic species has established a firm foothold near the edge of the reserve by Taban Valley in slightly less than a decade.

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Chapter 6

Bryophytes

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Introduction

Tropical rainforest harbours 25-30% of the world's bryophytes or 3,000-4,000 species of mosses and liverworts, more species than any other of the world's major ecosystems (Gradstein & Pocs, 1989). The bryophyte flora increases in richness from lowland rainforest to lower montane and then to upper montane forest. Together with this increase is the luxuriant development of epiphytic species, especially liverworts, and also filmy ferns, swathing the boles and even crowns of trees in festoons (Whitmore, 1984) such that these forests are often termed mossy forests. There is also an increase in species with increase in latitude, from tropical to temperate forests. Such increases in species richness with altitude and latitude are due to the more favourable climatic conditions, especially lower temperature and higher humidity (Gradstein & Pocs, 1989; Richards, 1984).

The bryophyte families of tropical lowland rainforest are largely pantropical, such as the Calymperaceae, Hookeriaceae and Lejeuneaceae, while montane forest bryophytes include temperate families as well (Gradstein & Pocs, 1989). Richards (1984) subdivides the bryophyte habitats of lowland tropical rainforest and lower montane rainforest into the "euphotic" and "oligophotic" zones. The former, which is relatively exposed, includes the twigs and main branches of trees of the main and lower canopies of the forest. The latter on the other hand is relatively shaded and made up of tree trunks, leaves of the shrubs and the ground surface.

As the largest remaining piece of primary forest left in Singapore, Bukit Timah is a major refuge for forest bryophytes. There is no published work on the liverworts of Singapore but there are a number of reports on the moss flora (Dixon, 1926; Holttum, 1927; Johnson, 1964, 1973, 1980; Eddy, 1988; Mohamed & Tan, 1988).

Epiphytes

Epiphytes are those bryophytes that grow from the trunks and branches of trees. Some authors prefer the term 'microepiphytes,' as compared to the larger, vascular macroepiphytes (Tixier, 1966). This group of bryophytes may be subdivided into corticolous (on the living bark of trees and shrubs), ramicolous (on branches and twigs), epiphyllous (on leaf surfaces) and lignicolous (on rotten logs). Corticolous species collected from the reserve include *Desmotheca apiculata, Ectropothecium monumentorum, Meiothecium microcarpum, Taxithelium capillipes* and *T. planum.* To what extent these species also grow in other habitats has yet to be established.

The part of the tree that has the most bryophytes, and usually the highest bryophyte diversity, is the base of the trunk, for here it is always shaded and the humidity consistently high (Pocs, 1982; Richards, 1954). Generally, those species growing around the tree base are facultative epiphytes, such as *Acanthorrhynchium papillatum, Trismegistia lancifolia* and *Vesicularia montagnei,* which are also found on the soil, rocks and rotting logs. The species growing on the trunk and large branches are either facultative or obligate epiphytes and those on the smaller branches and twigs, obligate epiphytes (Smith, 1982).

Corticolous epiphytes may become lignocolous when the trees they grow on die with age. Such species include *Leucophanes albescens, Mitthyridium repens, Sematophyllum saproxylophilum* and *Taxithelium planum.* Other corticolous species that have also been collected from rocks include *Calymperes erosum, Isopterygium minutirameum, Syrrhopodon albovaginatus, S. involutus* and *S. spiculosus.*

Epiphyllous bryophytes, developing on the upper surface of living leaves, are largely confined to tropical rainforest. Most of these belong to the liverwort family Lejeuneaceae, with sometimes up to 8-15 species on one leaf (Pocs, 1978). For such species to survive, the leaves need to have a relatively long life span, thus they never occur on deciduous shrubs and trees (Procs, 1982). There are many epiphyllous species in the reserve and many of the mature leaves of the herbs and shrubs are covered with growths. However, there has been no work on epiphylls at Bukit Timah.

Terrestrial

Terrestrial bryophytes can be differentiated into terricolous species, growing on soil, and rupicolous species, growing on rocks and concrete. On the forest floor, where there is a layer of leaf litter, few bryophytes are found. However, along forest paths and on earth banks, where there is some light, terricolous species may be plentiful. *Leucobryum sanctum* is commonly seen in thick mats on the soil surface along shaded forest paths. Occasionally, it may also grow on decaying logs and on the trunks of trees. Other terricolous species in the reserve include *Campylopus serratus, Orthodontium infractum, Barbula indica, Bryum nitens* and *Hyophila involuta,* although the last three species have only been collected from sides of drains. *Vesicularia kurzii* and *V. reticulata* were found growing on soil and rocks, as well as on tree trunks and decaying logs.

The six species of *Fissidens* (table 1) were all collected on soil, especially along earth banks where light filters through, although they have been reported to grow around the base of trees. *F. ceylonensis,* on the other hand, has also been collected from rocks.

Rupicolous species included *Diphyscium involutum, Dip. mucronifolium, Distichophyllum schmidtii.*

Table 1: List of mosses collected from Bukit Timah

Bryaceae
Bryum nitens Hook.
Orthodontium infractum Dozy & Molk.
Calymperaceae
Calymperes afzelii Sw.
Calymperes beccari Hampe.
Calymperes crassinerve (Mitt.) Jaeg.
Calymperes dozyanum Mitt.
Calymperes erosum C.M.
Calymperes lonchophyllum Schwaegr.
Calymperes palisotii Schwaegr.
Calymperes porrectum Mitt.
Calymperes serratum A.Braun ex C.M.
Calymperes taitense (Sull.) Mitt.
Calymperes tenerum C.M.
Mitthyridium cardotii (Fleisch.) Robins.
Mitthyridium fasciculatum (Hook. & Grev.) Robins.
Mitthyridium jungguilianum (Mitt.) Robins.
Mitthyridium repens (Harv. in Hook.) Robins.
Mitthyridium wallisii (C.Mull.) Robins.
Syrrhopodon albovaginatus Schwaegr.
Syrrhopodon involutus Schwaegr.
Syrrhopodon spiculosus Hook. et Grev.
Dicranaceae
Campylopus serratus Lac.
Diphysciaceae
Diphyscium involutum Mitt.
Diphyscium mucronifolium Mitt. in Dozy & Molk.

Table 1 (continued).

Fissidentaceae
Fissidens ceylonensis Dozy & Molk.
Fissidens crassinervis Lac.
Fissidens laxus Sull. & Lesq.
Fissidens splachnobryoides Broth.
Fissidens zippelianus Dozy & Molk.
Fissidens zollingeri Mont.
Hookeriaceae
Distichophyllum schmidtii Broth.
Hypnaceae
Ectropothecium monumentorum (Dub.) Jaeg.
Isopterygium minutirameum (C.Mull.) Jaeg.
Vesicularia kurzii (Lac.) Broth.
Vesicularia montagnei (Bel.) Broth.
Vesicularia reticulata (Dozy & Molk.) Broth.
Leucobryaceae
Leucobryum sanctum (Brid.) Hamp.
Leucophanes albescens C.Muell.
Orthotrichaceae
Desmotheca apiculata (Dozy & Molk.) Lindb.
Pottiaceae
Barbula indica Brid.
Hyophila involuta (Hook.) Jaeg.
Sematophyllaceae
Acanthorrhynchium papillatum (Harv.) Fleisch.
Meiothecium microcarpum (Hook.) Mitt.
Sematophyllum saproxylophilium (C.Mull.) Fleisch.
Taxithelium capillipes (Lac.) Broth.
Taxithelium planum (Brid.) Mitt.
Trichosteleum boschii (Dozy & Molk.) Jaeg.
Trismegistia lancifolia (Harv.) Broth.

Conclusion

In all, 48 species from 23 genera and 11 families of mosses have been reported from the reserve (table 1). This list has been compiled from published literature as well as from casual collections. A detailed collection needs to be done to record more thoroughly the bryophyte species that are found in the reserve, especially the liverworts. (see table 2).

Table 2: List of liverworts collected from Bukit Timah

Acromastigum inaquilaterum (Lehm. et Lindenb.) Evans **log**
Bazzania tridens (Reinw. et al.) Trev. **on tree**
Blepharostoma trichophyllum (L.) Dum. **bark, tree, log, rock**
Cephaloziella sp.
Cheilolejeuna intertexta (Lindenb.) Steph. **bark**
Heteroscyphus argutus (Reinw. et al.) Schiffn.
Jackiella singapurensis Schiff.
Jungeirmannia sp.
Kurzia borneensis Mizut. **soil**
Lepidozia sp.
Mastigolejeunea sp.
Pallavacinia indica Schiffn.
Pallavacinia levieri Schiffn. **soil**
Riccardia decipiens Schiffn.
Telaranea neesii (Lindenb.) Fulford. **soil**

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Chapter 7

Algae

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Introduciton

Algae are ubiquitous. They are most abundant in aquatic habitats, in waters of a wide range of salinity from fresh to brackish to marine (Bold *et al.*, 1987). They are also found on the surface of the soil as well as to a certain depth below (Bold, 1970; Metting, 1981) and on subaerial habitats like trunk of trees and walls of buildings (Wee, 1990). In an area such as Bukit Timah, where there is a cover of tall trees and where freshwater habitats are limited to a very few streams which run to a trickle during dry periods, the presence of algae tends to be restricted. Studies on the algal flora of Singapore have contributed to our knowledge of the algae present in the reserve - Johnson (1978) and Chan (1985) on corticolous algae; Lim (1987) on freshwater algae; Johnson (1962, 1973a, 1973b) and Nashita (1988) on soil algae; and Thin (1988) on diatoms. A total of 19 species have so far been documented from the reserve - 5 Cyanophyta, 3 Chlorophyta, 2 Euglenophyta, 8 Bacillariophyta and 1 Rhodophyta (table 1). With further research more will certainly be reported.

Freshwater Algae

There are few streams in the reserve. The one at Jungle Fall Valley (fig. 2, chap.1) runs at a slow trickle except during wet periods. The one half-way between South View Hut and Catchment Hut along Boundary Path makes a sort of a small pond with its water. The water at Bukit Timah is relatively pure and does not suffer from the pollution streams in urban areas are subjected to. The red alga *Batrachospermum vagum* used to be common in this pond but has disappeared for some time now. Besides this red alga, eight diatoms have been collected (*Cocconeis pseudomarginata* var. *intermedia, Cyclotella stelligera, Cymbella ventricosa, Desmogonium rabenhorstianum, Eunotia pectinalis* var. *minor, Gomphonema gracile, Gomphonema parvulum* var. *lagenula* and *Tabellaria fenestrata*), one green alga (*Golenkinia radiata*) and two euglenoids (*Euglena sanguinea* and *Trachelomonas volvocina*), making a total of 11 freshwater species (Lim, 1987; Thin, 1988).

Soil Algae

The soil algal flora occurs in the top few centimetres of the soil, although there are traces of them as far as a metre down (Johnson, 1962). The subterranean species probably have their origin from the soil surface, washed down by the rain and remaining viable for long periods (Round, 1975). However, actively growing species are confined to the upper few millimetres, where light is available. The epiterranean soil algae contribute to the organic content of the soil and improve its water-holding capacity as well as its fertility, especially as certain members of the family Nostocaceae are capable of fixing free nitrogen.

However, forest soils are never rich in algal species, mainly because there is not enough light reaching the surface. The presence of a layer of leaf litter again reduces growth of soil algae. Of the 80 species of algae collected by Johnson (1973a,b) from eight soil types in Singapore, four were green algae and one was a diatom. No mention was made of where the forest soil came from and it is possible that it did not come from Bukit Timah. The soil algae definitely collected from the reserve consist of five species of blue-green algae (*Lyngbya diquetii, L. martensiana, Phormidium ambiquum, P. faveolarum* and *P. minnosentense*), all coming from the periphery of the forest (Nashita, 1988).

Subaerial Algae

Subaerial algae, or those growing on any objects in the air above the soil, litter or water surface (Schlichting, 1975), are seen here on leaf surfaces (epiphyllous), the bark of trees (corticolous) and the surfaces of boulders and rocks (lithophilous). *Trentepohlia aurea* is commonly found on the surface of boulders along the periphery of the reserve, especially where the humidity is high. This alga forms a bright orange, hair-like layer, which turns green when exposed to light. On leaves of trees and shrubs, *Phycopeltis treubii* form irregular colonies as a result of radial filamentous growth (Johnson, 1978). *Trentepohlia* has been reported to be the dominant algal partner in tropical rainforest lichens (Sipman & Harris, 1989) but there have been no studies of lichens in Singapore.

Table 1. List of algae recorded from Bukit Timah.

Cyanophyta
Lyngbya diquetii Gomont
Lyngbya martensiana Meneghini
Phormidium ambiquum Gomont
Phormidium faveolarum (Montagne) Gomont
Phormidium minnosentense (Tilden) Drouet
Chlorophyta
Golenkinia radiata (Chodat) Willie
Phycopeltis treubii Karsten.
Trentepohlia aurea (L.) Martiu

Table 1 (continued).

Euglenophyta
Euglena sanguinea Ehr.
Trachelomonas volvocina Ehr.
Bacillariophyta
Cocconeis pseudomarginata Greg. var. *intermedia* Grun.
Cyclotella stelligera Cleve et Grun.
Cymbella ventricosa Kuetz.
Desmogonium rabenhorstianum Grun.
Eunotia pectinalis (Kutz.) Rabh. var. *minor* (Kutz.) Rabh.
Gomphonema gracile Ehr.
Gomphonema parvulum Kutz. var. *lagenula* (Kutz.& Grun.) Hust.
Tabellaria fenestrata (Lyng.) Kutz.
Rhodophyta
Batrachospermum vagum (Roth) C. A. Ag.

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Chapter 8

Vesicular-arbuscular Mycorrhizae

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Introduction

The coexistence of a diverse range of plant species and their spatial organisation and distribution create the complexity of the tropical lowland rainforest. As Bowen (1980) stressed, "....there is no one 'tropical' system or environment, for a wide range of soils, climates and land uses that occur in the tropics." The soils of the tropical rainforest are for the most part poor in mineral nutrition. Under such conditions, a wide range of tropical plants are reported to be associated with symbiotic vesicular-arbuscular (VA) mycorrhizal fungi (Redhead, 1968, 1977; Thapar & Khan, 1973; Thomazini, 1974; Janos, 1975; Herrera & Ferrer, 1980; Alwis & Abeynayake, 1980; Noordwijk & Hairiah, 1986; Newbery *et al.*, 1988). Through their physical distribution of hyphae in soil or litter, mycorrhizae contribute significantly to the acquisation and cycling of available nutrients. It is well-established that mycorrhizae improve mineral nutrient uptake, especially phosphorus, and in addition, mycorrhizal plants have been shown to have greater tolerance to toxic metals, root pathogens, drought, high soil temperatures, saline soils, adverse soil pH than non-mycorrhizal plants (Tinker, 1978; Nelson, 1987; Stribley, 1987). These almost universally occurring fungi associate with a wide variety of plants of different taxonomic groups and low phophorus availability in tropical soils provides the environment for mycorrhizae to be of maximum benefit to the plants.

In Southeast Asia, primary rainforests, with established slow-growing hardwood trees, like the dominant Dipterocarpaceae, are the end products of a very long process of succession. Subjected to various types of human pressure, extensive areas of these forests are currently being cleared. Disturbance of an ecosystem creates a departure from its normal functioning (Drury & Nisbet, 1973). It influences succession by changing the levels of available resources and the efficiency of species recruitment and therefore the nature and distribution of the successional plant communities (Bazzaz & Pickett, 1980). Within mycorrhizal associations, interdependency between plant and symbiont could influence the next generation of plants during succession as well as the turnover rates of mycorrhizae and their distribution in the soil (Janos, 1980b).

Singapore (1° 20'N, 103° 50'E) supported a humid tropical rainforest type of vegetation before the 19th century. Extensive areas were subsequently cleared

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and currently, secondary forests exist in areas where cultivation was abandoned and revegetation progressed. A coastal hill variant of lowland dipterocarp rainforest, Bukit Timah is the largest and least disturbed remnant of the original forest cover of Singapore (Wee & Corlett, 1986). As such, it provides a unique environment where secondary forest adjoins the remains of primary rainforest. In this chapter, emphasis is placed on the occurrence and distribution of vesicular-arbuscular mycorrhizal fungi in primary and secondary rainforest within Bukit Timah.

Mycorrhizal Types

There are several types of mycorrhizal fungi and a comprehensive account is presented by Harley & Smith (1983). Mycorrhizal types are distinguished on the basis of their morphology, anatomy and taxonomic position of host and fungi. Table 1 briefly summarises these characteristics. There are predominantly two types of mycorrhizae - endomycorrhizae, of which vesicular-arbuscular (VA) mycorrhizae are the most common, where the major fungal component is in the root cortical region, and ectomycorrhizae where most of the fungus remains external to the host cell wall. While VA mycorrhizae will provide the major discussion in this chapter, ectomycorrhizae will also be mentioned; a brief introduction to both is first presented.

Table 1. Mycorrhizal types and their characteristic features

	Endomycorrhizae					Ecto-mycorrhizae
	VA	Arbutoid	Ericoid	Orchid	Monotropa	
Sheath	-	+	-	-	+	+
Hartig net	-	+	-	-	+	+
Intra-cellular hyphae	+	+	+	+	+	-
Vesicles	+	-	-	-	-	-
Inter-cellular hyphae	+	+	+	+	+	+
Hosts	*AGBP	Er	Er	Or	Mo	A

*A: Anigosperms; G: Gymnosperms; B: Bryophytes; P: Pteridophytes; Er: Ericales; Mo: Monotropaceae; Or: Orchidaceae

Vesicular-arbuscular (VA) mycorrhizae

VA mycorrhizae are the most common and widespread of the mycorrhizal associations and are formed by a large variety of herbaceous plants, shrubs and trees of diverse taxonomy and geographical distribution excepting only a few families such as Amaranthaceae, Brassicaceae, Chenopodiaceae and Cyperaceae (Gerdemann, 1968). There is very little evidence of host specificity though host preference has been demonstrated on many crop plants (Hayman, 1987).

The fungal symbionts appear to be restricted to a few genera of the family Endogonaceae, in the Phycomycetes. Producing azygospores, chlamydospores or multispored sporocarps (sporocarpic), the spores are the largest of fungal spores and their morphology provides the basis for distinguishing the fungal species. The fungi have proven to be difficult in establishing pure cultures and spores are multiplied on suitable host plants and maintained as pot-cultures.

Roots become infected with VA mycorrhizal fungi by hyphae growing from spores in soil or from nearby roots. Root colonisation results from extension of infection units that coalesce through inter- and intracellular hyphal connections. The main characteristic features of this association are the presence of vesicles and arbuscules in the root cortical region or on the external mycelium. Vesicles are swollen hyphal terminals with a probable storage function and arbuscules are dichotomously branching intracellular terminals that are short-lived and suggested to be sites of nutrient exchange. Environmental conditions, such as nutrients, light, pH and temperature influence the extent and quality of colonisation. There is no doubt that carbon supply to the fungus is provided by the host and it has been clearly demonstrated that VA mycorrhizae increase plant growth under conditions of nutrient deficiency (Stribley, 1987).

Ectomycorrhizae

Ectomycorrhizal roots are characterised by a fungal sheath or mantle which encloses the tips of fine absorbing rootlets and the Hartig net which is a plexus of hyphae between epidermal and cortical cells. The extent of sheath and Hartig net distribution varies between plants but the fungal tissues are nourished by carbon compounds from the host and any soil-derived nutrient must pass through them enroute to the host. Hyphal strands extend from the sheath into the surrounding soil or litter but there is very little intracellular hyphal penetration and hyphae never penetrate beyond the cortex.

Host plants are mainly woody perennials including the Fagaceae, Dipterocarpaceae, Leguminoseae, Rosaceae and Pinaceae whose roots are colonised by many species of the Basidiomycetes and some Ascomycetes and Fungi Imperfecti. Present evidence suggests that a wide range of host plants may be associated with a single strain of fungal species or vice versa. Many of the fungal symbionts have been isolated and cultured axenically, as have been their host plants enabling various aspects of the symbioses to be investigated in vitro.

Mycorrhizae Sampling

Nutrient cycling in tropical soils is more rapid than in other regions of the world and the soil is an important factor which can also exert a substantial influence upon the type of vegetation community present in a given area (Vitousek, 1984). The soils in Bukit Timah are of the Rengam sandy clay loam series. High clay content increases cation exchange capacity and subsequently soil acidity. The high acidity then increases the leaching potential of cations which will immobilise phosphorus. Hence, the lower the soil pH, the greater the proportion of phosphorus in the soil that becomes fixed, with less being available for plant uptake. Tropical soils are generally low in available phosphorus and indeed, phosphorus levels in Bukit Timah range from 0.05 ppm to 4.75ppm; soil pH was in the range of 2.8 to 5.6.

Root sampling in a lowland rainforest is complicated by the interweavings of roots of a large variety of plants in dense superficial layers and it is difficult to distinguish the roots of individual plant species. In Bukit Timah roots are mainly concentrated in the upper 20 cm and mycorrhizal spore numbers and % mycorrhizal roots are also highest in this layer. The adaptation of pronounced root concentration on or near the root surface and a highly developed root biomass consisting mainly of fine roots that are predominantly mycorrhizal serves to enhance nutrient absorption. From their studies in the Amazonian rainforest, Went and Stark (1968) proposed that a direct nutrient cycling should exist in very poor soils in which mycorrhizae play an important role in reutilising the nutrients held in the organic matter. Mycorrhizal hyphae in such root biomass was also shown to act as a bypass for P by direct transfer through the external hyphae to the root (Herrera *et al.*, 1978).

Roots are screened for ectomycorrhizae by sectioning and staining and for endomycorrhizae following clearing and staining. VA mycorrhizal spores are extracted from soil using the wet sieving and decanting technique described by Gerdemann and Nicolson (1963). Due to the high clay content in tropical soils, soil samples are first suspended in calgon, a soil dispersant. Following sieving through a series of sieves (853 μm, 250 μm and 75 μm), the spores retained are extracted using the sucrose centrifugation technique (Tommerup & Kidby, 1979), before identification and enumeration. Keys available for identification of VA mycorrizal fungi include Hall (1984) and Schenck and Perez (1988).

Occurence And Distribution

Studies on mycorrhizal fungi, conducted between 1984 and 1988, showed that the spore density of VA mycorrhizal fungi in the primary forests of Bukit Timah ranged from 10-50/g soil, depending on the time of the year. These low numbers were consistent with reports of 0.5/g soil in Nigeria (Redhead, 1977) and 4-11/g soil in Sri Lanka (Waidyanathan, 1980). Spore density in the secondary growth forest, however, were higher and ranged from 80 - 120/g soil. Janos (1980b) also reported low spore numbers in a lowland rainforest in Central America (2.6/400 ml soil) while an adjacent 15-year-old secondary forest that had been recently cleared had 11.5 spores/400 ml soil. In the Ulu Endau region of Malaysia, similar contrasting populations between disturbed and undisturbed sites have been reported (Louis & Lim, 1987b).

Some of the more commonly occurring species of VA mycorrhizal fungi that were recovered from forest types are listed in table 2. These spores are not unique to Bukit Timah and have been reported from other parts of Singapore as well as world-wide, reflecting their wide host range (Louis & Lim, 1987c; Schenck & Perez, 1988). Unlike the tropical regions of Florida, where azygosporic species were reported to be dominant (Nicolson & Schenck, 1979), spores of chlamydosporic species (*Glomus and Sclerocystis*) were more frequently encountered in Bukit Timah with *Glomus* species being most frequent and abundant, consistently averaging 50 - 60% of the total spore density. The absence of species in one or more sites in this study is not conclusive proof, however, of its non-occurrence as they may have a low frequency of occurrence.

Species distribution is one method of determining the distribution of a mycorrhizal species as a percentage of the total number of species recovered from the rhizosphere. In Bukit Timah, distribution of VA mycorrhizal species varied between host plants within sampled sites (table 2). Some species, like *G. botryoides, G. NUS20, G. intraradices, G. mosseae, S. pachycaulis* and *S. calospora* were present in the rhizosphere of most of the sampled plants in Bukit Timah but with significant variation in their distribution. Although species distribution describes the prevalence or uniqueness of a species in terms of numbers, spore biovolume is an important indicator of the actual proportion of space occupied by the species in the rhizosphere, in relation to its size (Dickman *et al.*, 1984). In all the sampled areas, spore biovolumes of >0.05 were mainly contributed by *G. botryoides, G. intraradices* and *S. calospora.*

A substantial proportion (47.6%) of the spore numbers in the secondary forest was also contributed by sporocarpic species and this may have also accounted for the variation in spore density and dominance. The significance of knowing the proportion occupied by a species in the rhizosphere, in addition to its distribution and occurrence, is highlighted by the observation that among the more frequently occurring species, *G. botryoides, G. microcarpum* and

Table 2. Some of the more commonly recovered vesicular-arbuscular mycorrhizal fungi from Bukit Timah.

VAM fungi	Primary forest	Secondary forest
Acaulospora foveata Trappe & Janos	-	+
Acaulospora laevis Gerdemann & Trappe	+	+
Glomus botryoides Rothwell & Victor sp.nov.	+	+
Glomus claroideum Schenck & Smith	-	+
Glomus clarum Nicolson & Schenck	-	+
Glomus intraradices Schenck & Smith	+	+
Glomus macrocarpum Tul. & Tul.	+	-
Glomus microcarpum Tul. & Tul.	+	+
Glomus mosseae (Nicol.& Gerd.) Gerd.& Trappe	-	+
Glomus multicaule Gerd.& Bakshi	+	+
Glomus NUS20	-	+
Gigaspora NUS40	-	+
Scutellospora calospora (Nicol. & Gerd.) Walker & Sanders	-	+
Scelerocystis pachycaulis Wu & Chen	+	+
Auxilliary cells	-	+

S. pachycaulis were sporocarpic as well as being the dominant species in the sites. Most of these sporocarps were also large e.g. *G. microcarpum* and *Sclerocystis pachycaulis* had up to or more than 150 spores per sporocarp. In humid tropical soils, under native vegetation, spore numbers were reported to decline rapidly if sporulation is infrequent due to absence of host plants or if subject to predation and parasitism (Redhead, 1977, Herrera & Ferrer, 1980). Sporulation, however, is an indispensable process to maintain survival of the community and with a wide host range, the large numbers of sporocarps contribute to the high spore numbers.

Although spore numbers are indicative of mycorrhizal presence, one has to observe plant roots to confirm a mycorrhizal association. Table 3 lists the occurrence of mycorrhizae in some of the plants sampled within Bukit Timah. It is quite apparent that a large number of plant species are VA mycorrhizal. Some of the legumes are exceptional in being both ecto- and endomycorrhizal, a feature also reported for many African legumes (Hogberg, 1982; Newbery *et al.*, 1988). A common occurrence on the roots of *Adinandra dumosa* was the presence of auxiliary cells and subtending hyphae of *Gigaspora* or *Scutellospora* species, the spores of either of which were not recovered around the roots. Present in very close association with the roots, the hyphae could represent mycorrhizal inteconnections between mature and young plants, as suggested by Whittingham and Read (1980).

Table 3. The mycorrhizal status of some of the plants encountered in Bukit Timah.

Mycorrhizal Status:	Non	Ecto	VA
Araceae			
Aglaomema picta	-	-	+
Aglaonema simplex	-	-	+
Aglaonema connadatum	-	-	+
Schismatoglottis calyptra	-	-	+
Scindapsus pictus	-	-	+
Anacardiaceae			
Mangifera griffithii	-	-	+
Mangifera lagenifera	-	-	+
Annonaceae			
Fissistigma latifolium	-	-	+
Apocynaceae			
Alstonia angustifolia	-	-	+
Dyera costulata	-	-	+
Tabernaemontana peduncularis	-	+	
Bombacaceae			
Durio griffithii	-	-	+
Neesia altissima	-	-	+
Burseraceae			
Dacryodes rostrata	-	-	+
Connaraceae			
Connarus ferrugineus	-	-	+
Cyperaceae			
Carex cryptostachys	+	-	-
Fimbristylis acuminata	+	-	-
Dilleniaceae			
Dillenia grandifolia	-	-	+
Dillenia suffructicosa	-	-	+
Dipterocarpaceae			
Dipterocarpus cornatus	-	+	-
Hopea griffithii	-	+	-
Hopea mengarawan	-	+	-
Shorea curtisii	-	+	-
Shorea leprosula	-	+	-
Shorea parvifolia	-	+*	-
Shorea paucifolia	-	+	-
Dracenaceae			
Draceana singapurensis	-	-	+
Ebenaceae			
Diospyros argentea	-	-	+

* also associated with ectendomycorrhizae

Table 3 (continued).

Mycorrhizal Status:	Non	Ecto	VA
Euphorbiaceae			
Baccaurea griffithii	-	-	+
Baccaurea parvifolia	-	-	+
Macaranga lowii	-	-	+
Macaranga triloba	-	-	+
Fagaceae			
Lithocarpus cantleyanus	-	+	-
Guttiferae			
Calophyllum ferrugineum	-	-	+
Garcinia griffithii	-	-	+
Lauraceae			
Litsea grandis	-	-	+
Leguminosae			
Adenanthera bicolor	-	-	+
Albizia splendens	-	-	+
Bauhinia semibifida	-	-	+
Dalbergia parvifolia	-	-	+
Dalbergia rostrata	-	-	+
Koompassia malaccensis	-	+	+
Parkia speciosa	-	+	+
Loganiaceae			
Fragraea fragrans	-	-	+
Melastomaceae			
Melastoma malabathricum	-	+	-
Clidemia hirta	-	-	+
Moraceae			
Ficus fistulosa	-	-	+
Ficus grossularioides	-	-	+
Myrtaceae			
Eugenia densiflora	-	-	+
Palmae			
Licuala ferruginea	-	-	+
Pinanga malaiana	-	-	+

The Dipterocarpaceae in the primary forest at Bukit Timah were predominantly ectomycorrhizal. Large areas of primary rainforest in Southeast Asia are dominated by dipterocarps. Within a 500 km^2 tropical lowland rainforest in East Malaysia, Proctor *et al.* (1983) described four types of vegetation (dipterocarp forest, alluvial forest, heath forest and forest on limestone) with heterogenous soil properties. Ectomycorrhizal associations with several genera of Diperocarpaceae is now well-established (Redhead, 1982; Alexander & Hogberg, 1986). The dipterocarps of Bukit Timah are no exception and display the characteristic ectomycorhizal symbioses. More recently, it was demonstrated that *Shorea parvifolia* in Bukit Timah is associated with both ecto- and ectendomycorrhizae (Louis, 1988). In ectendomycorrhizae, the Hartig net is much reduced and there is intracellular penetration of the cortical region.

The role of mycorrhizae in the ecology of the tropical lowland rainforest is one of complex integration involving diversity, biomass production, reproduction and population biology of both plants and their symbionts. The concept of defining mycorrhizal (facultative and obligate) and non-mycorrhizal plants depends on the plant's need for symbioses-supplied nutrients (Janos, 1980a). Over a study period of 17 months, in secondary and primary forests within Bukit Timah, variation in spore density and mycorrhizal colonisation were demonstrated although the dominant VA endophytes and host plants were different (Louis & Lim, 1987a). In the rhizosphere of *Aglaonema connadatum* and *Clidemia hirta* in a previously disturbed site and *Schismatoglottis calyptra* and *Tectaria singaporeana* in an undisturbed site, highest spore numbers were recorded form August to October and highest percentage mycorrhizal root colonisation from December to March. Thus, when spore numbers were high, percentage mycorrhizal colonisation was low, but as spore numbers began to decline, root colonisation increased.

As stressed earlier, Bukit Timah represents a unique area within which are a variety of plant communities. The differences in mycorrhizal types and propagule density could be attributed to differences in mycorrhizae species composition, floristic diversity, soil type and the nature and extent of disturbance which, in turn, could affect the persistence of a fungal species following disturbance and during succession. The higher proportion of ectomycorrhizal plants, as compared to endomycorrhizal plants in the dipterocarp stands probably accounted for the lower VA mycorrhizal spores recovered there. But the incidence of VA mycorrhzial plants and subsequently, VA mycorrhizal fungi was higher in the previously disturbed sites. Thus, the distribution of ecto- versus endomycorrhizae may be crucial in influencing succession by favoring plant species with increased dependency on a particularly benefical fungus. For tropical flora, regardless of the disturbance regime, early secondary forest pioneer species are outnumbered by species occurring later in the succession (Whitmore, 1984). The recovery of forest vegetation, following disturbance, sequesters some proportion of the carbon released as a result of clearing (Hall *et al.*, 1985). Growth of early successional trees in the tropics are extremely fast with the average growth rate of secondary vegetation two to three times that of mature dipterocarp forest species in a primary forest (Richards, 1952). With early colonisation and establishment, rapid plant growth will result in rapid accumulation of nutrients and exploitation of the soil nutrient reserves (Drury & Nisbert, 1973; Golley *et al.*, 1975); this is accompanied by an extensive, thick network of intermingling roots in the top 100 cm of the soil surface. Under experimental conditions, the competitive abilities of plant species were shown to be influenced by the mycorrhizal content of the soil (Fitter, 1977). The increase in vigour of the plant community, especially of VA mycorrhizal dependent plants, accompanied by increased root growth could account for the increase in sporulation and spore numbers of the existing VA mycorrhizal fungal community in the disturbed sites within Bukit Timah.

Over time, man will determine the fate of the rapidly changing tropical rainforest. For the present, however, Bukit Timah will help us understand, even partially, the existing primary rainforest and the consequences of disturbance; below-ground associations between the plant commmunity and microorganisms, like the mycorrhizal symbioses, are but one of the many interactions that need to be further explored.

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Chapter 9

Mammals of Bukit Timah

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Mammals of Singapore

Less than half the species of mammals found in the lowland rainforests of Johor occur wild in Singapore today, although the narrow straits separating Singapore from the mainland were probably first inundated only 7000 years ago. Part of the explanation may be the greater diversity of habitats available on the mainland but, even when apparently similar habitats are compared, Singapore's fauna is still much less rich. Where are the gibbons, the tapirs, the elephants, the bears, the deer, the tigers, and a variety of smaller species?

The most reasonable explanation is that they have become extinct some time in the 7000 or so years since Singapore became an island. Many of the "missing species" have never been reliably recorded in Singapore, so they must have died out before the founding of the modern colony in 1819. Others were present in the nineteenth century or even later but have become extinct subsequently. Some pre-1819 extinctions may have been hastened by man, but the ultimate causes were most probably connected with Singapore's small area and isolation. Small areas support smaller populations of each species. Smaller populations are more likely to die out and isolation prevents subsequent recolonization.

If this explanation is correct, we would expect the missing species to be predominantly large and/or carnivorous and thus requiring larger areas to support each individual. At first sight, the presence of tigers in Singapore, at least from the 1830s to around 1940, would appear to disprove this argument. No Malayan mammal requires more space than the tiger. However, the tiger is an excellent swimmer and Singapore's tigers were known to regularly swim the Straits, using Singapore as only part of their range. Singapore is not an island to a tiger! Singapore is not an island to an elephant, either. In June 1990, three males swam to Pulau Tekong from Johor and there seems no reason why elephants may not have visited Singapore many times after the inundation of the Straits. The same may be true of several other large vertebrates (such as the Sambar Deer) although there is less information on their swimming abilities.

The Johor Straits clearly are an effective barrier to gibbons and many other mammals, however, and the influence of reduced area is the simplest explanation for their absence, if not entirely convincing for some of the smaller species. Unfortunately, for many of the less conspicuous absences there is a major problem in deciding if they became extinct before or after 1819. Nineteenth century mammal records are very difficult to interpret. Some museum specimens attributed to Singapore were undoubtedly acquired in the market and are of unknown origin. Other, genuinely native, species were probably overlooked or confused with similar species. Yet others were probably imported as food or pets and subsequently escaped or were deliberately released. This is a particular problem with the civets (Groves, 1984) but is also a possible explanation for the records of the pig-tailed macaque and possibly other species.

Hunting and deforestation have certainly caused the extinction of several species since 1819, including the larger deer and the Wild Pig, but for others the present status is uncertain. With a few exceptions, mammals are far less conspicuous than birds and they have also attracted far less attention from both professional zoologists and skilled amateur naturalists in Singapore. Most species are nocturnal, which reduces their chance of being observed still further. For our largest group of mammals, the bats, there have been few systematic observations anywhere in Singapore.

Mammals of Bukit Timah

Bukit Timah Nature Reserve is an island within an island, isolated from the more extensive forests of the central water catchment area by the Bukit Timah Expressway (fig. 1, chap. 11). The same basic principles apply to habitat islands as to real islands, so we would expect fewer mammal species at Bukit Timah than in the catchment area, despite the immaturity of most of the catchment forests. However, sightings of most rare or inconspicuous species are far too infrequent to distinguish real differences from the influence of chance. For the moment, it is best to assume that mammalian species seen in the catchment area are also likely to occur at Bukit Timah.

The following annotated list of mammal species at Bukit Timah has been compiled from various sources, including our own observations, published or unpublished observations of others, and the books by Harrison (1974) and Medway (1983). Information on the occurrence of mammals in Singapore at the end of the nineteenth century was obtained from Ridley (1895). Additional information on the biology of the species was taken from Lekagul & McNeely (1977) and Payne *et al.* (1985). For common (English) names we have followed Corbet and Hill (1992), because this is likely to be the standard source for the region in the future.

The majority of the mammals found today in the Bukit Timah rain forest are species that are equally at home in secondary forest and shrubland. This is in agreement with observations in other parts of the world which show that the first species to disappear when extensive areas of forest become reduced and fragmented are those confined to primary forest and unable or unwilling to cross open areas between forest fragments (Laurence, 1989). Bukit Timah is clearly too small to be of great value as a mammal reserve. However, the surviving mammals play an essential role in the ecology of the forest: as predators, herbivores and seed dispersal agents (chap. 3). Conservation of the mammals is therefore a necessity for the long term survival of the rest of the reserve's biota (Dirzo and Miranda, 1990, 1991; Leigh *et al.,* 1993). A purely botanical reserve is an impossibility.

Adequate fencing and patrolling of the reserve would not only contribute to the conservation of the existing mammalian fauna but would also make possible the reintroduction of some of the species lost in the past century. At Limas Belas, Perak, Malaysia, a similar 70 hectare area of rain forest, isolated for more than 60 years, still contains some of the mammalian species that have been lost from Bukit Timah, as well as species never found in Singapore (Bennett and Caldecott, 1981). The survival of the Slow Loris, Greater Mouse Deer and Porcupine at Lima Belas suggests that their reintroduction might be successful at Bukit Timah. The Barking Deer is also known to do well in disturbed areas in Malaysia. The risk of "genetic swamping" of locally-adapted genotypes, as well as the possibility of introducing new diseases, would argue against the release of "foreign" animals of any species known or suspected to still survive in the reserve. However, the number of pets and officially-confiscated animals released there already probably makes this precaution meaningless. Thus the systematic importation and release of animals to "rescue" the declining populations of other species, such as the Lepoard Cat, should perhaps also be considered. In any case, it will eventually be necessary to swap animals between Bukit Timah and the catchment area to reduce inbreeding and maintain genetic diversity.

INSECTIVORA

Soricidae

Crocidura fuliginosa Common White-toothed Shrew

This tiny shrew is the smallest non-flying mammal in the reserve. It is nocturnal and rarely seen, although probably common. Murphy (1973) mentions that it is often taken in pitfall traps at Bukit Timah. It feeds on insects on the forest floor.

The taxonomy of the *Cruocidura fuliginosa* species complex is in urgent need of revision. There seem to be at least two distinct species in this complex (Ruedi *et al.,* 1990) - possibly many - and the correct scientific name for the form found in Singapore is not clear.

SCANDENTIA

Tupaiidae

Tupaia glis Common Treeshrew

The Common Treeshrew is superficially very similar to the Plantain Squirrel, from which it can be distinguished (with some practice) by its longer, more pointed muzzle and a reddish stripe on the shoulders. It is also somewhat smaller. It is very common at Bukit Timah, foraging mainly on or near the ground, and is most commonly seen in the early morning and late afternoon. The diet is varied, consisting of invertebrates and some fruit, including figs (Langham 1979; Emmons, 1991).

The first major field study of tree shrews was carried out at Bukit Timah (Kawamichi & Kawamichi , 1979). This established that they are solitary in their foraging behaviour but that males and females may be pair-bonded. Individuals have home ranges of about one hectare from which they attempt to exclude adults of the same sex.

This preliminary study merely scratched the surface and many important observations remain to be made. For example, in captivity, it has been shown for several species that females leave the young unattended in nests and return to suckle them for 5-10 minutes only once every two days (Martin, 1984). Confirmation of this unique behaviour in the field would probably require radio-tracking to establish the location of the nests. However, tree shrews are easily disturbed and it is unlikely, given the huge increase in visitor numbers since the Kawamichis' study, that Bukit Timah would be the best location for further work.

The tree shrews were originally included in the order Insectivora and then later considered to be the most primitive members of the Primates. They are now, however, accorded their own order, the Scandentia.

DERMOPTERA

Cynocephalidae

Cynocephalus variegatus Flying Lemur

This curious animal is not a lemur but one of only two living species (the other in the Philippines) in its own order, Dermoptera. Nor does it fly, but rather it glides from tree to tree by means of a web of skin which extends from the neck to the tip of the tail, enclosing all four limbs. It is helpless on the ground and climbs slowly, but efficiently, always hanging upside down. Its largely nocturnal habits and the greyish-brown colour of its fur makes it inconspicuous but it is regularly seen in the reserve and is probably fairly common. Little is known about its diet. Most authorities state that it feeds on leaves, shoots and flower buds but Payne *et al.* (1985) say that the form of the teeth suggests a diet including plant sap. Wallace (1879) comments that this species has "such a remarkable tenacity of life that it is exceedingly difficult to kill it by any ordinary means".

CHIROPTERA

The two suborders of bats - the "megabats" (Megachiroptera) and the "microbats" (Microchiroptera) - are very distinct ecologically in tropical Asia. Indeed, there have been suggestions that the obvious morphological similarities of these two groups are the result of convergent evolution from independent origins, with the megabats related more closely to the primates than to the microbats.

However, recent molecular studies have convincingly disproved this "flying primate" hypothesis and shown that the two suborders are closely related.

CHIROPTERA - MEGACHIROPTERA

Pteropodidae

The "megabats" are all potential seed-dispersal agents and their survival is probably essential to the long-term conservation of the flora of the reserve.

Pteropus vampyrus Flying Fox

This is the biggest of all Asian bats, with a wing-span of up to 1.5 m. Flying Foxes have probably never been permanent residents at Bukit Timah but must have been regular visitors in the past from their gregarious roosts elsewhere in Singapore and on the mainland. Ridley estimated that 70,000 once roosted in the Botanic Gardens' jungle. Persecution and habitat loss have greatly reduced the numbers of these magnificent bats in recent years but small numbers were seen at Bukit Timah in 1987, feeding on *Campnospermum* (Corlett and Lucas, 1989).

Cynopterus brachyotis Lesser Dog-faced Fruit Bat

This medium-sized fruit bat seems to be the commonest bat at Bukit Timah. It eats a variety of fruit, including those protected by an inedible rind. The fruits are carried off to a nearby temporary feeding roost for processing. Only the smallest of seeds are swallowed while larger ones are spat out or dropped under the feeding roost (Phua and Corlett, 1989). In either case, the seeds are dispersed undamaged away from the parent tree.

Several other species of fruit bat are recorded from Singapore and, unless extinct, are likely to occur at Bukit Timah. These include the Long-tongued Fruit Bat (*Macroglossus minimus*), the Cave Nectar Bat (*Eonycteris spelaea*), the Dusky Fruit Bat (*Pethetor lucasi*), and Geoffroy's Rousette (*Rousettus amplexicaudatus*). The last three are cave-dwellers, which raises the interesting question of where they could live in modern Singapore.

CHIROPTERA-MICROCHIROPTERA

We do not know which of the many "microbats" recorded from Singapore are found at Bukit Timah. All the Singapore species feed on insects, usually caught on the wing.

PRIMATES

Lorisidae

Nycticebus coucang Slow Loris

The Slow Loris is probably extinct in the wild in Singapore, although it was apparently common in Ridley's day (Ridley, 1895). The occasional animals captured or seen in recent years are most likely to be escaped or released pets.

Cercopithecidae

Macaca fascicularis Long-tailed Macaque

This is the common monkey at Bukit Timah. Its ecology is treated in detail in Chapter 10.

Macaca nemestrina Pig-tailed Macaque

The past status of this monkey in Singapore is uncertain but it is not present now. There are apparently no nineteenth century records of truly wild Pig-tailed Macaques, although Ridley mentions half-wild escapes near the town. The only clear support for this species in Singapore is a hand-written note by Corner in 1941 on the copy of Chasen (1940) housed in the Zoological Reference Collection of the National University of Singapore. In this note, part of which is missing, Corner refers to the testimony of Ngadiman, forest ranger at Mandai, who saw a large troop there that included young. This may have been the troop seen by Corner in the late 1930s (Corner, 1978). Could these monkeys have been the descendants of escapes? In any case, there is no evidence that this species was ever found at Bukit Timah.

Presbytis femoralis Banded Leaf Monkey

This monkey is the largest surviving mammal in Singapore. It is represented here by the subspecies *Presbytis femoralis femoralis*, which is almost completely black, except for a vertical white stripe on the thorax and abdomen and on the inside of the thighs. Its characteristic alarm call sounds like "Kak-kak-kak-kak". Newborn young are white, except for a cross-shaped black mark on the back. This species feeds largely on seeds and young leaves in Malaysia (Bennett, 1983). The seeds are destroyed so langurs, unlike the macaques, are not significant seed-dispersal agents.

Although extremely common in the Malay Peninsula, this species has been rare in Singapore since the 1930s, when Chasen asked for a restriction on gun permits on the grounds that there were only a dozen of these monkeys left (Lucas *et al.*, 1988). Chasen was probably unaware of the troop in the Nee Soon forest, seen by Corner (Corner, 1978) and rediscovered there recently. At Bukit Timah, a troop survived into the 1960s (Harrison, 1974), was probably down to a pair in the 1970s (Murphy, 1973) and finally died out in October, 1987 (Lucas *et al.*, 1990).

The remaining troop of these monkeys, at Nee Soon, deserves top conservation priority, as the Singapore sub-species may be entirely restricted to the island.

CARNIVORA

Viverridae

Paradoxurus hermaphroditus Common Palm Civet or Musang

The Common Palm Civet is rather like a large, greyish cat but with shorter legs and longer, more pointed, muzzle. Although largely nocturnal, it is occasionally seen during the day. It climbs well but also feeds on the ground, taking fruits, insects and rodents. The significance of the Palm Civet as a seed dispersal agent is discussed in Chapter 3.

As mentioned in the introduction, the past status of the civets in Singapore is confused by their transportation for food. Only the Common Palm Civet is certainly present today at Bukit Timah but others may well still occur. The most likely additional civet species are the Masked Palm Civet (*Paguma larvata*), the Malay Civet (*Viverra tangalunga*), the Large Indian Civet (*Viverra zibetha*), and the Small Indian Civet (*Viverricula indica*), but there are doubtful old records of other species as well.

Felidae

Felis bengalensis — Leopard Cat

Placed in the genus *Prionailurus* by Corbet and Hill (1992). Although not seen at Bukit Timah in recent years, the Leopard Cat may still survive in Singapore, as it does in other densely-populated parts of Asia. It is the size of a large domestic cat with dark spots on a yellowish background. The Leopard Cat apparently feeds mostly on the ground although it can also climb trees. It lives on small vertebrates, such as frogs, lizards, birds and rodents.

Although there are no other species of wild felid in Singapore today (except for semi-feral domestic cats), there were others in the recent past. Tigers (*Panthera tigris*) are not mentioned in the earliest accounts of the colony but were frequent enough to be a major problem by the middle of the nineteenth century, when Wallace, staying near Bukit Timah, sometimes heard a tiger roar in the evening. The initial stages of deforestation may have made Singapore more attractive to a large carnivore by increasing populations of pigs and deer. The last definite record of a tiger at Bukit Timah was in the 1940s. Leopards (*Panthera pardus*) seem also to have roamed the island in the nineteenth century, although Ridley expresses doubt about this. Records of two other species, the Clouded Leopard (*Pardofelis nebulosa*) and the Flat-headed Cat (*Prionailurus (Felis) planiceps*) are even less firmly based.

ARTIODACTYLA

Suidae

Sus scrofa — Wild Pig

The wild pig, at one time "far too abundant" (Ridley, 1895), is now extinct in Singapore, at least on the main island. Wild pigs still occur on Pulau Tekong and Pulau Ubin, although these may be feral animals of domestic origin.

Tragulidae

Tragulus javanicus — Lesser Mouse Deer

This is the smallest Asian deer and probably the only one that still survives at Bukit Timah. Ridley recorded mouse deer as abundant in Singapore but it is not clear which species he was referring to. The Lesser Mouse Deer is a very small deer with stick-like legs and high hindquarters. It has no antlers but the male has tusk-like upper canines which protrude below the lips and presumably serve a similar function. Mouse deer are reported to feed on fallen fruits and leafy shoots.

Mouse deer are of particular interest because they are in some ways intermediate in form between the pigs and the true deer (Dubost, 1984). They are considered to be the most primitive of living ruminants .

The Greater Mouse Deer (*Tragulus napu*) is somewhat larger and presumed extinct, although one can never be sure with so secretive an animal. The other two, much larger, species of deer recorded from Singapore - the Sambar (*Cervus unicolor*) and the Barking Deer (*Muntiacus muntjak*) - are now certainly extinct, the former in the 1940s and the latter even earlier. The Barking Deer is an obvious candidate for reintroduction: it is harmless, a potentially important seed-dispersal agent, and it thrives in the degraded landscape of Hong Kong.

PHOLIDOTA

Manidae

Manis javanica — Pangolin

Although rarely seen, the pangolin probably still occurs at Bukit Timah. The large scales which cover the entire upper part of the body make this animal unmistakeable. It is usually nocturnal, sleeping during the day in an underground burrow or hollow log. The pangolin feeds largely (some authors say exclusively) on ants and termites. The strong, clawed feet are used to break open the nest and the incredibly long, sticky tongue to lap up the contents. Pangolins both dig and climb well so no nest is safe from them.

RODENTIA

Sciuridae

Callosciurus notatus — Plantain Squirrel

This is the very common medium-sized, arboreal squirrel at Bukit Timah. The belly is reddish-brown and there are buff and black stripes on each side. However, neither feature is easy to see in life when it simply appears brown all over. It is usually seen at heights below 15 m, although it will also venture into the upper canopy at times. The very varied diet includes fruits, seeds, shoots, bark and insects. The possible role of this and other arboreal squirrels in the dispersal of the hard, dry fruits of the oak family (Fagaceae) is discussed in Chapter 2. It is also known to take small vertebrates and bird eggs (Duckett, 1982).

Sundasciurus tenuis — Slender Squirrel

This is the common, small arboreal squirrel at Bukit Timah, distinguished also by its rather long and slender tail. It is seen predominantly away from the ground but rarely in the canopy. This species apparently feeds mostly on bark and sap (Mackinnon, 1984) although it also consumes a wide range of other items.

Ratufa affinis Pale Giant Squirrel

This is the largest tree squirrel in Singapore and was common in Ridley's day. It still survives in the water catchment area and may well be present at Bukit Timah. The colouration in this species is variable but skins in the Zoological Records Collection and a recent sighting (Ho, 1987) suggest that the common form in Singapore is cream all over, but with some dark hairs on the back. Its diet consists largely of fruit, with some leaves and bark.

Lariscus insignis Three-striped Ground Squirrel

There seem to be no recent records for this species in Singapore but there is no reason to believe it extinct. It is a diurnal, ground-dwelling squirrel with a shorter tail than the arboreal species and three black stripes along the back. In contrast to *Rhinosciurus*, its diet has been reported to include fruit (Medway, 1983) and leaves, shoots and insects (Mackinnon, 1984).

Rhinosciurus laticaudatus Shrew-faced Ground Squirrel

This ground squirrel has dull-red fur, a short, bushy tail and a distinctive long muzzle, like that of a treeshrew. It still occurs at Bukit Timah but is probably most often confused with other squirrels or the treeshrew. It is insectivorous and its long tapering muzzle and reduced, forceps-like incisors are presumably adapted to this diet.

Petaurista petaurista Red Giant Flying Squirrel

This is the largest of the flying squirrels and apparently still survives at Bukit Timah. Being largely nocturnal, it is probably underrecorded. Ridley reported it still common in 1895. Like the flying lemur, flying squirrels do not really fly, but glide between trees with the aid of the furred skin stretched between the extended limbs. Unlike the flying lemur, however, this flying membrane leaves the neck and most of the tail free, and the animal has a typically squirrel-like posture when at rest. Its diet is reported to consist of leaves and seeds. The much smaller Horsfield's Flying Squirrel (*Iomys horsfieldii*) has also been reported from Singapore but is presumed extinct.

Muridae

Maxomys surifer Red Spiny Rat

This is a reddish-brown terrestrial rat with numerous black spines mixed in with the fur. In Singapore, this species may be confined to primary forest (Alaudin, 1986), where it lives in burrows.

Rattus annandalei Singapore Rat

A greyish-brown terrestrial rat with a white belly. This species is common in both primary and secondary forest, as well as shrubland.

The other species of rats and mice found in Singapore apparently do not enter the forest and none of the other forest rats of the Malay Peninsula have been recorded on the island.

Hystricidae

Hystrix brachyura Porcupine

The porcupine was still common in Ridley's day, when it was very destructive of the pineapple crop. Flower (1900) recalls buying a live porcupine which he was told was caught on Bukit Timah. However, there are no recent sightings and although, as a chiefly nocturnal animal, it could perhaps be missed, the extensive burrow systems which porcupines excavate are more conspicuous. Porcupines have a varied vegetarian diet, including roots, bark and fallen fruit.

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Chapter 10

Long-Tailed Macaques

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Introduction

Macaca fascicularis, the long-tailed macaque, is a small cercopithecine monkey, weighing between 3-5 kilograms, with a distribution that stretches from Burma to the Philippines. It lives in large multi-male groups of between 15-30 individuals and is almost exclusively arboreal in rain forest. It occupies all forested habitats except montane forest and has been successfully introduced to various islands by man (e.g. Mauritius - Sussman and Tattersall, 1986). This apparent flexibility, coupled with its high population density in secondary forest (up to 1 individual per hectare), has led to its being described as a "weed" species, in that its numbers and distribution may have increased as a result of man's activities in clearing forest (Richard, Goldstein and Dewar, 1989). Certainly, long-tailed macaques are not reported as common in virgin, undisturbed, lowland primary rainforest except in the successional forest close to rivers (Chivers, 1980).

In Singapore, long-tailed macaques survive mainly on the main island in the area between the Bukit Timah and Pan Island Expressways and the Upper Thompson and Mandai Roads (fig. 1, chap. 11). Outside these boundaries, one group is reported to inhabit the restricted area near the firing range on the West Coast, another is located near the Swiss Club, an isolated group molests a small housing estate between Braddell Road and Toa Payoh and 3-4 groups are found on Bukit Timah. A survey by the Malayan Nature Society in August 1986 helped to establish that the total population on the island is unlikely to exceed 1,000 individuals. On other islands, two groups are found on Sentosa, one each at its eastern and western extremes, and one or two groups are probably still present on Pulau Ubin.

Groups on Bukit Timah

In March 1986 when the Bukit Timah Expressway had just opened, there were four groups of macaques on Bukit Timah composed as follows:

Group		Individuals
A		32-39
B		23+
C		12
D		15+
	Total	82+

Adult males and older females are the most individually distinctive and the most useful in recognising particular groups. The sex of an adult long-tailed macaque can be determined from :

(a) the shape of the ischial callosities (bare areas on the rump distinctive of Old World monkeys) - a cleft is present in females to accomodate their genitalia,

(b) the presence of large nipples in the female,

(c) the presence of peripheral hair around the face (beards) in females and

(d) the males being noticeably more muscular around the shoulders and somewhat larger in size than females.

Only a few minutes of observation is necessary to pick out individual characteristics. For example, the dominant male of group C had a long vertical scar on the upper lip rather like a hare-lip. The largest male of group A had a flat face with a bushy beard somewhat like a female's.

However, the adult composition of the groups appears to change quickly. Six adult males and two old females disappeared from groups A-C between July, 1986 and November, 1987, which fact renders any detailed descriptions of individuals time-dated. Furthermore, in October, 1987, a survey by 8 observers failed to re-establish contact with group D. However, at the time of writing (October, 1989), groups A, B and C can still be recognised in the reserve.

Group A sleeps in large *Shorea* trees (*S. curtissii* and *S. parvifolia*) around the Telecoms summit and on the Telecoms towers themselves. At that time, there were four adult males and at least nine adult females in a troop of 33 individuals. Eight of these females gave birth over the period between June-August, 1986 and there were seven births in the same period a year later. However, two males disappeared from the group at that time. Both probably travelled and foraged separately in late 1986. One was apparently caged for several weeks by a kampong dweller who was attempting to stop the macaques raiding fruit trees, but both later rejoined the group. Censuses of the group in 1986-7 never exceeded 39 individuals.

Most of the data reported in this chapter concerns Group A because it was followed by myself for about 500 hours between July, 1986 and November, 1987. The home range of group A is about 33 hectares, comparable to those recorded in Peninsular Malaysia (Mah, 1980; MacKinnon and Mackinnon, 1980). Approximately two-thirds of this range is primary rain forest with the rest being secondary forest of variable height and composition. East of the Cave Path (fig. 2, chap.1), some of this secondary forest contains groves of abandoned fruit trees. Most of the edges of the reserve that are bounded by kampong houses also contain fruit trees. A small part of their range contains an 80 year old *Palaquium gutta* plantation in Taban Valley (fig. 2, chap. 1).

Interspersed between these trees are other large members of the Sapotaceae (*Payena lucida* and *P. maingayi*) and dipterocarps (*Anisoptera* and *Dipterocarpus* spp.). These are unlikely to have been planted which suggests that the Taban Valley was never completely cleared.

The method of observation was scan-sampling (Lucas and Corlett, 1991) whereby every 15 min, the activity of each visible member of the group was recorded. The group was initially approachable to within 10m. However, within the forest, most group members quickly accepted observers to within 5m and some within 1m. These are very good conditions for recording diet and feeding behaviour, even better than with captive animals. Most of the natural history in this account is based on these records.

Groups B inhabits most of the floristically rich Fern Valley (Corlett, 1989) and also the region of the Kampong located in the reserve (which has since been demolished). The group contained two adult males in 1986-7, one being the largest macaque in the reserve. This group did not become habituated to accept an observer closer than 10m. It occasionally came to Telecoms Tower (fig. 2, chap. 1) in the evenings, precipitating fights between the adult and subadult males of groups A and B.

Group C is based at the summit, being seen typically sitting in a large *Prunus polystachya* (Rosaceae) and a *Intsia palembanica* (Leguminosae) opposite the radio mast. Their apparently small home range is probably influenced by the quantity of artificial food available at the summit, but in 1986, at least, it included part of the other floristically rich area, Jungle Falls Valley (fig. 2, chap. 1). The group had only one adult male, who was often very aggressive. Group C also came to the Telecoms Tower, attracted by food offered by an employee there, but avoided contact with group A.

Group D was only seen twice in the far north of the reserve and little is known of its composition.

Diet

Use of the home range by a macaque group depends largely on the daily availability of the most important component of its diet, fruit. The composition of the diet of group A during the study period was :

fruit	44%
probable animal matter	27%
artificial feeding	14%
vegetative parts	8%
flowers	7%

None of these commonly-used categories is homogeneous and they do little on their own to explain behavioural observations. A brief discussion of these categories follows.

Fruit

Long-tailed macaques are primarily frugivorous. We have observed them eating 186 species of fruits, a considerable proportion of the estimated 300 species to fruit in Bukit Timah during the period of observation. Insofar as long-tailed and pig-tailed macaque diets are known in Peninsular Malaysia (Mah, 1980, Caldecott, 1986), our list overlaps considerably with others. Because parts of fruit are dropped by the macaques, this is the easiest part of their diet to observe, forming an obvious observational bias. In ecological studies that concentrate on frugivory, the structure of fruits is often found to correlate strongly with the method by which seeds are observed to be dispersed away from the parent plant. For a forest tree, 20m is a reasonable minimum estimate of the horizontal distance, measured from the trunk of the parent, needed to ensure the survival of sufficient seeds, dispersed both from each other and from the parent (Howe, 1980). Nearly all forest plants require this dispersal (Howe and Westley, 1988).

A degree of co-evolution between fruit and dispersal agent can seen in fruit design. For example, fruits that have an appreciable horizontal movement when they fall in the air have an enlarged surface area-to-volume ratio. These fruits do not have a wet flesh surrounding the seeds and are therefore not immediately attractive to animals. Fruits that do get eaten attract particular groups of animals by appealing to their dominant sense. Thus, birds (which are highly visual animals) are attracted to fruits by colour while mammals may concentrate on fruits that they can learn from experience as having desirable tastes. The oral sensation of taste is partly that of smell. Very few wild fruits are really sweet but some are not designed to be. Fruits which are dispersed primarily by some birds. (e.g. hornbills) contain a lipid-rich (oily/fatty) flesh (Leighton and Leighton, 1983). Examples are the fruits of the Lauraceae (many *Litsea* species on Bukit Timah) and Myristacaceae ("nutmeg" fruit such as *Myristica cinnamomea* and *M. elliptica* on Bukit Timah). However, it is one thing to attract a particular set of animals who are likely to disperse seeds and another to fend off others who would either damage the seeds or drop fruits and seeds under a tree (Howe, 1980, Corlett and Lucas, 1990).

Some degree of protection from unwanted consumers can be achieved mechanically by constructing a thick peel around a fruit (Janson, 1983). Most fruits that the macaques ate possessed a juicy flesh surrounded by a thin flexible skin (114 species) but many were surrounded by a thick peel (38 species). Most birds eat only unprotected fruit in rainforest (Janson, 1983) whereas monkeys and apes are known to eat fruits from both categories. A key difference between such anthropoid primates and birds is the presence in all anthropoid primates of large spatulate incisor teeth at the front of the mouth which can rapidly remove the peel from protected fruit. Only some mammals, such as monkeys (Janson, 1983) and bats (Phua and Corlett, 1989), appear to have the necessary dental capacity to open peeled fruits. Whether other important arboreal frugivorous mammals such as civets are equally adept at peeling fruits (their dental anatomy suggests not) is unclear. In most species of fleshy fruits, the enclosed seeds survive incisal preparation and subsequent mastication by macaques.

Many fruits, particularly those of canopy trees and climbers, are dry and are apparently designed for wind dispersal although a few, mostly Fagaceae, are dispersed by squirrels. Macaques ate 16 species of such fruits. Dry fruits were under-represented in the diet compared to their availability. Over the entire study period, 20% of fruiting trees bore dry fruits while such fruits only accounted for 11% of dietary observations (Lucas and Corlett, 1991).

Fruits house a variable number of seeds for which fruit structure acts to effect dispersal. The seeds of all dry fruits that I was close enough to see processed (13 species) were destroyed by the macaques; they are the reason for consuming the fruit.

That so few dry fruit species were consumed suggests that these seeds were protected against destruction. Indeed, evolutionary theory would strongly predict this because seeds form the potential next generation of plants. This protection is variably chemical (Janzen, 1971; Bell, 1978) or mechanical. Mechanical protection is afforded by woody seed coats (e.g. *Mezzettia parviflora,* Annonaceae - Lucas, 1989; Lucas *et. al.*, 1991) and rigid endosperms (e.g. rattan palms). Unless such seeds are opened, they cannot be digested by primates. Opening them either exposes the primate to toxins or involves the necessity to exert great jaw forces. Long-tailed macaques seem to refrain from breaking seeds in the mouth (only 13 out of 116 species for which seed fate could be established) despite most seeds being apparently well within their oral capacity to open them. Their "mechanical" limit lies somewhere between rattan seeds (which captive macaques could open) and oil-palm seeds (*Elaeis guineensis*) which wild animals could not.

To avoid seed toxins, the macaques could either have swallowed seeds whole or else spat them from the mouth onto the ground. In fact, the macaques spat almost all seeds whose average size (maximum width) was above 4 mm, i.e. almost 70% of seeds by species (Corlett and Lucas, 1990). Such a pattern has not been established in any other primate species. However, it is becoming generally clear that a major factor determining the fate of seeds enclosed in fleshy fruits that are eaten by animals is seed size. Unlike long-tailed macaques, most primate species swallow very large seeds (20 mm and above). This incurs a significant dead weight in the gut. For example, *Hylobates klossii*, a gibbon from the Mentawai islands, has been shown by Whitten (1982) to eat ~ 15% of its body weight of whole (and therefore undigestible) seeds within a day. The alternative involves separating seeds from fruit flesh with the mouth and then spitting them out. Long-tailed macaques (and other cercopithecine Old World monkeys) have a key oral adaptation to enhance the speed of this operation. They possess cheek pouches into which they place large amounts of small fruit, which have first been peeled, if necessary, at the front of the mouth. These fruits are then returned one by one to the mouth for removal of the flesh. It is very likely that the flesh can be more thoroughly masticated without the seed.

Animal matter

The only vertebrate seen eaten was a single observation of predation on a lizard. The skin was fractured by a single incisal bite on the dorsal surface of the prey and the skin was then stripped from the flesh by hand. Muscle from the lizard's back was being consumed as the macaque involved, a juvenile male, was lost from vision.

It was difficult to identify the invertebrates that macaques consumed because of their size and because nothing was thrown to the ground. I recorded foraging, defining this as slow investigation of the foliage (but without consumption of plant parts) followed by a rapid hand movement bringing something to the mouth and chewing movements. It is on this basis that 27% of feeding observations were likely to have been on animal matter. This percentage is similar to that obtained by Mah (1980) for long-tailed macaques in Peninsular Malaysia. I ascertained that stick insects, spiders, cockroaches, some caterpillars and ant eggs were eaten. Honeycomb from an *Megapis dorsata* hive was also eaten. Visits to one Lauraceous tree (possibly *Beilschiemidia* sp.) in which up to ten individuals spent approximately ten minutes on two occasions seemed only for the purpose of foraging for a large species of stick insect. Foraging for a species of the St. Andrew's Cross spider (genus *Achiope*) was particularly conspicuous.

Artificial feeding

In the late 1980's, the items fed to group A included peanuts, bread and fruits (bananas, oranges, apples, grapes, rambutans, chikus and limes). These were given by personnel stationed in the reserve at the Telecoms Towers and the summit and by forest rangers. Visitors also contributed, offering bizarre items such as green-leafed vegetables (market produce " to balance their diet" said the visitor) and desserts such as little biscuits with icing on them. However, more often than not, visitors made a bee-line for the summit (and group C) if feeding monkeys was their main objective.

Almost all people who fed the macaques and who I questioned felt that, without this help, the macaques would starve. This attitude seems to stem from two sources - that macaques are totally frugivorous, (which no tropical mammals or birds are), and that all fruits are large and conspicuous and therefore that there aren't any in the forest for most of the time because none are clearly visible. The latter attitude confuses cultivated fruits, which have been selected for taste and looks, and most attractive forest fruits such as some *Strychnos* spp. (Loganiaceae) and Araceous fruits which are toxic to man and, possibly, to macaques. Cultivated fruits have been subjected to selection for the size of the flesh. In contrast, many wild fruits also appear to offer rather little for an animal. For example, the fruit of *Embelia ribes* (Myrsinaceae) offers 0.4 cm^3 of flesh per fruit. Macaques eat these in quantity; they have no choice in a general sense because they have not cultivated their own fruits (see section on Evolutionary Adaptation). Though the most consistent of the self-appointed provisioners to group A, an employee at Telecoms Tower, was convinced that he was keeping the group alive, I feel that it was the opportunity to be near to and occasionally touch the macaques, as something akin to undemanding (but unpredictable) pets, that formed a prime motivation to interfere.

In fact, the benefits of artificial feeding to macaques are negligible compared to deleterious effects on their behaviour (Spencer, 1979). The aggressive begging habits of long-tailed macaques seen in Penang Waterfall Gardens and Bali and the hybrid macaques in Hong Kong (Fellowes, 1992), and which are associated with very rapid increase in population numbers, threaten such groups everywhere with extermination by the authorities (Edington and Edington, 1986). This is particularly so when the macaques progress from being a nuisance to biting visitors who refuse to hand over their plastic bags. Such macaques also become more aggressive amongst themselves, for which two reasons have given. One is that an increase in aggression is inevitable when animals are fed because it brings the group closer together than they would be in the forest and so their spacing mechanisms for averting conflicts break down. The other concerns the method of feeding which usually means that adult males get most of the food and expend much energy controlling the attempts of other group members to obtain a share (Spencer, 1979). At "feeding times" on Bukit Timah, adult male macaques receive more food than other group members and disputes between adult and subadult males and between these and adult females are common.

In May-June, 1987, notices were placed in the reserve asking visitors to refrain from feeding animals. This had no immediate effect on some of the staff in the reserve and over one year later the animals were still being fed. Our study on group A revealed that there was a significant negative correlation between the availability of fruit in the primary forest and artificial feeding of the macaques. Though there might be several interpretations of this relationship, it could indicate that the macaques use provisioning only as a supplement when sufficient fruit is not available (Lucas and Corlett, 1991).

Flowers

The macaques were very selective about the flowers that they consumed. This is reflected in the fact that there was a low correlation between species in flower in the forest and the number of species eaten by the monkeys. Some flowers were undoubtedly consumed for the nectar (e.g. *Passiflora* spp. - Passifloraceae) while they consumed the whole flower in other cases (e.g. *Payena lucida* - Sapotaceae). Almost one-third of observations were on the everflowering *Pternandra echinata* (Melastomataceae) and 17% were on grass spikelets. Most of the latter were eaten after 5 p.m. local time, a period in which Berenstain (1986) also saw macaques descending to the ground to eat grasses in east Kalimantan.

Vegetative parts

This category covers a wide variety of structural plant tissue including young leaves, petioles, stems, pith, shoots and bark. It also includes leaf galls, which are growths in response to insect attack. Though galls were relatively unimportant as foods, those caused by *Gallococcus anthonyae* were the only food provided by *Shorea curtissii* which are the dominant trees at Bukit Timah. Young leaves of the Moraceae (certain *Ficus* spp., *Streblus elongatus* and *Artocarpus elasticus*), *Gluta wallichii* (Anacardiaceae), the shoots of two bamboo species and the pith of *Smilax bracteata* var. *barbata* (Smilacaceae) contributed half of the records in this category. The most important species was *G. wallichii*, a species which is notably allergenic to humans (von Baer, 1983) but not apparently to the macaques. The leaf of this species resembles that of the mango, *Mangifera indica,* and is typically marked with a black stain (Corner, 1940). It is very common at Bukit Timah (Wong, 1987) and saplings can be seen in many parts of the primary forest. Most feeding records on *G. wallichii* were on saplings but the young leaves of large trees (30 m or more) were also eaten. Most leaves were eaten only when relatively young. On those trees where the crown re-leafed simultaneously, for example *Ficus variegata* (Moraceae), the consumption of new leaves lasted only for a few days.

Daily Activity Pattern

For most of the study period, macaque groups made radial forays each morning from preferred sleeping trees, returning by a different route in the late afternoon. The macaques spent 29% of their time on the ground. The scan-sampling method overestimates this figure due to differential visibility at different heights but, nevertheless, it is still a higher figure than that recorded in Borneo (Berenstain, 1986). In part, this is related to artificial feeding but the monkeys also commonly came to the ground at other times which could be related to the lack of remaining predators at Bukit Timah (van Schaik and van Noordwijk, 1986). They spent most of their time at about 10-25 m above ground. This level includes the crowns of understorey and medium- sized trees in primary forest. There could be several reasons for this height preference:

(i) *The canopy of primary forest rarely fruits.* When it does, it is an attraction for the macaques although many tree species produce dry fruit in a short synchronised spell and, as stated above, macaques seem not to prefer dry fruits. Most of the feeding on dry fruits by the macaques took place when few fleshy fruits were available, e.g. on *Castanopsis lucida* (Fagaceae), a tropical chestnut. However, irregularly over the year, the primary forest at Bukit Timah does have strangling figs that can produce vast quantities of figs for periods of several days. However, while orang-utans (Rijksen, 1978) and gibbons (Chivers, 1980) eat vast quantities of figs, long-tailed macaques in Bukit Timah rarely stop to eat their way through an entire fig crop (but see below) and seem to prefer to move constantly onto new food sources (also in Sumatra - Cant, 1988).

In contrast, there always appear to be some fleshy fruits available below the canopy. One of the most commonly-eaten fruits in the study period was that of *Calamus oxleyanus,* a climbing understorey rattan that can fruit as low as 3 m. The fruits, which are available for much of the year, are covered with a thin scaly layer. This peel probably protects them from most birds and the only likely competitors for this type of fruit would be civets. Many other climbing rattans also fruit in the understorey, including *Calamus lucidus, Daemonorops didymophylla* and *Korthalsia scortechinii,* but they produce fruit too infrequently to be important sources of food for macaques. However, *Pternandra echinata* (Melastomataceae) and the *Urophyllum-Ixora-Canthium* group of genera (Rubiaceae) are often in fruit and are eaten regularly by macaques. In the Neotropics, such unprotected fruits in these plant families are devoured by understorey frugivorous birds (Terborgh, 1983) and monkeys do not get to eat them. In southeast Asia, there is much less competition from specialised birds at this height (C.J.Hails, *pers. comm.*). The macaques appear to eat a wide variety of fruit but avoid to some degree those species producing "bat" fruits. These fruits are often green when ripe and distinctly unpalatable to humans. Examples at Bukit Timah are *Pellacalyx saccardianus* (Rhizophoraceae) which is in fruit for almost half of the year and is common along paths and the road, *Adinandra dumosa* (Theaceae) and *Ficus fistulosa* (Moraceae), which is found in disturbed areas and secondary forest. The young leaves of *Gluta wallichii, Streblus elongatus, Ficus chartacea, Urophyllum* spp. and *Symplocos fasciculata* (Symplocaceae) were those most commonly eaten in the understorey.

(ii) *The understrata of the forest may be rich in edible invertebrates.* Murphy (1973) attempted to assess the vertical distribution of animals in Bukit Timah and found a rich fauna on those trees whose crowns were low enough for the foliage to be beaten. A comparison with the high canopy was complicated by the difficulty of obtaining an unbiased sample. There is some evidence for a stratification in spider genera but there is, unfortunately, no information on stick insects except that they seem to be in large numbers (Murphy, 1973). The richest areas of Bukit Timah for insect life appear to be the Fern, Jungle Falls and Taban valleys (Murphy, 1973). The latter was particularly thoroughly combed by the macaques of group A.

(iii) *This height (10-25 m) is also the height of the canopy of secondary forest which is reproductively active for much of the year.* The secondary forest at Bukit Timah is very variable in composition. Tree figs (*Ficus variegata, F. glandulifera* and *F. lamponga*) are commonest at the fringes of primary forest and *F. grossularioides* is abundant in secondary forest. On the boundary path beside Hindhede Quarry, the fruits of the naturalised exotic *Acacia auriculiformis* (Leguminosae), particularly in August/September, were an attraction, fruiting later than most fleshy fruits in the primary forest (see below). In others, *Rhodamnia cinerea* fruits twice yearly and *Macaranga conifera, M. triloba* (Euphorbiaceae), *Eugenia longiflora* and *E. filiformis* (all Myrtaceae) appear to fruit annually. The unripe fruit of *Caryota mitis* (Palmae) and the fruit and flowers of *Dillenia suffruticosa* (Dilleniaceae) were constantly available.

The macaques often spent the middle of the day resting in these peripheral areas and grooming each other. The dehydrating heat of secondary forest was rarely countered by the drinking of water (only five records over 500 hr). However, the pattern of consumption of the pith of the tips of *Smilax bracteata* var. *barbata* (Smilacaceae) plants, common climbers in these areas, was suggestive of its use as a water source. The plants were never touched before midday.

Beyond the margins of the reserve are groves of fruit trees surrounding kampongs. Macaques often raid these when in season, particularly for rambutans (*Nephelium lappaceum* - Sapindaceae), starfruit (*Averrhoea carambola* - Oxalidaceae) and guava (*Psidium guajava* - Myrtaceae). Small plots of tapioca (*Manihot esculenta* - Euphorbiaceae) were also attacked, with the adults and subadults having sufficient knowledge and force to lift plants out of the ground and detach the tubers. To the east of the Cave Path (fig. 2, chap. 1) lies an abandoned fruit grove containing many rambutan and durian (*Durio zibethinus*) trees. The flowers of durians are apparently relished by the monkeys for their nectar content. However, the forest rangers say that the monkeys do not appear to be able to open the ripe fruits unless they have been mechanically damaged or have opened. The observations of the rangers can be trusted because of their participation in a curious day and night "festival" in June. As macaques entered a durian tree in fruit, the branches bounced often causing ripe fruit to fall and a scramble on the ground among the addicted human frugivores gathered there.

During July-August, 1987, there was a fruit glut in the primary forest which included the Dipterocarpaceae. *Dipterocarpus caudatus* fruited heavily and while some *Shorea* fruit were found, the quantity may not have been sufficient for 1987 to qualify as a mast year. During this period, the macaques stayed away from their regular sleeping sites around the Telecoms Tower and were usually found in primary forest. The usual pattern where primary forest functioned more as a conduit than as typical habitat was reversed. Fruit consumption by the macaques mirrored production in the primary forest (Lucas and Corlett, 1991) except that some understorey species were eaten unripe (*Popowia fusca* - Annonaceae, *Prismatomeris tetranda* - Rubiaceae) before the peak and that *Castanopsis lucida* fruited afterwards. At the peak, it was noticeable that some annually fruiting species were less important in the diet than in the year before (e.g. *Campnosperma auriculatum* - Anacardiaceae; Corlett and Lucas, 1989). In contrast, four individual *Artocarpus lanceifolius* (Moraceae) fruited heavily and the crop was apparently totally demolished by the macaques which are probably important dispersers for this species. The most important plant species for the macaques at this period were in the Moraceae (*Artocarpus elasticus, A. lanceifolius*), Sapotaceae (genus *Palaquium*), Euphorbiaceae (*Baccaurea kunstleri*), Annonaceae (*Xylopia malayana*) and the Burseraceae (*Santiria apiculata*) as well as rambutans.

Evolutionary Adaptation

The *Macaca* genus contains four subgroupings in which *Macaca fascicularis* and *Macaca mulatta,* the rhesus macaque, are lumped together in one subgroup (Delson, 1980). The two species are morphologically similar (with the exception of tail length) and occupy similar habitats. Their distributions do not overlap which suggests competitive exclusion. They hybridize freely when brought into contact - e.g. in Hong Kong (Southwick and Southwick, 1983). These macaques differentiated and spread into Asia rapidly over the last one million years; no macaques have been in Asia much longer than this (Delson, 1980).

This time period is the same as that for the spread of hominids from sub-Saharan Africa. *Homo erectus,* the earliest non-African hominid species, was a tool-user and is first known in Asia from deposits in Java dated at about one million years (Lewin, 1986). It has been suggested that the geographical expansion of early man and these macaques could be linked (Richard, Goldstein and Dewar, 1989). As forest was disturbed, possibly involving fires, and later in time cleared, long-tailed and rhesus macaques (or their ancestors) moved into the regenerating forest to feed on successional plant species (not human's garbage) such as they fed on in riverine forest. These evolutionary changes are probably very recent compared to those of the plants that long-tailed macaques feed on. Many of the plant genera producing fruits mentioned as key components of the macaque diet (Caldecott, 1986) in Asia as a whole have been in the region since the Miocene period (i.e. 5 million years or more). It is highly unlikely that there has been much coevolution between macaque and fruit anatomy. Whatever they eat anywhere was probably first adapted to something else. However, it is conceivable that long-tailed macaques have adapted towards their plant foods in the last one million years. But, a key adaptation for this, their dental anatomy, seems remarkably conservative. The measure of success of long-tailed macaques is their ability to invade new geographic regions without any obvious adaptations for it.

The benefits of the man-macaque relationship in the past would have been totally in favour or the macaques. The current trade in long-tailed macaques for medical research and other purposes has redressed the balance dramatically! The total population in the wild is still estimated at more than four million individuals (MacKinnon, 1987; MacKinnon and Mackinnon, 1987), which does not cause immediate alarm, but relatively few of these animals are in reserves or in areas earmarked for conservation.

Current Situation At Bukit Timah

I surveyed the macaque population again during mid-March 1994. There were at least 94 individuals present in three groups. This is a small increase in numbers on 1986-7 but a decline in group numbers from four down to three. Two groups had also moved core areas. Group A is now seen most often around the car park area and has at least 41 individuals with four adult males. The lead male was immature in 1986-7 and is now 11 years old. He has a distinct crest (nickname "Jambul"). One other adult male has a crest as well. This latter male appears very adventurous and was observed crossing the railway lines and moving into fruit trees in the gardens of houses close to upper Bukit Timah Road. Group B is now resident around the Telecoms Tower and had at least 27 members, including two adult males. Group C remains around the summit but has shown the largest increase in numbers, up from 12 in 1986-7 to 26 members now (with two adult males). Limited observations and periods combing the reserve make the above figures tentative. They are mimimum estimates only.

All the monkey groups were better habituated to visitors than before - only group C seemed to panic at being observed closely while in the forest. In a very encouraging note, I witnessed only one instance where the monkeys were fed by visitors (though the location of the core areas of groups B and C are suspicious). However, the monkeys are now inveterate raiders of the rubbish bins, particularly group A.

Everything considered, the situation at Bukit Timah is now very encouraging for the survival of the macaques with a reasonably intact natural diet. The attitude of the staff at the reserve is exemplary and the facilities at the Visitor's Centre make research there much easier than before.

Acknowledgements

I am very grateful to National Parks for permission to re-visit Bukit Timah. Many thanks are due to the rangers there past and present for their great friendliness - I would mention particulary Md. Noor for his prodigious knowledge and his concern about the reserve, Ismail, Ragu, Veda, Bala and Ong.

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Chapter 11

The Birds Of The Bukit Timah Nature Reserve And Central Catchment Area

KANG NEE[1] AND CHRISTOPHER J. HAILS[2]

Introduction

Tropical rainforest was one of the major habitats for the birds of Singapore. But since the establishment of a trading post here in 1819, systematic destruction of the forest to make way for settlements, farms and industrialisation has resulted in considerable changes to the local avifauna. Many species of birds, particularly forest inhabitants, became extinct, others adapted and ensconced themselves in the new habitats created while the losses were partly made up for by the establishment of some new species (see Hails and Jarvis, 1987).

Today, the hill at Bukit Timah bears the only remnants of the original forests. Although occupying a small area of only 81ha, and the low height (162.5m) of Bukit Timah precludes certain habitats such as montane forest, the Bukit Timah Nature Reserve is nevertheless important as a habitat used by a diverse number of species of birds. Together with about 1,925 ha of secondary forest located in the centre of the island (known as the Central Catchment Area; see fig. 1), this 2,000 ha of land provides refuge for many stenotopic species of birds.

The Birds

Table 1 lists 173 species of birds that have been sighted in the forest in recent years. It is compiled by R. Subharaj of the Bird Study Group (Nautre Society, Singapore), and is current up to December 1989. It is not restricted solely to birds seen in Bukit Timah but includes sightings recorded from the Central Catchment Area. The status of each species is designated according to whether it is common or rare, and whether it is a resident, migrant, visitor or accidental species. Species which have been introduced in Singapore are also listed. A resident species is one which breeds locally while a migrant species is either a winter visitor (i.e. one which stays in Singapore during the annual migration period between September to April) or a passage migrant (i.e. one that passes through Singapore during the annual migration period). Visitor species are those which occur unpredictably. Rare species are those which are recorded in small numbers.

A great diversity of plant species is characteristic of tropical rainforests: more than 200 tree species may be found in one hectare of primary forest (see Whitmore, 1986). These plants provide a large variety of infrahabitats that can be exploited by the other forest inhabitants. For instance, plant-feeding arthropods can be

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Current addresses
1 Radio Corp. Singapore, Caldecott Hill, Andrew Road, Singapore 1129.
2 WWF International, Ave Du Mont Blanc, Ch - 1196 Gland, Switzerland.

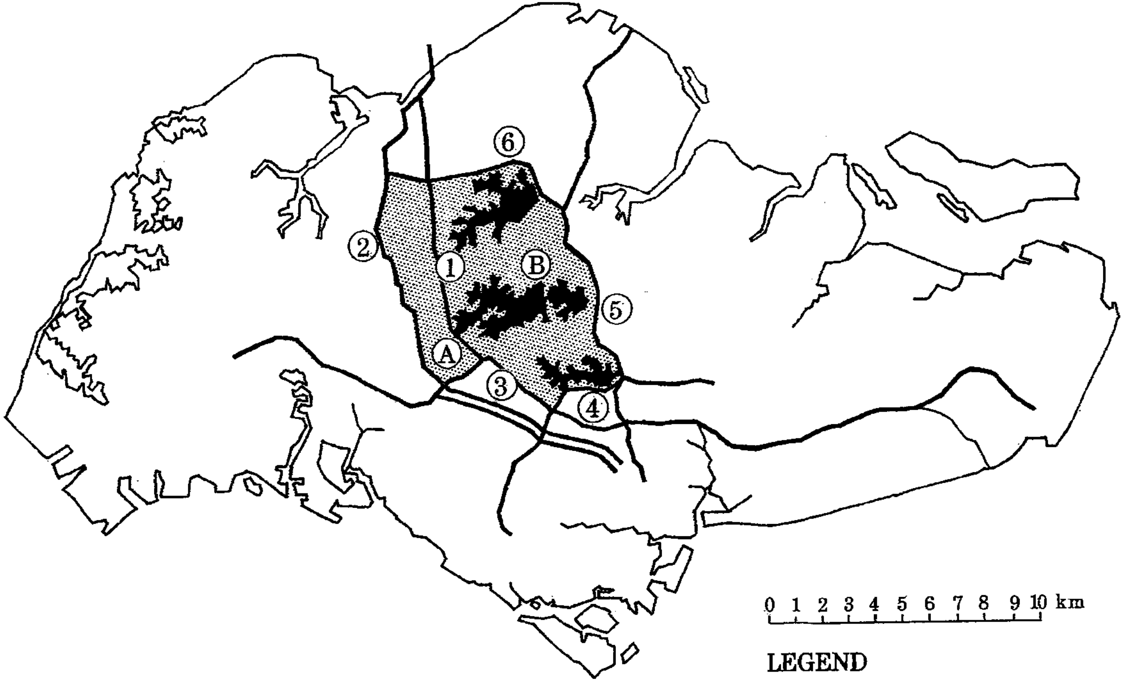

Figure 1. Map of Singapore showing the Bukit Timah Nature Reserve and the Central Catchment Area.

segregated according to the species of plant and the part of the plant they feed on: some species may feed on the leaves, others on the stem or trunk and others among the roots and ground litter. Insectivorous species of birds may also be specialised in their turn: each foraging only at certain types of sites, thereby concentrating on a particular range of the arthropod prey available. In this way, competition for identical foods may be reduced or avoided and many species can co-exist in the same habitat.

The Bukit Timah Nature Reserve, like other tropical lowland rainforests, can be grossly divided into four main zones: the canopy or upper storey, the middle storey, the lower storey and the ground storey. In addition, a fifth zone can be included, comprising vegetation bordering the edge of the forest and clearings within the forest and around the reservoirs. Following the terminology used by Medway & Wells (1976), the canopy comprises the crowns of the big trees, lianes, rattans and other palms which are exposed to full sunlight. The middle storey includes the trunks of the big trees and the smaller trees and palms below the canopy. The lower storey consists of small woody plants, stemless palms and ferns, while the ground storey includes the litter layer and fallen twigs and timber.

Table 1 also shows the feeding guild to which each species belongs and the forest zone(s) in which it forages, while fig. 2 summarises the total number of species belonging to each feeding guild in each forest zone. The data presented are collated from personal observations and the work of various people (see Glenister, 1971; King *et al.*, 1975; Forshaw, 1977; Hails, 1985a; R. Subharaj, pers. comm.). Many species are euryphagous and thus belong to more than one feeding guild. Differential use of the various forest zones as foraging sites is evident as each zone appears to be used by distinct groups of birds. Both table 1 and fig. 2 are to be referred to during the following discussion on the use of the five forest zones as foraging sites by the birds.

The Canopy

The canopy is the foraging zone of a number of species from several feeding guilds. Frugivores like the parrots, leafbirds, Red-crowned Barbet (*Megalaima rafflesii*), Asian Fairy Bluebird (*Irena puella*), Ashy Bulbul (*Hypsipetes flavala*), Hill Myna (*Gracula religiosa*) and most of the frugivorous pigeons are the common inhabitants of this zone where flowering in tall trees is mainly concentrated. Medway & Wells (1976) have suggested that a finer scale of ecological separation among frugivores operates partly through food specialisation, but is unlikely to involve concentration on specific species of trees as a single fruiting tree may attract a wide variety of frugivorous species. Instead, it is likely that factors such as variations in ripeness of the fruit, firmness of attachment and position of the fruit are important in partitioning the fruit crop among the frugivore community. For instance, Thick-billed Pigeon (*Treron curvirostra*) and Little Green Pigeon (*T. olax*) have mutually exclusive weight ranges so that *T. olax* can feed on

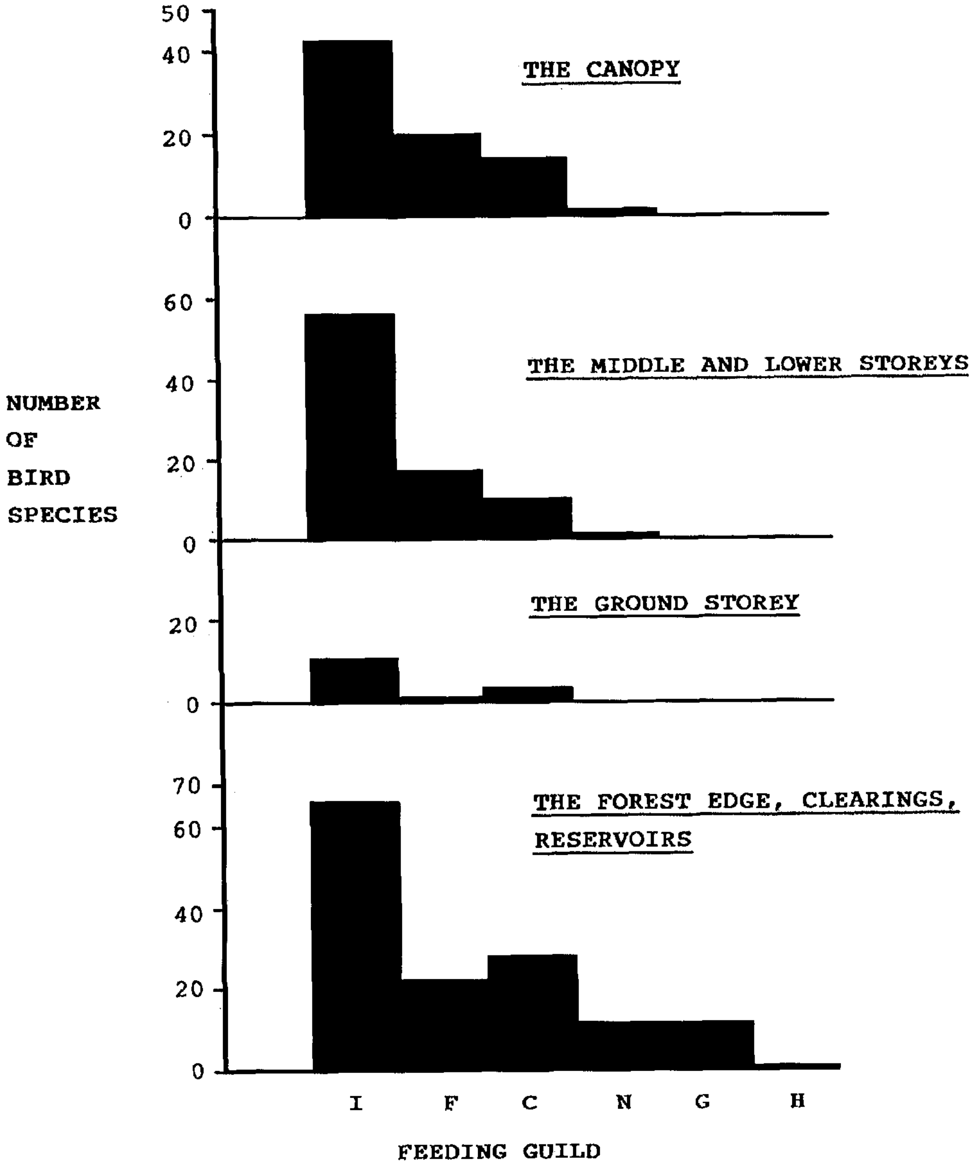

Fig. 2. The number of species of birds belonging to each feeding guild in various foraging zones.

I : insectivore	N : nectarivore
F : frugivore	G : granivore
C : carnivore	H : herbivore

thinner branches than *T. curvirostra. T. curvirostra* also has a more powerful beak which allows it to tackle larger and tougher fruit than *T. olax* (Medway and Wells, 1976). Another way of partitioning the fruit crop according to the size of the fruit and bird is suggested by Lambert (1989). In a study of fig-eating birds in Peninsular Malaysia, Lambert (1989) found that larger birds fed more commonly on larger-fruited *Ficus* and small birds tended to eat small figs.

The forest canopy also abounds with a variety of insectivorous birds which feed in and around it. Unlike frugivores which do not need to adopt any special techniques for finding fruiting trees as such trees are by themselves conspicuous, the forest insectivores have become specialised in particular techniques of catching and handling their prey. Aerial insectivores like swallows and swifts can be seen soaring above the canopy, feeding on swarms of insects. But insect density and diversity change with altitude, and aerial insectivores exploit this difference in the vertical distribution of insects by feeding at different heights (Waugh, 1978 from Waugh & Hails, 1983). Swallows often feed just above the forest canopy, at lower heights than swifts. Further partitioning of the feeding niche occurs among the swifts, with different species exploiting different feeding heights (Waugh & Hails, 1983; Tarburton, 1986).

Woodpeckers are also sometimes seen at the canopy level, searching for arthropod prey by probing and prying into the bark of rotting trees. Another insectivore, the Dollarbird (*Eurystomus orientalis*), often perches on a vantage point from which it swoops down on its prey. Leafbirds and the Campephagids are canopy-feeders which supplement their diet of fruit, berries, seeds, nectar and buds with insect prey (Olney, 1982). The Arctic Warbler (*Phylloscopus borealis*) is a small, inconspicuous insectivore which searches for its prey amongst the leaves of the canopy.

A third feeding guild frequenting the upper levels of the forest are the carnivorous birds of prey or raptors. These soar over the forest canopy, diving to grab small birds, reptiles or mammals from the tree tops. The birds of prey also use branches that protrude above the forest canopy as look-out perches for prey.

Nectarivores such as sunbirds and flowerpeckers also exploit the canopy level, particularly when the trees are in flower.

The Middle and Lower Storeys

The middle and lower storeys of the forest are inhabited mainly by insectivorous birds. The Greater Racket-tailed Drongo (*Dicrurus paradiseus*) is perhaps the most common bird of Bukit Timah. It can be found both in the canopy and middle levels of the forest. Several species of bulbuls can also be seen at the middle and lower levels of the forest, and the Striped Tit-babbler (*Macronus gularis*) is quite a common inhabitant of this area. Sunbirds, flowerpeckers and the Little Spiderhunter (*Arachnothera longirostra*) also occur here, imbibing nectar from a variety of flowering plants or catching insects. The Blue-eared Kingfisher

(*Alcedo meninting*) is sometimes seen perched on low branches along streams in the forest, waiting to seize fish or amphibians from the water. It may also feed on insects or reptiles which it grabs from the ground. Flycatchers are also middle and lower storey inhabitants of the forest. Most of the flycatchers seen locally are migrants. The feeding technique of these birds is to make short flights from their perch on the branches of trees to catch insects flying past.

At night, the middle and lower levels of the forest are taken over by the nocturnal birds of prey, the owls. These hunt for vertebrate prey like rodents and other small nocturnal mammals. The Collared Scops Owl (*Otus bakkamoena*) and the Brown Hawk Owl (*Ninox scutulata*) are common residents of Bukit Timah. Another owl which is a rare resident species in Singapore is the Spotted Wood Owl (*Strix seloputo*) which is more commonly seen or heard in secondary forest.

The Ground Storey

The ground storey of the forest is inhabited by a number of species which are specialised in searching for food amongst the leaf litter and branches of low shrubs. These include the common Dark-necked Tailorbird (*Orthotomus atrogularis*), the *Trichostoma* babblers, Chestnut-winged Babbler (*Stachyris erythroptera*) and the thrushes of the family Turdidae. The Hooded Pitta (*Pitta sordida*) was once found in the forests of Singapore but is now very rarely seen. A ground-feeding frugivore sometimes seen in the forest is the Green-winged Pigeon (*Chalcophaps indica*). The Forest Wagtail (*Dendronanthus indicus*) is an uncommon migrant to our forest; it feeds on flies, beetles, spiders, molluscs, crustaceans and seeds which it finds in the understorey layer (Olney, 1982).

The edge of the forest and clearings within the forest are areas where a myriad of birds can be seen, ranging from canopy-feeders such as the Thick-billed Pigeon (*Treron curvirostra*) to the Banded Bay Cuckoo (*Cacomantis sonnerati*), Plaintive Cuckoo (*Cacomantis merulinus*) to starlings and mynas. Particular inhabitants of this area are bee-eaters and shrikes which feed around the fringes of the forest. This forest zone is perhaps the only area where some species of granivorous birds can be found. The Peaceful Dove (*Geopelia striata*) and Spotted Dove (*Streptopelia chinensis*) and munias can be seen feeding on the seeds from grass growing around the boundaries of Bukit Timah Nature Reserve and the clearing at the top of the hill.

The birds that are currently present in the forests of the Bukit Timah Nature Reserve and the Central Catchment Area may represent those species which are ecologically more robust, that were able to adapt and survive despite extensive destruction of the forest habitat. Those which were unable to adapt to the changes in the forest ecosystem either became greatly decimated in numbers or even extinct. Hails (1985b) and Hails and Jarvis (1987) estimates that of 106 species of birds that have been lost from Singapore, 87 species are forest birds. Entire groups that have disappeared from Singapore include the hornbills (Bucerotidae), trogons (Trogonidae) and broadbills (Eurylaimidae), which are still present in the forests of Peninsular Malaysia. Many families of birds also suffered reductions in the number of species: the most drastically affected being the woodpeckers with the loss of 8 species, the bulbuls (4 species), babblers (1 species), cuckoos (2 species) and cuckoo-shrikes (3 species). The barbets have also been decimated, the only barbet which is found solely in the forest habitat to have survived is the Red-crowned Barbet (*Megalaima rafflesii*). Of four species of spiderhunters which were formerly recorded in Singapore (Medway & Wells, 1976), only the Little Spiderhunter (*Arachnothera longirostra*) remains. Many species which were noted by Medway & Wells (1976) and Johnson (1973) as being common in Singapore have now become rare or are classified as visitor or accidental species. Examples include the frugivorous pigeons: Thick-billed Pigeon (*Treron curvirostra*), Jambu Fruit Dove (*Ptilinopus jambu*) and Little Green Pigeon (*Treron olax*); Oriental Dwarf Kingfisher (*Ceyx erithacus*), and the Hooded Pitta (*Pitta sordida*).

Not all forest birds, however, have been as badly affected: several species have even extended their natural ranges to the other types of habitat in Singapore. For instance, the Collared Scops Owl (*Otus bakkamoena*) and Long-tailed Parakeet (*Psittacula longicauda*) have spread into open country (Hails and Jarvis, 1987). The converse is also true where some of the forest-edge species, like the Crimson Sunbird (*Aethopyga siparaja*), Purple-throated Sunbird (*Nectarinia sperata*) and Olive-winged Bulbul (*Pycnonotus plumosus*), have penetrated into the depths of the forest proper, probably due to the absence of competitors within.

The forests of Singapore do not have as rich an avifauna as, for instance, those in the nearby land mass of Peninsular Malaysia. While Singapore only carries about 86 resident species in 2,000 hectares of forest, 166 species are resident in about 777 hectares of forest at Pasoh in Peninsular Malaysia (2.59°N: 102.18°E) (Medway & Wells, 1976). A total of 224 species, excluding forest-edge birds, inhabit the tropical lowland rainforests of Peninsular Malaysia; when the forest-edge birds are included, the total exceeds 300 species (Medway & Wells, 1976). This figure is nearly twice the number of species listed in table 1 for Singapore.

The occurrence of fewer species of birds in the forests here is a consequence of Singapore being an island. It is an established ecological phenomenon that islands contain fewer species than land masses (MacArthur & Wilson, 1967) and thus by nature, Singapore would hold fewer species of birds than mainland Peninsular Malaysia. This situation is also true of other islands like Phangan (9.45°N: 100.02°E), Samui (9.30°N: 100.00°E), Phuket (7.56°N: 98.26°E), Tarutao (6.35°N: 99.40°E), Langkawi (6.22°N: 99.49°E), Penang (5.26°N: 100.15°E) and Tioman (2.47°N: 104.10°E), which are two to thirteen times poorer in forest birds than smaller representative areas of forest on mainland Peninsular Malaysia (Medway & Wells, 1976).

Another feature of the flora and fauna of small islands is that populations may be more unstable because of their smaller contiguous size and prone to quicker extinction than on land masses. Thus, when the forests of Singapore were destroyed, stenotopic species which were unable to adapt to changes in the ecosystem became extinct because there were few refuges for the birds to retreat to. For instance, 87 species were lost within the period from 1819 to the turn of this century (Hails and Jarvis, 1987), resulting in a decrease in the diversity of forest species. In contrast, Peninsular Malaysia has not yet lost any bird species from her lowland forests probably because populations that were affected by habitat changes could retreat to the reservoirs provided by other forested areas.

The absence of other types of forest other than lowland forest is another reason for the lower diversity of birds in Singapore. The highest point on the island is Bukit Timah hill, which is only 162.5m high and thus there are no montane forest species. In contrast, mainland Peninsular Malaysia has 73 species of montane forest birds. There are fewer species of birds in the montane forest than the lowland forests because montane forest has poorer flora which presents less varied foraging sites. However, the montane forest habitat is richer in bryophytes and epiphytes that provide unique foraging sites for probing and crevice-searching insectivores (Medway & Wells, 1976). These include nuthatches, wren babblers, laughing thrushes, shrike babblers, fulvettas and niltavas, many of which represent genera that are absent from the lowland forest communities of both Peninsular Malaysia (Medway & Wells, 1976) and Singapore.

The Future

Despite their history of disturbance, the forests of Singapore still contain a diverse avifauna: of the 173 species recorded, 48 are unique to, or largely dependent on the forest habitat. Today the government of Singapore recognises the importance of preserving the remaining forest habitat and thus there is no immediate danger of the forests being completely destroyed. But in a highly urban Singapore, where land is at a premium, there is the very real danger of 'isolation'. This occurs when pockets of forest are developed and the forest avian community becomes further divided into islands that are isolated by roads and built-up areas. This can be seen now where Bukit Timah has become isolated from the Central Catchment Area by a major road, the Bukit Timah Expressway (fig. 1). "Isolation" creates a "double island" effect where not only are the bird populations separated from those of mainland Peninsular Malaysia, but also from each other. For those species which are operating at their threshold, "isolation" may prevent them from obtaining certain essential resources because they cannot or will not cross the barriers between the islands. Consequently these species are exposed to the possibility of extinction (see Butcher *et al.*, 1981; McCoy, 1982; Terborgh, 1975). This situation is perhaps accentuated for birds inhabiting the understorey and ground levels of the forest as most of them are weak fliers and the wide Bukit

Timah Expressway is a real barrier for them. And once a species (particularly a stenotopic species) becomes extinct on an island like Singapore, it is difficult for it to recolonise naturally. Two reasons account for this: firstly, both water and land form a physical barrier between the forests in Singapore and those on mainland Peninsular Malaysia, which may deter birds from the Malaysian forests from entering Singapore. Secondly, eurytopic species may expand their range in Singapore, thus preventing stenotopic species from establishing themselves. This difficulty in recolonisation is evident from the data that are currently available. Hails and Jarvis (1987) reported that most of the 78 new species that were added to the Singapore checklist up to 1987 are migrant or accidental species, and few have established themselves in the forests.

It is important therefore, that conservation of the forest habitat in Singapore should not be directed solely at preserving clumps of forest *per se*, but allow for the maintenance of viable populations to sustain species diversity. To do this, research is needed to add to the existing knowledge of the niche requirements of the forest birds that was obtained by Hails (1985b). For instance, it is not known why the Little Spiderhunter (*Arachnothera longirostra*) is the only species of spiderhunter to have survived in our forests, when the Spectacled Spiderhunter (*Arachnothera flavigaster*) is prevalent in the forests of Peninsular Malaysia, and even in the gardens there (Hails and Jarvis, 1987). Or why is the Blue-eared Barbet (*Megalaima australis*) absent from Singapore but present in similar habitats in Peninsular Malaysia? Moreover, the status of the forest birds is still dynamic as more than 44 new species have been added to the Singapore checklist since the first compilation by Hails in 1984. Is this phenomenon linked in some way to the logging of forests in Johore in Peninsular Malaysia (R. Subharaj, pers. comm.)? Clearly then, for these examples, a detailed analysis of the specific requirements of each species is needed before the questions can be answered.

Other than conserving the avifauna currently present in our forests, species diversity may be increased by a judicious programme of reintroduction. Hails (1985b) has suggested some 44 species of birds that are extinct here, which could be reintroduced into our forests. Again, proper study of their niche requirements is essential if such a programme were to be implemented.

But for any conservation effort to succeed, it must be complemented by an effective law enforcement plan to prevent poaching. While poaching in Bukit Timah is checked by the presence of park rangers, there is little control over trapping of birds in the forests of the Central Catchment Area. And even though the Wild Birds and Animal Act may protect all bird species in Singapore (except the House Crow, *Corvus splendens,* mynas and starlings), and poachers can be fined and jailed, it is only partially effective as most poaching activities go unreported. One native forest bird that certainly became extinct due to illegal trapping is the popular cage-bird, the White-rumped Shama (*Copsychus malabaricus*). Today, it is rarely seen in the forests except for a small wild population in the Central Catchment Area, which is probably re-established from escapes from the cage-bird trade. Thus if a programme of reintroduction were to be adopted by the authorities, more effective measures must be implemented simultaneously to protect the birds from poachers.

The 2,000 hectares of forest in Singapore may seem meagre beside the vast forests of Malaysia and Indonesia, but it is nevertheless important as a site for research, educational and recreational purposes. Students of ecology, botany and zoology are often brought to Bukit Timah to study the flora and fauna of the tropical rainforest. For other members of the public, the exhilarating walk to the top of the hill brings them to a scenic and tranquil site for a picnic with friends and family. And last but certainly not the least important, with the widespread destruction of rainforests elsewhere in the world, Bukit Timah becomes even more crucial as one of the bastions of the most diverse habitats in the world.

Table 1. Checklist of birds recorded in the forests of Bukit Timah Nature Reserve and the Central Catchment Area (current up to December 1989).

The status, forest zone used, and the feeding guild to which each species belong are summarised from personal observations, the work of several authors and a checklist compiled by R. Subharaj, and are defined as follows:

Status	Forest zone	Feeding guild
R = resident	C = canopy	I = insectivore
M = migrant	M = middle storey	F = frugivore
V = visitor	L = lower storey	N = nectarivore
A = accidental	G = ground storey	C = carnivore
I = introduced	E = forest edge	G = granivore
? = uncertain	clearings	H = herbivore
C = common	reservoirs	E = euryphagous
U = uncommon		
Ra = rare		

BT = found only in Bukit Timah
CC = found only in the Central Catchment Area

Family and species	Status	Forest zone	Feeding guild
Ardeidae			
1. Grey Heron (*Ardea cinerea*)	UV (CC)	E	C
2. Purple Heron (*Ardea purpurea*)	UV (CC)	E	C
3. Little Heron (*Butorides striatus*)	CV (CC)	E	C
4. Black-crowned Night Heron (*Nycticorax nycticorax*)	CV	E	C

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
5. Malayan Night Heron (*Gorsachius melanolophus*)	UM (CC)	G	C
6. Schrenck's Bittern (*Ixobrychus eurhythmus*)	UM (CC)	G,E	C
7. Cinnamon Bittern (*Ixobrychus cinnamomeus*)	UV? (CC)	E	C
8. Black Bittern (*Ixobrychus flavicollis*)	UM (CC)	G,E	C
Anatidae			
9. Lesser Treeduck (*Dendrocyna javanica*)	RaR (CC)	E	E(G,H,C)
Pandionidae			
10. Osprey (*Pandion haliaetus*)	UM	C	C
Accipitridae			
11. White-bellied Sea Eagle (*Haliaeetus leucogaster*)	CR	C	C
12. Brahminy Kite (*Haliastur indus*)	CR	C	C
13. Black Baza (*Aviceda leuphotes*)	CM	C	C
14. Crested Honey Buzzard (*Pernis ptilorhyncus*)	CM	C	C
15. Changeable Hawk-eagle (*Spizaetus cirrhatus*)	UR	E	C
16. Crested Serpent Eagle (*Spilornis cheela*)	RaV (CC)	C	C
17. Grey-headed Fish Eagle (*Icthyophaga ichthyaetus*)	RaR (CC)	C	C
18. Eastern Marsh Harrier (*Circus aeruginosus*)	A (CC)	C	C
19. Japanese Sparrowhawk (*Accipiter gularis*)	CM	C	C
20. Crested Goshawk (*Accipiter trivirgatus*)	RaV (CC)	C	C

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
21. Chinese Goshawk (*Accipter soloensis*)	UM	C	C
Falconidae			
22. Peregrine Falcon (*Falco peregrinus*)	UM	C	C
Rallidae			
23. White-breasted Waterhen (*Amaurornis phoenicurus*)	CR	G	I
Charadriidae			
24. Pacific Golden Plover (*Pluvialis fulva*)	UM (CC)	E	E(I,C)
Scolopacidae			
25. Common Greenshank (*Tringa nebularia*)	UM (CC)	E	E(I,C)
26. Common Sandpiper (*Actitis hypoleucos*)	CM (CC)	E	E(I,C)
27. Pintail Snipe (*Gallinago stenura*)	UM (CC)	E	E(I,C)
Glareolidae			
28. Oriental Pratincole (*Glareola maldivarum*)	UM (CC)	E	I
Laridae			
29. White-winged Tern (*Chlidonias leucopterus*)	UM (CC)	E	C
30. Little Tern (*Sterna albifrons*)	A (CC)	E	C
Columbidae			
31. Pink-necked Pigeon (*Treron vernans*)	CR	C,M,E	F
32. Thick-billed Pigeon (*Treron curvirostra*)	UR,V (CC)	C,M	F
33. Little Green Pigeon (*Treron olax*)	RaR,V (CC)	C,M	F
34. Green-winged Pigeon (*Chalcophaps indica*)	UR	G	F

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
35. Jambu Fruit Dove (*Ptilinopus jambu*)	UV	C,M	F
36. Spotted Dove (*Streptopelia chinensis*)	CR	E	G
37. Peaceful Dove (*Geopelia striata*)	CR	E	G
38. Feral Pigeon (*Columba livia*)	I	E	G
Psittacidae			
39. Long-tailed Parakeet (*Psittacula longicauda*)	CR	C,M,E	F
40. Rose-ringed Parakeet (*Psittacula krameri*)	I (CC)	E	F
41. Red-breasted Parakeet (*Psittacula alexandri*)	I (CC)	E	F
42. Blue-rumped Parrot (*Psittinus cyanurus*)	RaR?	C,M	F
43. Blue-crowned Hanging Parrot (*Loriculus galgulus*)	RaV?(CC)	C,M,E	F
44. Goffin's Cockatoo (*Cacatua goffini*)	I (CC)	C,E	F
Cuculidae			
45. Banded Bay Cuckoo (*Cacomantis sonnerati*)	UR	C,M,E	I
46. Plaintive Cuckoo (*Cacomantis merulinus*)	UR	M,E	I
47. Violet Cuckoo (*Chrysococcyx xanthorhynchus*)	UR	C,E	I
48. Drongo Cuckoo (*Surniculus lugubris*)	RaR,UM	M,E	I
49. Indian Cuckoo (*Cuculus micropterus*)	CM	M,E	I
50. Hodgson's Hawk Cuckoo (*Cuculus fugax*)	UM (CC)	M,E	I
51. Indonesian Cuckoo (*Cuculus sepulcralis*)	UR	M,L	I

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
52. Chestnut-winged Cuckoo (*Clamator coromandus*)	UM	M,L,E	I
53. Chestnut-bellied Malkoha (*Phaenicophaeus sumatranus*)	UR	C,M	E(I,C)
54. Greater Coucal (*Centropus sinensis*)	UR	E	E(I,C)
55. Lesser Coucal (*Centropus bengalensis*)	UR	E	E(I,C)
Strigidae			
56. Collared Scops Owl (*Otus bakkamoena*)	CR	M,L,E	C
57. Oriental Scops Owl (*Otus sunia*)	A (CC)	M	C
58. Brown Hawk Owl (*Ninox scutulata*)	CR	M,L	C
59. Spotted Wood Owl (*Strix seloputo*)	RaR (CC)	C,M,E	C
Caprimulgidae			
60. Large-tailed Nightjar (*Caprimulgus macrurus*)	CR	E	I
61. Grey Nightjar (*Caprimulgus indicus*)	A (CC)	M,E	I
62. Malaysian Eared Nightjar (*Eurostopodus temminckii*)	UR (CC)	C,E	I
Apodidae			
63. Edible-nest Swiftlet (*Aerodramus fuciphagus*)	CR	C	I
64. Black-nest Swiftlet (*Aerodramus maximus*)	CR?	C	I
65. House Swift (*Apus affinis*)	CR	C	I
66. Fork-tailed Swift (*Apus pacificus*)	CM	C	I
67. White-vented Needletail (*Hirundapus cochinchinensis*)	UM	C	I

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
68. Brown Needletail (*Hirundapus giganteus*)	UM	C	I
69. Asian Palm Swift (*Cypsiurus balasiensis*)	UR	C	I
Hemiprocnidae			
70. Grey-rumped Treeswift (*Hemiprocne longipennis*)	UR	C	I
Alcedinidae			
71. Stork-billed Kingfisher (*Pelargopsis capensis*)	UR (CC)	E	C
72. White-breasted Kingfisher (*Halcyon smyrnensis*)	CR	E	E(C,I)
73. Collared Kingfisher (*Halcyon chloris*)	CR	E	E(C,I)
74. Black-capped Kingfisher (*Halcyon pileata*)	CM	E	E(C,I)
75. Ruddy Kingfisher (*Halcyon coromanda*)	UM	L	E(C,I)
76. Oriental Dwarf Kingfisher (*Ceyx erithacus*)	A (BT)	L	E(C,I)
77. Common Kingfisher (*Alcedo atthis*)	CM (CC)	E	C
78. Blue-eared Kingfisher (*Alcedo meninting*)	RaR (CC)	L	C
Meropidae			
79. Blue-throated Bee-eater (*Merops viridus*)	CR	C,E	I
80. Blue-tailed Bee-eater (*Merops phillippinus*)	CM	C,E	I
Coraciidae			
81. Dollarbird (*Eurystomus orientalis*)	UR,CM	C,E	I
Capitonidae			
82. Red-crowned Barbet (*Megalaima rafflesii*)	UR	C,M	F

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
83. Coppersmith Barbet (*Megalaima haemacephala*)	UR	E	F
Picidae			
84. Banded Woodpecker (*Picus miniaceus*)	CR	M,E	I
85. Rufous Woodpecker (*Micropternus brachyurus*)	UR	M,E	E(I,F)
86. White-bellied Woodpecker (*Dryocopus javensis*)	RaR	M	I
87. Common Goldenback (*Dinopium javanense*)	RaR	E	I
88. Brown-capped Woodpecker (*Picoides moluccensis*)	UR (CC)	E	I
Pittidae			
89. Hooded Pitta (*Pitta sordida*)	A (BT)	G	I
Hirudinidae			
90. Pacific Swallow (*Hirundo tahitica*)	CR	C	I
91. Barn Swallow (*Hirundo rustica*)	CM	C	I
92. Red-rumped Swallow (*Hirundo daurica*)	CM	C	I
93. Asian House Martin (*Delichon dasypus*)	UM (BT)	C	I
Campephagidae			
94. Pied Triller (*Lalage nigra*)	CR	E	I
95. Ashy Minivet (*Pericrocotus divaricatus*)	UM	C,E	I
96. Scarlet Minivet (*Pericrocotus flammeus*)	RaR?	C,M	I
97. Lesser Cuckoo-shrike (*Coracina fimbriata*)	A? (BT)	C,M	I

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
Chloropseidae			
98 Common Iora (*Aegithina tiphia*)	CR	E	I
99. Lesser Green Leafbird (*Chloropsis cyanopogon*)	RaR	C,M	E(I,F)
100. Greater Green Leafbird (*Chloropsis sonnerati*)	RaV? (CC)	C,M	E(I,F)
101. Blue-winged Leafbird (*Chloropsis cochinchinensis*)	UR	C,M	E(I,F)
Pycnonotidae			
102. Yellow-vented Bulbul (*Pycnonotus goiavier*)	CR	E	E(I,F)
103. Olive-winged Bulbul (*Pycnonotus plumosus*)	CR	E	E(I,F)
104. Cream-vented Bulbul (*Pycnonotus simplex*)	UR	C,M	E(I,F)
105. Red-eyed Bulbul (*Pycnonotus brunneus*)	UR	C,M	E(I,F)
106. Red-whiskered Bulbul (*Pycnonotus jocosus*)	I (CC)	E	E(I,F)
107. Black-headed Bulbul (*Pycnonotus atriceps*)	RaR (CC)	C,M	E(I,F)
108. Straw-headed Bulbul (*Pycnonotus zeylanicus*)	RaV? (CC)	E	E(I,F)
109. Ashy Bulbul (*Hypsipetes flavala*)	V	C	I
110. Streaked Bulbul (*Hypsipetes malaccensis*)	A? (BT)	C,M	E(I,F)
Dicruridae			
111. Greater Racket-tailed Drongo (*Dicrurus paradiseus*)	CR	C,M	I
112. Crow-billed Drongo (*Dicrurus annectans*)	UM	C,M,E	I
113. Ashy Drongo (*Dicrurus leucophaeus*)	A (CC)	C	I

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
Oriolidae			
114. Black-naped Oriole (*Oriolus chinensis*)	CR	E	E(I,F,C)
115. Asian Fairy Bluebird (*Irena puella*)	CR	C,M	E(I,F)
Corvidae			
116. House Crow (*Corvus splendens*)	A (CC)	E	E(I,F,C)
117. Large-billed Crow (*Corvus macrorhynchos*)	CR	C,E	E(I,F,C)
Timaliidae			
118. Short-tailed Babbler (*Trichastoma malaccense*)	CR	L,G	I
119. White-chested Babbler (*Trichastoma rostratum*)	RaR (CC)	L	I
120. Abbott's Babbler (*Trichastoma abbotti*)	UR (CC)	L,G,E	I
121. Striped Tit-babbler (*Macronus gularis*)	CR	M,L,E	I
122. Chestnut-winged Babbler (*Stachyris erythroptera*)	UR	L,E	I
123. Moustached Babbler (*Malacopteron magnirostre*)	RaR (CC)	M,L	I
124. Hwamei (*Garrulax canorus*)	I (CC)	E	I
Turdidae			
125. Siberian Blue Robin (*Erithacus cyane*)	UM	G	I
126. Eye-browed Thrush (*Turdus obscurus*)	UM	C,M,G	I
127. White-throated Thrush (*Monticola gularis*)	RaM (BT)	L,G	I
128. Orange-headed Thrush (*Zoothera citrina*)	RaM (BT)	L,G	I

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
129. Siberian Thrush (*Zoothera sibirica*)	A (BT)	M,L,G	I
130. White-rumped Shama (*Copsychus malabaricus*)	RaR	L	I
131. Magpie Robin (*Copsychus saularis*)	UR (CC)	E	I
Sylviidae			
132. Flyeater (*Gerygone sulphurea*)	CR	E	I
133. Yellow-bellied Prinia (*Prinia flaviventris*)	UR	E	I
134. Arctic Warbler (*Phylloscopus borealis*)	CM	C,M,E	I
135. Eastern Crowned Leaf Warbler (*Phylloscopus coronatus*)	UM	C,M	I
136. Dark-necked Tailorbird (*Orthotomus atrogularis*)	CR	M,L,E	I
137. Common Tailorbird (*Orthotomus sutorius*)	CR	E	I
138. Rufous-tailed Tailorbird (*Orthotomus sericeus*)	UR	E	I
Muscicapidae			
139. Asian Brown Flycatcher (*Muscicapa latirostris*)	CM	C,M,E	I
140. Dark-sided Flycatcher (*Muscicapa sibirica*)	UM	C,M	I
141. Ferruginous Flycatcher (*Muscicapa ferruginea*)	UM	L	I
142. Mugimaki Flycatcher (*Ficedula mugimaki*)	UM (CC)	M	I
143. Yellow-rumped Flycatcher (*Ficedula zanthopygia*)	CM	M	I
144. Brown-chested Flycatcher (*Rhinomyias brunneata*)	RaM	L	I

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
Monarchinae			
145. Japanese Paradise Flycatcher (*Tersiphone atrocauda*)	A	M	I
146. Asian Paradise Flycatcher (*Tersiphone paradisi*)	CM	M	I
Motacillidae			
147. Grey Wagtail (*Motacilla cinerea*)	UM	G,E	I
148. Yellow Wagtail (*Motacilla flava*)	UM (CC)	E	I
149. Forest Wagtail (*Dendronanthus indicus*)	UM	G	I
150. Richard's Pipit (*Anthus novaseelandiae*)	CR	E	E(I,G)
Laniidae			
151. Brown Shrike (*Lanius cristatus*)	CM (CC)	E	I
152. Tiger Shrike (*Lanius tigrinus*)	UM	L,E	I
Sturnidae			
153. Philippine Glossy Starling (*Aplonis panayensis*)	CR	E	E(I,F)
154. Purple-backed Starling (*Sturnus sturninus*)	CM (CC)	E	E(I,F)
155. Black-winged Starling (*Sturnus melanopterus*)	I	E	E(I,F)
156. Common Myna (*Acridotheres tristis*)	CR	E	E(I,F, C,N)
157. White-vented Myna (*Acridotheres javanicus*)	I	E	E(I,F, C,N)
158. Hill Myna (*Gracula religiosa*)	UR	C	E(I,F)
Nectariniidae			
159. Brown-throated Sunbird (*Anthreptes malacensis*)	CR	E	E(I,N)

Table 1 (continued).

Family and species	Status	Forest zone	Feeding guild
160. Ruby-cheeked Sunbird (*Anthreptes singalensis*)	A? (CC)	E	E(I,N)
161. Purple-throated Sunbird (*Nectarinia sperata*)	CR	C,E	E(I,N)
162. Crimson Sunbird (*Aethopyga siparaja*)	CR	E	E(I,N)
163. Olive-backed Sunbird (*Nectarinia jugularis*)	CR (CC)	E	E(I,N)4
164. Little Spiderhunter (*Arachnothera longirostra*)	CR	L,E	E(I,N)
Dicaeidae			
165. Scarlet-backed Flowerpecker (*Dicaeum cruentatum*)	CR	E	E(I,F,N)
166. Orange-bellied Flowerpecker (*Dicaeum trigonostigmum*)	CR	C,E	E(I,F,N)
167. Yellow-vented Flowerpecker (*Dicaeum chrysorrheum*)	A? (CC)	E	E(I,F,N)
Ploceidae			
168. Eurasian Tree Sparrow (*Passer montanus*)	CR (CC)	E	G
169. Baya Weaver (*Ploceus philippinus*)	UV (CC)	E	G
Estrildidae			
170. White-headed Munia (*Lonchura maja*)	UR (CC)	E	G
171. Scaly-breasted Munia (*Lonchura punctulata*)	CR	E	G
172. Chestnut Munia (*Lonchura malacca*)	UR (CC)	E	G
173. Javan Munia (*Lonchura leucogastroides*)	I (CC)	E	G

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Chapter 12

Amphibians and Reptiles

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Introduction

A comprehensive study of the reptiles and amphibians inhabiting Bukit Timah has never yet been attempted and documented records remain few and far between. However, on the basis of these records alone, a surprisingly great diversity of reptiles and amphibians are known to occur in the diminishing forest. There is every possibility that many more species, including new ones, are present but have yet to be discovered and documented.

Both groups of lower vertebrates occupy all strata of the forest, from the canopy to below the forest floor as well as a variety of habitats existing within the forest. Shy and retiring by nature, they usually remain in hiding and are at most times difficult to spot against the forest backdrop.

Amphibians

Of the amphibians, the anurans (frogs and toads) and the apodans (caecilians) are represented, the urodeles (salamanders and newts) being confined to temperate areas. The apodans are likely to be mistaken for small eels or worms which they resemble. Their bodies are elongated and eel-like without any trace of the completely reduced limbs. They inhabit the moist stream areas and the adults usually burrow into the soft mud of the stream banks. Juveniles swim about the decaying leaf litter accumulated at the bottom of the shallow streams.

Two single-specimen records of the caecilian, *Ichthyophis paucisulcus* from the forest have been made. Both were collected from the streams of the Jungle Fall Valley. The first specimen, a 12 cm long juvenile, was discovered in 1984 (Ng *et al.*, 1988), while the second, a smaller 6 cm juvenile was found in 1989 (Ng, 1989). Only two very early records of caecilians have been made in Singapore but none of these were from Bukit Timah (Cantor, 1847; Hanitsch, 1908). The recent discoveries indicate the existence of species which were never known to be present within the forest and emphasise the need for further studies.

Among the frogs and toads found within the forest, the most well-camouflaged is the nose-horned frog *Megophrys monticola nasuta.* It has flattened projections over the snout and eyes which when viewed from above, hides the familiar head outline of normal anurans. This, together with its body colouration, makes the animal blend perfectly against the background of leaf litter on the forest floor which is its usual resting place. Johnson (1964) indicated this species as a forest dweller but did not specify whether it occurred in the Bukit Timah forest. The species has been seen in the forest and its presence confirmed by Chou *et al.* (1986).

Murphy (1973) records the existence of several frogs among which *Kalophrynus pleurostigma pleurostigma* is the most frequently encountered. Berry (1975) also noted this species as a primary rain forest frog of Peninsular Malaysia. The tree frog *Polypedates leucomystax* recorded by Murphy (1973) and Chou *et al.* (1986), was observed by the former to exhibit diurnal migration in response to the movement of insect prey. The frog comes down from the foliage to the base of small trees in the evenings and goes back up in the mornings. Choo-Toh *et al.* (1985) mentions two other frog species, *Rana erythraea* and *Rana macrodon* as present in the forest, in addition to the common Asiatic toad, *Bufo melanostictus.* They also recorded the presence of the narrow-mouthed toad *Kaloula pulchra,* commonly known as the Malayan bullfrog because of its loud resounding mating calls at night after rain. Both *Bufo melanostictus* and *Kaloula pulchra* are well known inhabitants of urban areas and are not true forest dwellers. Berry (1975) noted that these two species are not known to occur in the rain forests of Peninsular Malaysia. It is possible that these species moved into the outer fringes of the forest as a result of developments encircling the reserve.

The presence of *Rana macrodon* has also been confirmed by sightings as recorded in The Pangolin, a quarterly bulletin on the vertebrate fauna of Singapore published by the Singapore Branch of the Malayan Nature Society. This bulletin, which began publication in 1988, has two other amphibian species sighted in the forest. They are *Rana chalconota,* said to be common, and *Rana plicatella.*

Reptiles

The reptilian fauna of the reserve is represented by chelonians, lizards, skinks and snakes. Only one chelonian species appears in the records as an inhabitant of the forest and that is the spiny hill tortoise, *Heosemys spinosa*, a herbivorous ground dweller (Murphy 1973). This species is reportedly common in jungles (Tweedie & Harrison, 1954) and is easily recognised by the serrations of the shell margin which is more prominent in the young stages. A brown Burmese tortoise, *Geochelone (Testudo) emys*, was sighted in the forest in early 1989, but is believed to have been imported and released there in accordance with customary Buddhist rites.

Gekkonid lizards like *Gehyra mutilata* and *Cosymbotus platyurus*, which also frequent homes, are present in the reserve, the former recorded by Murphy (1973) and the latter by Boulenger (1912). *Gekko stentor*, one of the largest geckos known, has also been sighted. Very common in Malaysian jungle (Boulenger, 1912), it has previously not been recorded from Singapore (Sworder, 1925). The sighting therefore holds exciting prospects for future investigation. Another species recorded is *Gekko monarchus* (Chou et al., 1986). These geckos move about the tree trunks and hide beneath loose bark. Early records indicate the presence of the gecko, *Gonatodes kendalli,* which hides under large rocks during the day (Boulenger, 1912), and possibly the agamid *Gonyocephalus borneensis,* of which juvenile specimens present in the Raffles Museum collection (now Zoological Reference Collection of the National University of Singapore) were the only known record of the genus from Singapore then (Sworder 1925). Murphy (1973) has since mentioned the presence of unidentified species of this genus in the forest.

Another agamid lizard present in the forest (Choo-Toh *et al.*,1985) is the shy, retiring green-crested lizard, *Bronchocela cristatellus,* noted for its abilty to change colour rapidly, and commonly but mistakenly referred to as a chameleon. Two other well-known agamid lizards are the flying lizards, *Draco volans* and *Draco melanopogon,* whose elongated free-ending ribs can be extended to stretch out skin folds along the sides of the body to enable them to glide with a high degree of maneuverability. The presence of *Draco volans* in the reserve has been mentioned by Choo-Toh *et al.* (1985) and Chou *et al.* (1986), although Sworder (1925) had described this species as the commonest in settled districts with coconut and rubber plantations. *Draco melanopogon* with longer hind limbs is more a jungle species whose presence in the forest was recorded by Murphy (1973).

Skinks known to be present are *Mabuya multifasciata* of which sightings have been made in addition to the record of Choo-Toh et al. (1985), and *Mabuya rugifera,* which is uncommon, with the only specimen from Singapore collected by Flower in the Bukit Timah forest (Sworder, 1925). A more recent sighting of the latter was made by Subharaj (1990).

From existing records, snakes are clearly the most diverse among the reptiles, with 15 species reportedly present in the forest reserve. Among these, the family Colubridae dominates with 10 species. The families Typhlopidae and Boidae are represented by one species each. The remaining three venomous species belong to the families Viperidae (1 species) and Elapidae (2 species). It is most likely that more species than those presently on record inhabit the reserve.

The tiny common blind snake, *Ramphotyphlops braminus,* a member of the family Typhlopidae, is a burrower and the smaller ones appear like earthworms. Tweedie (1983) notes the possibility of this species reproducing by parthenogenesis, as all specimens which have been examined have turned out to be females. In contrast, the reticulated python, *Python reticulatus* (family Boidae) can attain lengths of under six metres. Pythons are primitive snakes and retain vestiges of the pelvic girdle and hind-limbs which appear as claws on either side of the cloacal opening. This species is seldom found far away from a water source. Both species have been recorded from the forest by Choo-Toh *et al.* (1985).

The three venomous snakes present are Wagler's pit viper (*Trimeresurus wagleri*) of the family Viperidae, the black spitting cobra (*Naja sumatrana*) and the blue Malayan coral snake (*Maticora bivirgata*), both of the family of front-fanged snakes known as Elapidae. The first two have been recorded by Choo-Toh (1985) while the last by Murphy (1973) and sightings recorded in The Pangolin. Wagler's pit viper has a distinct reddish tail and prefers low bushes. The black spitting cobra warns intruders by rearing the front part of its body upright with hood fully spread out and hissing. They will attack if the intruder does not retreat. The blue Malayan coral snake is known to feed on other snakes (Lim, 1956).

Back-fanged snakes of the family Colubridae occupy a variety of niches within the forest ecosystem. Recent sightings have been recorded in The Pangolin of the keeled rat snake, *Zoacys carinatus,* (Lim, 1989a) and the spotted keelback, *Macropophis maculatus* (Lim, 1989b), formerly known as *Natrix maculata*, which are new additions to known records.

A male specimen of an obscure colubrid, *Liopeltis baliodeira,* was collected from Bukit Timah by Sworder (1923). This species had not previously been recorded in Singapore and since then, there have been no further known records of the species from the forest.

The barred kukri snake, *Oligodon signatus,* recorded by Murphy (1973) is a known ground dweller. The blue-necked keelback, *Macrophisthodon rhodomelas,* recorded by Choo-Toh *et al.* (1985), feeds mainly on frogs and toads and has been described by Batchelor (1958) to rear up and flattened its neck like a cobra when alarmed.

The remaining five colubrid species are tree snakes and occupy different levels of the canopy. The painted bronze-back, *Dendrelaphis pictus* (previously known as *Ahaetulla ahaetulla*), and the elegant bronze-back, *Dendrelaphis formosus* (previously known as *Ahaetulla formosa*), are slender but active snakes confined most of the time to trees and bushes, where they prey on lizards, tree frogs and bird nestlings. Both species have been recorded by Choo-Toh *et al.* (1985), and the genus by Murphy (1973).

The paradise tree snake, *Chrysopelea paradisi,* is perhaps the most agile and fastest moving tree snake, and has the ability to go into a controlled glide through the air by flattening its body so that the ventral surface becomes concave and serves to trap air like a parachute. The presence of this species in the forest has been mentioned by Choo-Toh *et al.* (1985) and Chou *et el.* (1986).

Another elegant tree snake is the oriental whip-snake *Ahaetulla prasina* (known formerly as *Dryophis prasinus*). This green snake is long and slender and is generally docile when handled. Sworder (1923) confirmed its presence in the forest. The white-spotted cat snake, *Boiga drapiezii,* on the other hand is a fairly large tree snake and Sworder (1923) drew attention to a specimen obtained from the forest by Flower in 1896.

Conclusion

Bukit Timah does indeed contain a good dversity of amphibians and reptiles and it will not be surprising if new records continue to emerge. A full listing of the amphibian and reptilian fauna can only be made through future concerted efforts aimed at these two groups.

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Chapter 13

Freshwater Decapod Crustaceans

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Introduction

In sharp contrast to what many naturalists believe, there is a great diversity of freshwater crabs and prawns (Crustacea, Decapoda) in Southeast Asia. In Peninsular Malaysia and Singapore, about 50 species of true freshwater crabs are known at present. Singapore alone boasts of six freshwater crab species in three families. Of these, three species, *Johora singaporensis, Irmengardia johnsoni* and *Parathelphusa reticulata* are endemic to Singapore (Ng, 1989b, 1990a, 1990c). Johnson (1961), Ng (1990c) and Choy & Ng (1991) record 11 species of palaemonid prawns (*Macrobrachium*) and atyid prawns (*Caridina*).

At Bukit Timah, there are several small streams on the hill, but the richest area for freshwater life is without doubt Jungle Fall Valley (fig. 2, chap. 1). (Chou *et al.*, 1986). The freshwater decapod fauna is represented by four species of crabs (*Johora singaporensis, Irmengardia johnsoni, Geosesarma nemesis* and *Geosesarma peraccae*) and one of prawn (*Macrobrachium malayanum*). Of these, both endemic species of crabs have their "strongholds" in Bukit Timah.

Family Potamidae

This very large family of freshwater crabs is found throughout north Africa, southern Europe, tropical and temperate Asia (excluding most of India). The family is absent from Sulawesi, Moluccas, New Guinea and Australia, and is replaced by the related Potamonautidae in most of Africa. In Peninsular Malaysia and Singapore, the family is represented by only two wholly Malayan genera, *Johora* and *Stoliczia* (Ng, 1988). The genus *Johora* contains about 15 species of which only one is found in and is endemic to Singapore. All members of this family have large eggs which hatch out directly into miniature versions of the adult. Females brood the eggs and young for some time.

Johora singaporensis Ng, 1986

Roux (1936) described the freshwater crab *Potamon johorensis* from specimens sent to him by the Raffles Museum collected from Gunong Pulai (Johore) and Bukit Timah. Ng (1986, 1987) reassessed the taxonomy of the Singapore specimens, concluded that the Singapore specimens were a distinct species and named them *Johora singaporensis.* The closest relative of this species seems to be *J. johorensis* and *J. murphyi* from Gunung Pulai and Gunung Panti in southern Johor, Malaysia, respectively. Although the three species are superficially similar in appearance, they have very different reproductive structures.

Johora singaporensis is a brightly coloured species with patches of orange and white. The carapace measures about 1 – 1.5 cm in width. The legs often appear banded. the carapace and legs are covered with numerous short hairs (Ng & Maitland, 1986; Ng, 1988), characters which easily separate it from the sympatric parathelphusid *Irmengardia johnsoni* which is a duller and more uniformly coloured species with smooth and hairless legs and carapace. The frontal margin of *Irmengardia johnsoni* is usually straight, in contrast to the sinuous one of *Johora singaporensis.*

Johora singaporensis is omnivorous, and very aggressive towards all smaller crabs. Cannibalism is frequent under crowded conditions. They do not dig burrows but hide under leaf litter or rocks. Some specimens have been seen on rocks several metres away from the water, so it appears they have at least partial amphibious tendencies. Ovigerous (egg-bearing) and brooding (bearing young crabs) females are usually not submerged but prefer to be out of water. The young crabs stay with the female crab for several days, and gradually wander off into the leaf litter to lead an independent life. Adult crabs are occasionally parasitised by a small black unidentified species of leech which attaches itself to the joints of the legs and sides of the body.

Johora singaporensis is a highly endangered species and other than Bukit Timah, the only other population is near Bukit Batok Hill. This second population however, is very small and vulnerable, and with the area already disturbed and scheduled for development, it seems inevitable that Bukit Timah will eventually be the only habitat for this species. Even in Bukit Timah, the species appears to be less common in recent years. The loss of optimum habitat areas near the quarry (lost due to a landslide) and extensive treefalls around the streams appears to have affected the species. A study of the population status of this species is urgently needed.

Family Parathelphusidae

The definition of this family follows that adopted by Ng (1988). Ong (1965) reported *Parathelphusa maculata* from Bukit Timah, but I have never been able to find it there (Ng & Yang, 1985), although this species is common elsewhere in Singapore. It is, however, found in the streams and drains at the foothill of the reserve and is hence treated here. At present, only one parathelphusid is present in the reserve proper, the endemic *Irmengardia johnsoni.* Parathelphusids reproduce the same way as the Potamidae.

Irmengardia johnsoni Ng & Yang, 1985

The discovery of this very common species in Bukit Timah (Ng & Yang, 1985) was a surprise, considering the fauna there had been so well studied. Prior to its discovery, the genus was unknown to Singapore. The external morphology of *I. johnsoni* resembles *Johora* (= *Potamon* of older workers), and there is a very strong likelihood that the records of *Potamon johorense* by Ong (1965) and Johnson (1965; 1973) are in fact heterogeneous and based on both *Johora singaporensis* and *Irmengardia johnsoni.* I have seen specimens in the older collections which had been misidentified as such.

Irmengardia johnsoni is a uniform brown to grey colour, with the chelipeds brighter coloured. Specimens from acid waters in other parts of Singapore are a richer reddish-brown. The legs are occasionally bright yellow. It is a relatively small species, with carapace measuring about 1 – 1.5 cm in width. This species is easily recognised by having one of their claws (chelae) greatly enlarged, bright orange, and the fingers appearing blade-like. This appears to be a character associated with dominance. Smaller males and females lack these enlarged claws. Compared to *Johora singaporensis, I. johnsoni* is a generally more docile and less aggressive species.

They have been reported to feed on vegetable as well as animal matter (eg. worms). They usually hide under leaves and debris in the water, their generally dull colouration affording excellent camouflage. Some specimens have been observed foraging several metres from the water, and even under tree bark but this is rare. *Irmengardia johnsoni* is also occasionally attacked by small leeches.

In Singapore, *Irmengardia johnsoni* is relatively common in many small shaded forest streams in the Central Catchment Area, and is especially common in the Nee Soon Swamp Forest. The population in Jungle Fall Valley at Bukit Timah, appears to be doing well despite the landslides and treefalls, and is frequently encountered in the leaf litter.

Parathelphusa maculata De Man, 1879

This is a very common and wide-ranging lowland species, ranging throughout most of Peninsular Malaysia to Singapore and Sumatra. The taxonomy of this species has been resolved by Ng (1988; 1990b).

Species of *Parathelphusa* are easily separated from *Irmengardia* by the presence of three lateral teeth on each side of the carapace. Large males often have one of the pincers greatly enlarged, the fingers being long and gaping. It has been observed to use this pincer to crack small shellfish. Colouration is usually a uniform brown. *Parathelphusa maculata* is one of the largest freshwater crabs locally, with a carapace which may reach 5 cm in width.

The species digs relatively deep burrows by river banks, the opening always above the water margin but the base is always well below. They can also be found under leaves, wood and rocks in slow-flowing water. Smaller specimens do not dig burrows but hide among vegetation and mud. They are predominantly herbivores, feeding on dead leaves, roots, seed, fruits etc., but will also attack shells, worms and small animals when given the opportunity. *Parathelphusa maculata* is a very adaptable species, and is one of the first freshwater crabs to return to a heavily disturbed area, as long as there are places to burrow, some shade and the water is clean and unpolluted.

Family Grapsidae

Most members of the subfamily Sesarminae are estuarine, but some have adapted so well to living in freshwater that they have developed large eggs and a larval development independent of the sea, like the Potamidae and Parathelphusidae. All belong to the genus *Geosesarma*. Two species are known, *G. peraccae* and *G. nemesis,* both from the reserve and they are not easy to separate in the field. Both species make burrows by the banks of small streams and are generally nocturnal. They shun the water proper, preferring to scavenge in the wet leaf-strewn areas near the stream instead. For this reason, some authors classify them as land crabs (Johnson, 1965). Adults are usually difficult to collect.

Only the development of *G. peraccae* is known (Soh, 1969). This species has larvae which hatch at the bottom of their burrows. They are omnivores, but like other sesarmines, appear to eat more vegetable matter. Their mandibles and gastric teeth are ideally suited to deal with the tough plant materials.

To separate the two species, the most reliable characters are in the mouthparts and male reproductive organs. The general carapace shape of *G. peraccae* appears more trapezoidal than that of *G. nemesis,* its lateral margins being more divergent. The lateral margins of *G. nemesis* are more parallel and the carapace more squarish. The exopod of the third maxilliped is a useful character. In *G. peraccae*, the exopod has a long flagellum, which is completely absent in *G. nemesis*. This character can be used for both sexes and all sizes. The first pleopods (gonopods) of the male are very different. They are slender, the distal part rather spade-like in *G. peraccae,* but stout and the distal part pincer-like in *G. nemesis.*

Geosesarma peraccae Nobili, 1903

This species was first described from Singapore (Nobili, 1903b) and is a common but rarely seen species in Johore and other parts of Peninsular Malaysia. They generally prefer lower areas (especially in Seletar, Mandai and Nee Soon) where the habitat is swampier, but there is a small population in the reserve. This species is a rich to dull brown in colour, and reaches carapace widths of about one cm.

Geosesarma nemesis Ng, 1986

This species has long being confused with *G. ocypoda* from Sumatra. However, Ng (1986) showed that the Singapore specimens had different gonopods from those of Sumatra, and applied a new name for the Singapore species.

Geosesarma nemesis has also been found in southern Johor. This is the main *Geosesarma* in the reserve and adults possess maroon-coloured carapaces and brightly coloured red claws (Ng & Maitland, 1986; Ng, 1988). They have very large eggs but their larval development has not been documented. Although usually found near streams, adults will wander considerable distances, especially at night. Specimens have been collected many metres from the nearest water and even under bark of fallen trees. In Johor, one was even observed climbing a tree at night.

The species is also known from a small hill near the Hillview area along Bukit Timah Road, but Bukit Timah Hill is clearly its main stronghold. Although there is a good population of this species in Bukit Timah, the survival of this species is closely associated with the health of Jungle Fall Valley and associated areas.

Family Palaemonidae

There is only one freshwater prawn known from the reserve and it belongs to the genus *Macrobrachium*, a clawed prawn of the family Palaemonidae. The small filter-feeding prawns of the family Atyidae are absent.

Macrobrachium malayanum Roux, 1934

This clawed prawn was previously known as *Macrobrachium geron* but recent studies have shown this name to the same as *M. malayanum,* a species first described from Malaya (Roux, 1934) (see Chong & Khoo, 1987a).

Adult males are easily separated from all other *Macrobrachium* by their stout and pubescent chelae (claws) which are velvet-like. Colouration varies to some degree, from brown to almost transparent. Large males can reach 6 cm in total length (including the claws). Females are generally smaller and adults can easily be separated by their broad and expanded abdominal pleura (side plates). These are for holding the large oval eggs. Unlike many prawns, *M. malayanum* has few but large eggs which hatch out directly into very advanced, almost benthic larvae (Chong & Khoo, 1987b). These larvae can complete their development in freshwater. This abbreviated development characterises the most highly developed freshwater prawns. Other species of *Macrobrachium,* including the more famous *M. rosenbergii* of *udang galah* fame, have small eggs which hatch out into small, free-swimming larvae which have to complete their development in the sea. Young animals will then have to make the long journey upstream.

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Chapter 14

Fishes

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Introduction

Very little has been published on the freshwater fish fauna of the Bukit Timah Nature Reserve. Ahl (1929), Duncker (1904) and Tweedie (1950) together reported three species: *Puntius dunckeri, Betta pugnax* and *Channa gachua* from Bukit Timah. Whether their locality includes the present reserve area *per se* or the entire district in the broad sense is uncertain. Johnson (1973) stated that the common fish fauna '... in the small torrent streams especially on Bukit Timah ...' consists of *Rasbora elegans, Betta pugnax* and *Channa gachua.* However, as there is no direct reference to the nature reserve itself, it is uncertain whether these records can be credited to the Reserve. Ong (1965) in his survey of the fauna of the Jungle Fall drainage (fig. 2, chap. 1) within the present Bukit Timah Nature Reserve found only *Betta pugnax* present. Recent observations have shown that the feral Guppy, *Poecilia reticulata* also occurs within the reserve boundaries.

There is a large pond along the eastern boundary of the reserve, which was probably formed as the result of the blockage of drainages feeding one of the western arms of the Upper Peirce Reservoir during the construction of the Bukit Timah Expressway. This highway currently severs the only link between the Bukit Timah forest from the Central Catchment. Several fish species have been recorded from the Reserve proper and the area immediately around it (see table 1). A more thorough search is expected to produce more species, especially those which can now be found in the Central Catchment area.

Family Cyprinidae

Rasbora elegans Volz., 1903

The Two-spot Rasbora can easily be recognised by its overall grey colouration. There is a dark blotch at the middle of its body under the dorsal fin, another on the caudal peduncle, and an elongated one above the anal fin. The fins are hyaline with a tinge of silver on the rays. The distal edges of the tail fin are often dark brown or black. It is an active pelagic fish which travels in small schools, and feeds largely on insects and other small, aquatic organisms.

Table 1. List of fishes recorded from the Bukit Timah Nature Reserve and its immediate surroundings.

Species *Habitat:	A	B	C
Aplocheilus panchax	-	-	+
Betta pugnax	+	-	+
Channa gachua	-	-	**+
Channa lucius	-	-	+
Poecilia reticulata	-	+	-
Puntius binotatus	-	-	+
Puntius dunckeri	?	?	?
Puntius partipentazona	-	-	+
Rasbora einthovenii	-	-	+
Rasbora elegans	-	-	+
Trichogaster trichopterus	-	-	+
Trichopsis vittata	-	-	+

* A = streams on the hill; B = streams along the periphery, near settlements; C = pond along the eastern boundary, including associated streams.

** Has not been seen recently. It is likely that Johnson's (1973) record could have been from this type of a habitat.

? This species is believed to be now extinct. The exact location where it was found is not known.

Rasbora einthovenii Bleeker, 1851

The Einthoven's Rasbora is similar in shape to *Rasbora elegans*, but is smaller in size, this species is characterised by a bold black lateral bar on the sides. It tends to frequent dark and quiet, acidic waters.

Puntius binotatus Valenciennes, 1842

The Common Barb is often associated with *Rasbora elegans*, the two being similarly coloured. It has a dark saddle-like blotch on the back at the base of its dorsal fin. The fish is more rhomboidally shaped and has two pairs of barbels at the mouth. This omnivore swims near the substrates in small schools to browse on small benthic organisms. The juvenile fish undergo several changes in their body colour pattern before they reach adulthood (Lim & Ng, 1990).

Puntius dunckeri Ahl, 1929

Originally described from Singapore, Alfred (1966) regards the Malayan Clown Barb as extinct in Singapore. This is supported by recent observations. It is orange with reddish fins, and has at least five greenish blotches on the sides. Like the Common Barb, it is also a near-bottom dwelling omnivore. It makes an attractive aquarium pet.

Puntius partipentazona Fowler, 1934

The Tiger Barb is a distinctively marked fish which can be found along the grassy edges of the pond at the eastern boundary of the reserve. Alfred (1966) did not find it in Singapore during his extensive ichthyological survey, leading to the postulation that it may have been introduced sometime after 1966. At present it is fairly well-established in all the reservoirs of the Central Catchment and has even penetrated a few forest streams. The Tiger Barb is pale orange with four dark vertical bars. A fifth bar runs along the base of the dorsal fin and extends a little onto the back. The distal edge of the dorsal fin and the pelvic fins are red.

Family Aplocheilidae

Aplocheilus panchax Hamilton, 1822

The Whitespot is an elongated grey fish with a distinct white spot on the top of its head. It is a surface dweller and tends to frequent more open, grassy areas. Sexual dimorphism is evident in this species, the males being more slender and more colourful. It appears to be a very adaptable and hardy fish, being able to survive under conditions of high temperature, as shown by a small population living around a hot spring on Pulau Tekong.

Family Poeciliidae

Poecilia reticulata Peters, 1859

The extremely versatile Guppy was first brought to Singapore in the early part of this century apparently for mosquito control. It does this job well as it is tolerant of polluted as well as high salinity waters, and is highly prolific. It can be found in small streams at the edge of the Reserve, near rural settlements.

Family Belontiidae

This family comprises of fishes which possess an accessory respiratory organ in an extension of the gill chamber to enable utilisation of atmospheric air. This is useful as many species live in oxygen-poor waters.

Betta pugnax Cantor, 1849

The Forest Betta is a relative of the domestic Fighting Fish (*Betta splendens*) but it has a more peaceful disposition and a more robust build. It is usually olive-brown or grey with a green or blue spot on each scale. The fins are also marked with green or blue streaks and spots. Sometimes, depending on its mood, the fish may assume two broad lateral bands on the sides. The Forest Betta seems to be the only species of fish which lives in the small streams in Bukit Timah. It is perfectly adapted for this by being able to breathe atmospheric air (in case the streams dry up during dry spells leaving only small puddles) and by being a mouth-brooder (fast-flowing streams tend to destroy bubble-nests rapidly). The Forest Betta appears to eat mainly insects. It is rather shy and seeks refuge in accumulations of submerged leaf-litter when it feels threatened.

Trichopsis vittata Cuvier, 1831

Although similar to the above-mentioned in appearance, the Croaking Gouramy has a laterally flattened body, more elongated fins and a more tapering snout. There is a distinct green ring in the eye. It builds a bubblenest, and does not live in small or fast-flowing water bodies, prefering densely vegetated areas. In certain streams in the Central Catchment (eg. Sime Road forest), it occurs sympatrically with *Betta pugnax*. The Croaking Gouramy derives its name from its ability to emit a soft purring-croaking sound apparently during courtship activities.

Trichogaster trichopterus Pallas, 1770

Many varieties of this popular aquarium fish have been bred by aquarists, but the wild version of this Two-spot Gouramy can still be commonly found in streams and ponds in rural Singapore. It is usually bluish-grey with two black spots (one on the middle of the body, the other on the caudal peduncle), and numerous orange spots on the dorsal, anal and caudal fins. The pelvic fins are modified into elongate thread-like processes which function apparently as sensory organs. This omnivore spawns in a bubble-nest.

Family Channidae

Fishes in this family possess large scale-plated heads, and also an accessory respiratory organ for utilisation of atmospheric air. They are mainly predatory and nocturnal in habit. Brooding pairs are usually protective of their young.

Channa lucius Cuvier, 1831

The Forest Snakehead is brown above, marked by a series of black blotches across the sides, and a dark stripe which runs from the eye to the lower edge of the operculum. There is also a dark blotch on the upper edge of the operculum. Juveniles are cream with two (not three as in Lim & Ng, 1990) bold black or dark brown stripes running laterally across the head and body. It usually occurs in pairs in shady areas.

Channa gachua Hamilton, 1822

The Dwarf Snakehead was recently rediscovered in the Nee Soon swampforest (Ng & Lim, 1989), but is not currently known from Bukit Timah. However, as the streams in the area, especially at the base of the hill has not been properly surveyed, its existence there may be possible. This is a beautiful and commercially valuable fish. It is brown above, whitish below with dark fins. The dorsal and caudal fins have bright red edges while the anal fin is edged in cream. It is a mouthbrooder with the male carrying out egg incubation.

Discussion

The diversity of freshwater fish species in Bukit Timah Nature Reserve is poor compared to the Central Catchment area. This is almost certainly due to the topography of the area and the scarcity of larger and low-lying streams. The streams draining the Reserve, classified under 'torrent streams' by Johnson (1973) are very narrow and shallow, and flow over steep slopes. Such habitats appear to be unsuitable for many fishes with the exception of *Betta pugnax.* Although a major, if not the only conservation site for primary rainforest organisms in Singapore, this area is not an important site for freshwater fish. The fish species listed here are those that have been recorded in the literature as well as by the author and his colleagues. The low-lying drainage systems at the edge of the Reserve have not been studied in detail, and a complete picture has yet to be presented. It is expected that several more species may have to be added to the list in the years to come.

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Chapter 15

The Future of Bukit Timah Nature Reserve

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Can Bukit Timah survive? There is no longer a risk that Bukit Timah Nature Reserve will be cleared and developed, like most of the forest reserves which existed in the first decades of this century, or suffer the incremental encroachment which was the fate of the post-war mangrove reserves (Corlett, 1992a). The threats to the integrity of the Reserve today are different but they are no less real. However, lowland tropical rain forest is the most complex system on Earth and to predict accurately the effects of the multiple impacts to which Bukit Timah has been and continues to be subjected is an impossible task. Rather than attempt this, I will give two extreme, but not unrealistic, scenarios, between which I believe the future probably lies.

First, the pessimistic view. Bukit Timah Nature Reserve would suffer from the problems of small size, high edge-to-area ratio, and isolation from other forest areas even if it consisted of a solid, circular block of undisturbed primary forest. Most species in a small and extremely species-rich reserve must, by definition, have small populations. Such small populations are prone to extinction because of random fluctuations in births and deaths, fluctuations in the physical environment and, in the longer term, the effects of inbreeding. Near the margins of the reserve, the higher light intensity, larger temperature range, lower relative humidity and greater air movement make the enviroment unsuitable for forest specialists, further reducing the area available to them and increasing the extinction risk. Conversely, this "edge effect" favours non-forest species which compete with the forest specialists. When a species becomes extinct from the reserve, the isolation makes re-invasion impossible. Each extinction may lead to secondary extinctions as a herbivore loses its only host plant, an orchid its only pollinator, or a tree its major seed dispersal agent.

This is for an "ideal" 81 hectare reserve: the situation at Bukit Timah is much worse. Not all the Reserve is forested and much of the forest is secondary, with perhaps 50 hectares under primary forest. Secondary forest may be as valuable as primary forest for some vertebrates but it supports a much poorer flora (Corlett, 1991) and, probably, fewer invertebrates. Moreover, the Reserve has an irregular shape, greatly increasing the length of the forest margin, while a tarmac road, numerous walking trails and cleared areas of various sizes bring the external environment into the centre. Even ignoring the smaller paths, nowhere in the reserve is more than 200 metres from an edge (as opposed to a radius of 500 metres in an "ideal" 81 hectare reserve). Although no precise measurements have been made (they need to be!), this probably means that all the Reserve is influenced by the relatively "drying" environment outside the forest. This problem is undoubtedly worsened by the exposed position of the Reserve on the slopes and summit of Singapore's highest hill. Long-term observers of Bukit Timah believe that the upper storey of the forest is thinning out as emergent trees are blown down and not replaced.

Another problem is the adverse impact of the tens of thousands of people who visit the Reserve every year. Even the most well-behaved visitor contributes to the compaction of unsurfaced paths and a minority cause additional damage by leaving the marked trails, picking flowers or digging up seedlings. The noise and movements of visitors have an unquantified but significant effect on sensitive birds and mammals, again reducing the effective area of the Reserve for these species. Although the recreational value of the Reserve has undoubtedly been a major factor in its preservation, greater mobility, increased leisure time, and, ironically, the growth in environmental awareness, have all contributed to visitor numbers exceeding the carrying capacity.

This pessimistic scenario extrapolates present trends and fills gaps in our knowledge with largely-untested predictions from the theoretical conservation literature. It assumes that management of the reserve is limited to the minimal enforcement of the law which has occurred in the past. Some of the theoretical predictions may be too pessimistic but one conclusion is certain: without informed and active management the Reserve can only deteriorate. What is debatable is the rate of deterioration.

The optimistic scenario, in contrast, assumes that active management can slow or reverse the decline in Reserve health. The first necessity is a reduction in the edge-to-area ratio. The total length of the "internal edges" can be reduced by reforestation of all open areas, except the viewpoint at the summit, and the closure (and, if necessary, planting) of some paths. The margins of the Reserve need protection appropriate to their position. The boundaries should be fenced wherever necessary to prevent unregulated human access: there should be only one entrance to the Reserve. All open land within the Reserve boundaries should be planted and, where possible, this planting should extend outside the boundaries to act as a buffer zone.

As discussed above, however, even if Bukit Timah Nature Reserve can be brought nearer the ideal of one, solid block of forest, continued extinctions of both plants and animals are inevitable in the long term without intervention. Effective management at the species level requires more information than we currently have in most cases but some simple measures can be suggested for plants and vertebrates. The removal of both exotic plant species, such as *Clidemia hirta*, and weedy native species may be worthwhile, althought the presence of these non-forest species is probably more a symptom than a cause of degradation. Seed collections could be made from rare tree species and grown to sapling size in a nursery before planting into suitable sites in the forest. Alternatively, or in addition, planting could be biased towards species which provide food for birds and mammals. The giant strangling figs (*Ficus* spp.) are particularly valuable in this regard (Lambert, 1991; chap. 3) and research into methods of increasing their numbers would be worthwhile.

The reintroduction of locally extinct mammalian species was suggested in chapter 9 and the same arguements apply to birds (Hails, 1992). Reintroduction is expensive and the success rate is likely to be low but the risks are worthwhile. Many birds and mammals are keystone species, playing essential roles in the ecology of the forest, as grazers, predators and seed dispersal agents (chap. 3). The consequences of the partial "defaunation" of Bukit Timah are not very obvious yet but are likely to be drastic in the long term (Dirzo and Miranda, 1990, 1991; Leigh et al. 1993). A well-publicised reintroduction campaign would also have great educational benefit and would highlight the conservation significance of the Reserve.

Contrary to popular opinion, Bukit Timah is not the only area of primary forest in Singapore. There are other substantial and valuable areas around MacRitchie Reservoir and at Nee Soon, and scattered fragments elsewhere in the Central Catchment Nature Reserve (Corlett, 1992a, 1992b; Ng, 1992). The floras and faunas of these areas are, to some extent, complementary, so one cannot substitute for the others. The more extensive secondary forests of the Central Catchment also have an important conservation role, especially as a habitat for forest-dependent vertebrates (Lim, 1992). Conservation at Bukit Timah cannot be considered in isolation but as part of an overall plan for the conservation of Singapore's threatened forest biota.

Although the future of Bukit Timah Nature Reserve is in the balance, the future for nature in Singapore seems secure. The Singapore Green Plan, published in 1992, proposes that 5% of Singapore's total land area be set aside for nature conservation (Ministry of Environment, 1992). The Action Programmes, published a year later, identify 19 sites for protection, totalling 3,130 hectares (Ministry of Environment, 1993). The "Bukit Timah and Central Catchment Nature Reserve" is the largest of these sites. The Green Plan and Action Programmes recognize many of the problems discussed above, including the necessity of active management of the Reserves and the need to raise the level of conservation awareness in Singapore. The possibility of linking Bukit Timah with the Central Catchment Nature Reserve by a corridor across the Bukit Timah Expressway is mentioned and the dangers of increasing visitor numbers by the indiscriminate promotion of "ecotourism" is highlighted. After a long period in which the protection of nature was the concern of a small minority, biological conservation is finally taking centre stage in Singapore. Bukit Timah Nature Reserve has long been the best advertisement for nature conservation in Singapore: we must hope that it will also be a major beneficiary of the changed attitudes it has helped to bring about.

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