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Bukit Timah Forest Dynamics Plot, Singapore

Shawn K. Y. Lum, Sing Kong Lee, and James V. LaFrankie

Site Location, Administration, and Scientific Infrastructure

The 2-ha Bukit Timah Forest Dynamics Plot, established in 1993, lies within the Bukit Timah Nature Reserve, located in the center of the small island state of Singapore (Lum and Sharp 1996; fig. 25.1). The reserve encompasses approximately 125 ha of forest on the slopes of Bukit Timah hill, rising to 163 m above sea level. The reserve, two thirds of which is primary forest, lies within the center of the island, only 8 km from the city center and immediately adjacent to a highly developed urban area. Heavy construction of new residential complexes continues around the base of the hill. Since 1985, a six-lane expressway has separated the nature reserve from a 2600-ha parcel of 50-year old secondary forest of the Central Water Catchment.

Bukit Timah received protection since the mid-1800s and was gazetted a nature reserve by 1939 (Corlett 1992). It is now a totally protected area governed by the Singapore National Parks Board. The nature reserve includes an extensive network of trails and a visitor center at the entrance. Two quarries on the edge of the reserve have only recently been closed.

The 2-ha plot is located in primary forest, just off of one of the reserve's major hiking trails. A second 2-ha Forest Dynamics Plot is currently being established nearby in secondary forest.

The Bukit Timah Forest Dynamics Plot is a collaboration between the National Institute of Education of Nanyang Technological University and the Center for Tropical Forest Science.

Climate

The climate in Singapore is equatorial. The mean monthly temperature ranges from 23.1 to 30.7 °C. The mean annual rainfall of Singapore is 2473 mm (97-year record, central and southern stations combined, Watts 1955; see also Dale 1963 and table 25.1). During the last century, the year-to-year variation was significant: a low of 1605 mm in the year 1889 to a high of 3451 mm in 1914. In approximately half of the years, total rainfall differed from the mean value by more than 10%. Patterns of wind, rain, and temperature follow two monsoonal wind systems:

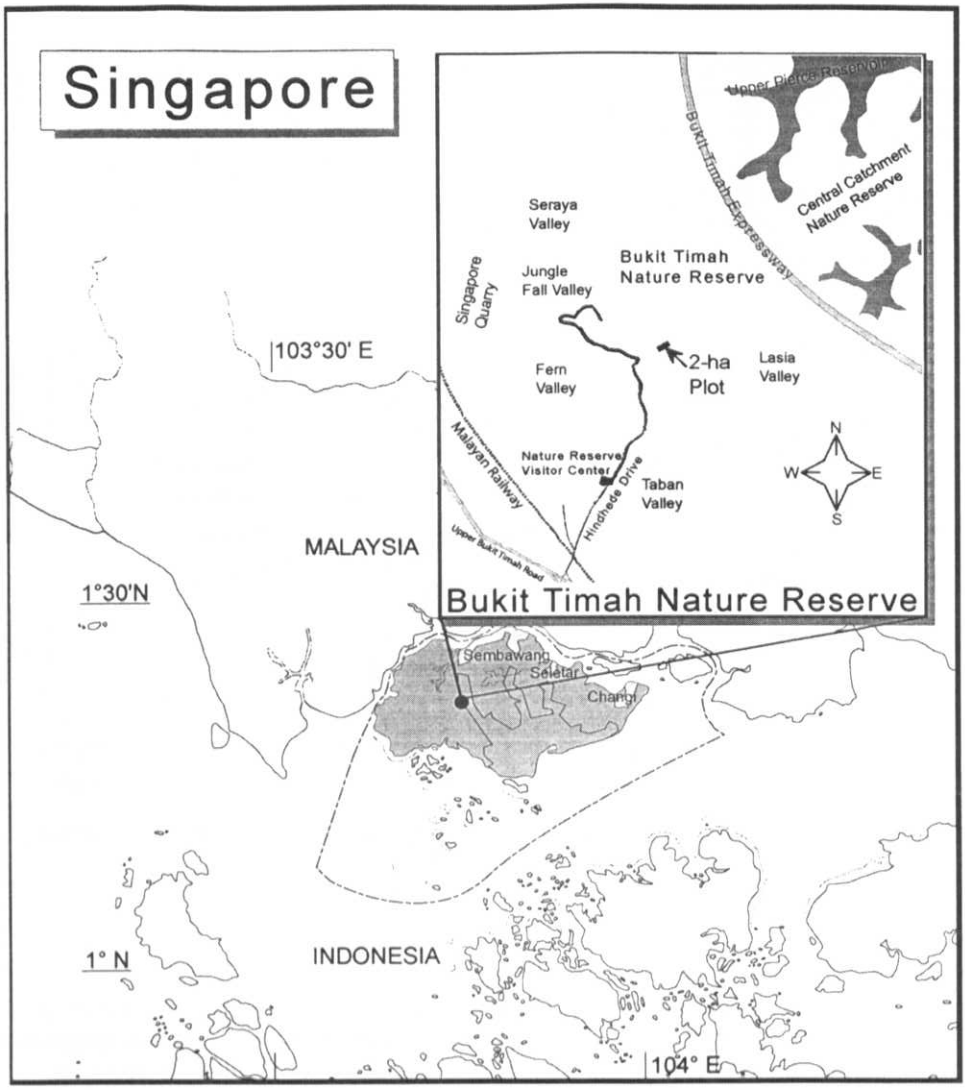

Fig. 25.1. Location of the 2-ha Bukit Timah Forest Dynamics Plot.

December to March weather is dominated by northeasterly monsoonal winds, and June to September weather is dominated by southwesterly monsoonal winds. Despite the relatively everwet, aseasonal conditions, evapotranspiration commonly exceeds rainfall for a 1–3 month period around February (Nieuwolt 1965).

Table 25.1. Bukit Timah Climate Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total/ Averages
Rain (mm)	256	184	212	200	200	171	158	179	177	216	249	271	2473
ADTMx (°C)	30.7	30.7	30.8	31.1	31.2	30.8	30.5	30.5	30.5	30.5	30.3	30.3	30.7
ADTMn (°C)	22.7	22.7	23.0	23.0	23.1	23.3	23.3	23.3	23.1	23.3	23.1	23.1	23.1

Note: Average daily maximum and minimum (ADTMx, ATDTMn) temperature, data are based on Singapore meteorological records from 1930–1941 and 1947–1960 using the mean of five stations (Dale 1963).

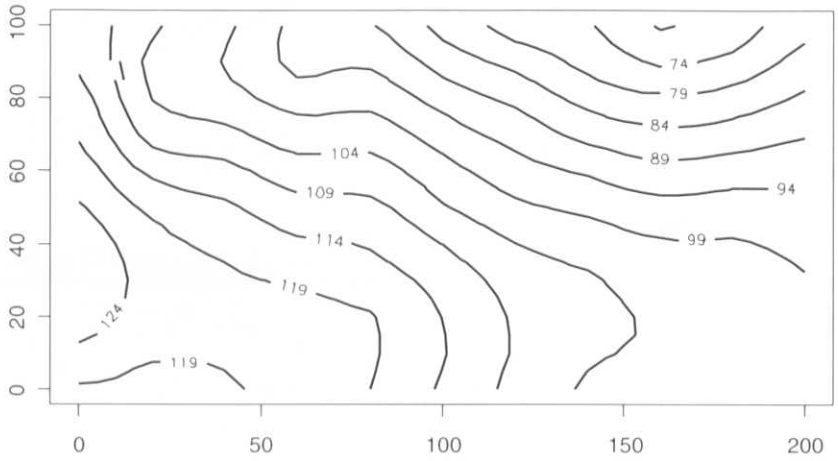

Fig. 25.2. Topographic map of the 2-ha Bukit Timah Forest Dynamics Plot with 5-m contour intervals.

Topography and Soil

At 163 m above sea level, the summit of the Bukit Timah Nature Reserve is the highest point in Singapore. The reserve is underlain by mid-Triassic granite (termed Bukit Timah Granite) which forms old, wet, and highly weathered (paleudult) soils of the rengam series in the Ultisols order (Ives 1977). Humults, highly weathered Ultisols with a shallow A^{0} organic horizon, dominate convex surfaces on ridges. The soils on the slopes are well-drained sandy loams or sandy-clay loams, which are acidic (pH 3.5–3.8 near the surface, increasing to 4.0–4.2 at 30 cm), relatively nutrient poor, and phosphorus limited (Grubb et al. 1994). See figures 25.2 and 25.3.

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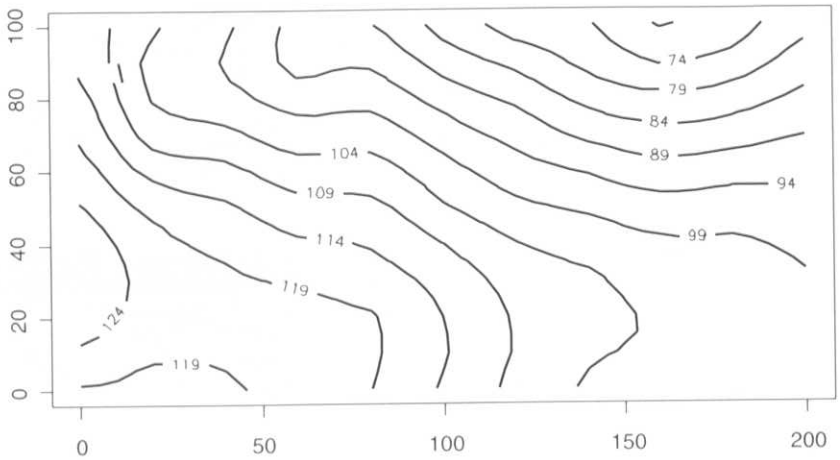

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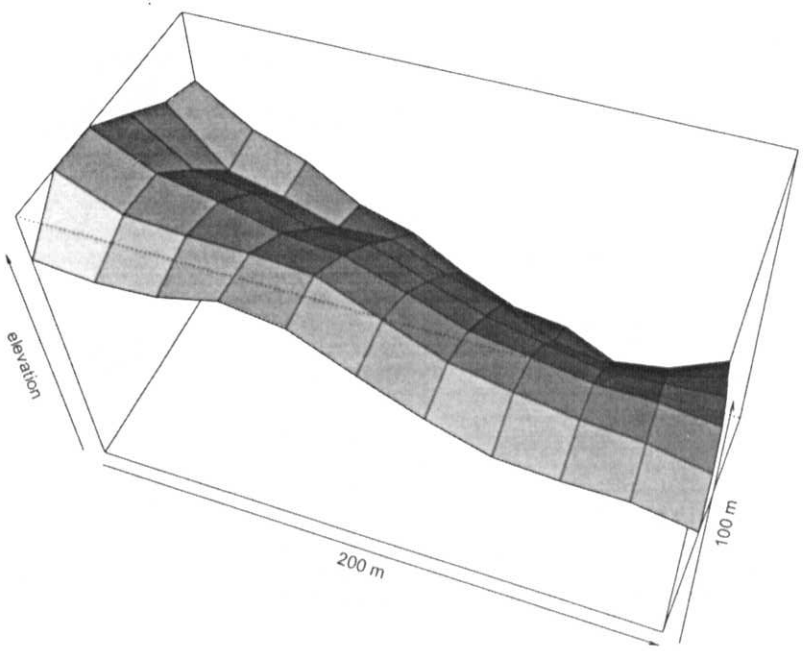

Fig. 25.3. Perspective map of the 2-ha Bukit Timah Forest Dynamics Plot.

Forest Type and Characteristics

The forest of Bukit Timah represents the typical coastal hill forest of the southern Malay Peninsula (Wyatt-Smith 1963), characterized by an upper canopy of mixed species, especially species of the family Dipterocarpaceae, mainly *Shorea curtisii* and *Dipterocarpus caudatus*. Patches of *S. curtisii* are restricted to the steep ridges. Other dominant emergent species include *Ixonanthes reticulata* and *I. icosandra* (Ixonanthaceae), *Artocarpus* spp. (Moraceae), and *Gluta wallichii* (Anacardiaceae). Although today most of the forest in the Bukit Timah Nature Reserve is of broken and irregular stature, the 2-ha Forest Dynamics Plot is comprised of many large-diameter timber trees with a basal area of more than 30 m^2/ha. The overall species diversity in the Forest Dynamics Plot is high with 321 species distributed among 60 families. Epiphytes are poorly represented but lianas are numerous, especially thorny climbing palms known as rattans. Thirty species of palms are documented by Corlett (1995), the sixth largest family of plants in the nature reserve. Nineteen of the 30 palm species are rattans. Examples of rattans

Table 25.2. Bukit Timah Plot Census History

Census	Dates	Number of Trees (≥1 cm dbh)	Number of Species (≥1 cm dbh)	Number of Trees (≥10 cm dbh)	Number of Species (≥10 cm dbh)
First	May 1993–June 1993	12,668	321	813	165
Second	November 1995–April 1996	12,892	335	843	170
Third	March 1997–September 1997	11,571	322	761	163
Fourth	March 2003–July 2003	11,918	329	843	160

Note: Four censuses have been completed of the Bukit Timah Forest Dynamics Plot. The next census is expected in 2005.

Table 25.3. Bukit Timah Summary Tally

Size Class (cm dbh)	Average per Hectare							2-ha Plot				
	BA	*N*	*S*	*G*	*F*	*H′*	α	*S*	*G*	*F*	*H′*	α
≥1	34.6	5959	276	152	58	1.90	60.0	329	170	62	1.94	62.6
≥10	30.3	422	113	78	37	1.77	51.2	160	103	46	1.86	58.5
≥30	22.8	102	41	36	21	1.36	25.1	63	51	29	1.46	31.2
≥60	11.5	20	10	8	6	0.85	8.4	15	11	8	0.96	8.9

Notes: *BA* represents basal area in m^2, *N* is the number of individual trees, *S* is number of species, *G* is number of genera, *F* is number of families, *H′* is Shannon–Wiener diversity index using $\log_{10}$, and α is Fisher's α. Basal area was calculated using only the largest stem of multiple-stemmed individuals. 252 individuals were not identified to species or morphospecies. Data are from the fourth census.

Table 25.4. Bukit Timah Rankings by Family

Rank	Family	Basal Area (m^2)	% BA	% Trees	Family	Trees	% Trees	Family	Species
1	Dipterocarpaceae	26.0	38.4	6.0	Burseraceae	1667	14.5	Euphorbiaceae	35
2	Moraceae	6.4	9.5	8.9	Euphorbiaceae	1243	10.8	Annonaceae	24
3	Euphorbiaceae	4.1	6.0	10.8	Moraceae	1027	8.9	Myrtaceae	22
4	Ixonanthaceae	3.1	4.6	0.5	Ebenaceae	803	7.0	Rubiaceae	18
5	Lauraceae	2.8	4.2	2.7	Guttiferae	771	6.7	Guttiferae	15
6	Burseraceae	2.7	4.0	14.5	Dipterocarpaceae	691	6.0	Lauraceae	13
7	Anacardiaceae	2.6	3.8	4.1	Anacardiaceae	471	4.1	Myristicaceae	13
8	Leguminosae	2.4	3.5	0.9	Myrtaceae	435	3.8	Sapotaceae	13
9	Rhizophoraceae	2.3	3.4	2.4	Annonaceae	419	3.6	Burseraceae	11
10	Rubiaceae	1.7	2.6	2.8	Sapotaceae	399	3.5	Leguminosae	11
					Ulmaceae	399	3.5		

Notes: The top 10 families for trees ≥1 cm dbh are ranked in terms of basal area, number of individual trees, and number of species. Data are from the fourth census.

found in Bukit Timah include *Plectocomia elongata*, *Daemonorops* spp., and *Calamus* spp. Other palms include *Oncosperma horridum*, which reaches canopy height, *Licuala* spp., and one that is not found anywhere else in Singapore, the delicate *Rhopaloblaste singaporensis*. For census data and rankings, see tables 25.2–25.7.

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Table 25.5. Bukit Timah Rankings by Genus

Rank	Genus	Basal Area (m^2)	% BA	% Trees	Genus	Trees	% Trees	Genus	Species
1	*Shorea* (Dipterocarpaceae)	20.2	29.9	4.7	*Santiria* (Burseraceae)	1057	9.2	*Syzygium* (Myrtaceae)	21
2	*Dipterocarpus* (Dipterocarpaceae)	4.1	6.1	0.9	*Streblus* (Moraceae)	824	7.1	*Diospyros* (Ebenaceae)	9
3	*Streblus* (Moraceae)	3.8	5.7	7.1	*Diospyros* (Ebenaceae)	803	7.0	*Aporusa* (Euphorbiaceae)	8
4	*Ixonanthes* (Ixonanthaceae)	3.1	4.6	0.5	*Calophyllum* (Guttiferae)	589	5.1	*Garcinia* (Guttiferae)	8
5	*Artocarpus* (Moraceae)	2.6	3.9	1.7	*Shorea* (Dipterocarpaceae)	537	4.7	*Polyalthia* (Annonaceae)	8
6	*Koompassia* (Leguminosae)	1.9	2.8	0.2	*Dacryodes* (Burseraceae)	480	4.2	*Artocarpus* (Moraceae)	7
7	*Santiria* (Burseraceae)	1.8	2.7	9.2	*Syzygium* (Myrtaceae)	430	3.7	*Memecylon* (Melastomataceae)	7
8	*Syzygium* (Myrtaceae)	1.5	2.3	3.7	*Gironniera* (Ulmaceae)	399	3.5	*Calophyllum* (Guttiferae)	6
9	*Litsea* (Lauraceae)	1.5	2.3	1.3	*Pimelodendron* (Euphorbiaceae)	361	3.1	*Elaeocarpus* (Elaeocarpaceae)	6
10	*Hopea* (Dipterocarpaceae)	1.4	2.1	0.3	*Gluta* (Anacardiaceae)	342	3.0	*Litsea* (Lauraceae)	6
								Xanthophyllum (Xanthophyllaceae)	6

Notes: The top 10 tree genera for trees ≥1 cm dbh are ranked by basal area, number of individual trees, and number of species. Data are from the fourth census.

Table 25.6. Bukit Timah Ranking by Species

Rank	Species	Number Trees	% Trees	Species	Basal Area (m^2)	% BA	% Stems
1	*Streblus elongatus* (Moraceae)	824	7.1	*Shorea curtisii* (Dipterocarpaceae)	17.1	25.3	4.3
2	*Santiria apiculata* (Burseraceae)	756	6.6	*Dipterocarpus caudatus* (Dipterocarpaceae)	4.1	6.1	0.9
3	*Diospyros lanceifolia* (Ebenaceae)	628	5.4	*Streblus elongatus* (Moraceae)	3.8	5.7	7.1
4	Shorea curtisii (Dipterocarpaceae)	495	4.3	*Ixonanthes reticulata* (Ixonanthaceae)	3.1	4.6	0.4
5	*Dacryodes rostrata* (Burseraceae)	470	4.1	*Shorea ochrophloia* (Dipterocarpaceae)	2.1	3.2	0.3
6	*Gironniera parvifolia* (Ulmaceae)	381	3.3	*Koompassia malaccensis* (Leguminosae)	1.9	2.8	0.2
7	*Pimelodendron griffithianum* (Euphorbiaceae)	361	3.1	*Hopea mengarawan* (Dipterocarpaceae)	1.4	2.1	0.3
8	*Gluta wallichii* (Anacardiaceae)	342	3.0	*Campnosperma auriculata* (Anacardiaceae)	1.4	2.1	0.1
9	*Gynotroches axillaris* (Rhizophoraceae)	232	2.0	*Gynotroches axillaris* (Rhizophoraceae)	1.3	1.9	2.0
10	*Calophyllum ferrugineum* (Guttiferae)	228	2.0	*Pellacalyx saccardianus* (Rhizophoraceae)	1.1	1.6	0.4

Notes: The top 10 tree species for trees ≥1 cm dbh are ranked by number of trees and basal area. Data are from the fourth census.

Table 25.7. Bukit Timah Tree Demographic Dynamics

Size Class (cm dbh)	Growth Rate (mm/yr)		Mortality Rate (%/yr)		Recruitment Rate (%/yr)		BA Losses (m^2/ha/yr)		BA Gains (m^2/ha/yr)	
	93–95	95–03	93–95	95–03	93–95	95–03	93–95	95–03	93–95	95–03
1–9.9	0.94	0.50	1.44	0.78	0.03	2.21	0.06	0.04	0.26	0.18
10–29.9	2.86	2.35	1.30	1.42	3.27	3.16	0.09	0.10	0.33	0.29
≥30	4.19	3.79	1.59	1.81	3.49	2.34	0.37	0.43	0.60	0.46

Note: Because information on the census date for individual trees was not available for the third census, the same date (June 15, 1997) was used for all records from that census.

Fauna

The annual census of Singapore's native birds conducted by the Singapore Bird Group (Nature Society) found 207 species, of which 127 are resident (unpublished data). Over 300 species of butterflies (excluding skippers) are found on the island of Singapore (Fleming 1975). Until recently, the mammals of Singapore were poorly surveyed. In the late 1990s, a survey by the Nature Society (Singapore) Vertebrate Study Group documented 44 species of mammals, including 17 bats, in Singapore (unpublished data).

Natural Disturbance

A forest fragment is more exposed to winds once it has lost the intervening protection of surrounding vegetation (Saunders et al. 1991). This can result in greater mortality of trees due to windthrows, decreased air moisture and increased temperature, and disturbed soil. The problem is exacerbated at Bukit Timah because it is a hill, with parts of the forest exposed at the edge of quarry cuts. While lightning strikes and local wind storms are infrequent, according to local naturalists, they are increasing in frequency in likely response to the fragmentation and isolation of the nature reserve. Emergent trees are blown down at a high rate and are not being replaced (Corlett 1995). Two large trees in the plot have been hit by lightning since 1993. As more big trees are felled, the survivors become increasingly conspicuous, potentially increasing their risk of becoming future lightning conductors (Lum and Sharp 1996).

Human Disturbance

Local extirpations have been relatively widespread (Corrlett 1992; Turner et al. 1996; Brook et al. 2003). Of the 44 mammal species, 60% are threatened with local extirpation. The number of extirpated mammal species is not known with certainty, but estimates suggest approximately 20 species, including all of the larger

animals—elephant (*Elephas maximus*), tiger (*Panthera tigris*), tapir (*Tapirus indicus*), and most primates—have been lost. Of the primates, the banded leaf monkey (*Presbytis femoralis*), which was extirpated from Bukit Timah in 1987, is represented by perhaps only one troop in the adjacent Central Water Catchment. Also in the Central Water Catchment, the long-tailed macaque (*Macaca fascicularis*) is represented by an overabundant population that varies between 500 and 1000 individuals among 30 troops. Lim (1992, 1997) records 70 native forest bird species that have been extirpated since the arrival of Sir Stamford Raffles in 1817, including the large seed dispersers such as hornbills, trogons, broadbills, and large pigeons. Besides species extirpations, significant shifts in composition are hinted at by recent surveys (Brook et al. 2003, Nature Society [Singapore] Vertebrate Study Group, unpublished data). An example of this is that the most abundant species of forest rats in Bukit Timah are not the spiny rats (*Maxomys* spp.) of primary forests, but rather *Rattus annandalei bullatus*, a species found in secondary forest and forest margins.

Direct human disturbance has been varied. Until recently, the hunting of tiger (*Panthera tigris*), deer (*Cervus* spp.), pigs (*Sus* spp.), flying foxes (*Pteropus* spp.), and wild birds was common. Specialized timber extraction was widespread by the mid-19th century and led to the enactment of the first tropical forestry regulations in southeast Asia. A paved road, passable for automobiles, was built to the summit of Bukit Timah in 1924. Near the summit, large granite quarries were built during the early 20th century and the open pits still remain. The Battle of Bukit Timah, at the commencement of the Japanese Occupation (1942–45), was accompanied by extensive short-term encampments near the base and scattered damage within the forest. The reserve is crisscrossed with paths and an asphalt road, affecting the internal environment by changing drainage routes, opening up the canopy, and allowing human disturbance. Various researchers fear a drying out of Bukit Timah (e.g., Corlett 1995). Wee (1995), for example, in his studies on the ferns of Bukit Timah, expressed fear that many moisture-sensitive shade ferns will disappear over time.

The nature reserve has more than a quarter million visitors a year. The increasing number of casual weekend visitors poses a threat to the delicate nature reserve. An announcement in 1995 that there would be 4000 new low-rise housing units by the year 2015 at the foot of Bukit Timah as part of the development plans for Bukit Panjang suggested that human intrusions into the nature reserve could only multiply further (Lum and Sharp 1996). Also of note is the risk from introduced alien plants, such the aggressive weed*Clidemia hirta* (Melastomataceae), which are increasingly common in the nature reserve, though not yet in the 2-ha plot. Exotic bird species such as white-throated laughing thrush (*Garrulax leucolophus*) and lineated barbet (*Megalaima lineata*) are also starting to multiply at the edge of the reserve. These birds, which prey on eggs and nestlings, are a big

threat to the dwindling population of native forest birds (L. K. Wang, personal communication.).

Plot Size and Location

The 2-ha Forest Dynamics Plot, 200 × 100 m, its long axis along a ridge in the southeast-northwest direction, is located at approximately 1°15′N, 103°45′E.

Funding Sources

The Bukit Timah Dynamics Plot has been funded chiefly by National Institute of Education of Nanyang Technological University and the Smithsonian Tropical Research Institute.

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