STAND STRUCTURE OF PASOH FOREST RESERVE, A LOWLAND RAIN FOREST IN PENINSULAR MALAYSIA

N. Manokaran

Forest Research Institute Malaysia, Kepong, 52109 Kuala Lumpur, Malaysia

&

J.V. LaFrankie, Jr.

Smithsonian Tropical Research Institute, P. O. Box 2072, Balboa, Panama

Received February 1990

MANOKARAN, N. & LaFRANKIE, J.V. 1990. Stand structure of Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. We tabulate and analyse the stand structure of Pasoh Forest Reserve, Malaysia, based on an enumeration of all trees ≥ 1 *cm* dbh in a 50-*ha* plot. Mean densities were 6769 trees ha^{-1}, ≥ 1 *cm* dbh, 530 trees ha^{-1}, ≥ 10 *cm* dbh, 3.0 trees ha^{-1}, ≥ 90 *cm* dbh. Mean basal area was 30.5 m^2 ha^{-1} for all trees, and 25.2 m^2 ha^{-1} for trees ≥ 10 *cm* dbh. Ground slope had a very weak negative correlation with density of small trees (<10 *cm* dbh) and a very weak positive correlation with density of large trees (>30 *cm* dbh). Compared with other primary forests in Malaysia, Pasoh was relatively dense in smaller trees and relatively sparse in very large trees. The forest within the 50-*ha* plot was generally homogeneous, with no evidence of major disturbance, and it is likely representative of mean conditions of lowland forest in south-central Malay Peninsula.

Key words: Ecology - stand structure - Malaysia - permanent plot

Introduction

Between 1985 and 1988, the Forest Research Institute Malaysia (FRIM) established a large scale forest plot at Pasoh Forest Reserve, Negeri Sembilan, to monitor long term changes in a primary forest. In this paper we summarise the stand structure of the trees and shrubs in the plot to answer two questions: Can the chosen forest site be generally regarded as representative of Malayan lowland type? Is there evidence that the plot has seen significant past disturbance? In the course of answering these questions we also provide a description of the plot that serves as a general reference for more specialized long-term studies that will follow. A companion paper considers these same questions from the point of view of floristics (Kochummen *et al.* 1990).

Site description and methods

Pasoh Forest Reserve is located at 2° 55' N latitude and 102° 18' W longitude, or about 140 *km* southeast of Kuala Lumpur, in the interior portion of Negeri Sembilan amidst a broad expanse of flat lands and gently rolling ridges that abut the westward side of the Main Range. The vegetation is primary rain forest and falls within the south-central subtype of the red meranti-keruing forest type of Wyatt-Smith (1987). The upper canopy is dominated by red meranti, *Shorea* section Muticae, especially *S. leprosula* Miq., *S. acuminata* Dyer, and *S. macroptera* Dyer. Other important canopy emergents are keruing, *Dipterocarpus cornutus* Dyer, balau, *Shorea maxwelliana* King, and chengal, *Neobalanocarpus heimii* (King) Ashton.

Mean annual rainfall at Pasoh is about 2000 *mm*, which is among the driest stations in Peninsular Malaysia. Further details of the ecology and vegetation of Pasoh Forest Reserve are provided in Kochummen *et al.* (1990) and Soepadmo and Kira (1977).

The plot is a 50-*ha* rectangle 1 *km* long by 0.5 *km* wide. The enumeration included all free standing trees and shrubs ≥ 1 *cm* dbh. Climbers were excluded. The details by which the plot was surveyed, the trees measured and species identified are recounted in Manokaran *et al.* (1990).

Results

Distribution among diameter classes

The forest bounded by the 50-*ha* plot was relatively dense in trees of 1 to 20 *cm* diameters and rather sparse in trees over 1 *m* diameter (Table 1).

Table 1. Comparison of tree densities above different diameters, for primary forest according to: (1) Wyatt-Smith 1949; (2) Wan Razali & Roslan Ismail 1983; (3) Wyatt-Smith 1954; (4) Anonymous 1985; (5) Riswan 1987; (6) Ashton 1964; (7) Kartawinata *et al.* 1981; (8) Miller 1981; (9) Lieberman *et al.* 1985; (10) Hubbell & Foster personal communication; (11) Richards 1952

		dbh (*cm*)									
Site	Type	>1	>2	>10	>15	>20	>30	>40	>60	>90	>100
Malaya:											
Pasoh	lowland	6769	3908	530	280	169	75	40	14	3.0	1.6
Sungai Menyala (1)	lowland	.	.	530	.	-	103	61	.	3.5	1.5
Bukit Lagong (1)	hill	.	.	559	.	.	143	83	.	9.9	7.4
Sungai Tekam (2)	hill	.	.	514	.	.	98	.	19	.	.
Rengam (3)	lowland	.	.	548	.	222	.	54	.	.	.
Pulau Jerak (3)	coastal	.	.	647	.	237	.	69	.	.	.
Gunung Raya (3)	hill	.	.	577	.	212	.	88	.	.	.
Kemahang (3)	storm	.	.	533	.	202	.	108	.	.	.
Negri Sembilan (4)	combined	.	.	.	291	.	98	.	19	6.6	.
Johore (4)	combined	.	.	.	257	.	91	.	23	4.4	.
Pahang (4)	combined	.	.	.	239	.	78	.	17	5.2	.
Kelantan (4)	combined	.	.	.	180	.	65	.	12	1.4	.
Borneo:											
Lempake (5)	lowland	.	2050	445	.	185	108	.	26	6.2	5.0
Andulau (6)	lowland	.	.	.	.	.	.	69	.	.	.
Waniriset (7)	lowland	.	.	541	.	.	.	.	.	.	.
East Kalimantan (8)	lowland	.	.	.	314	.	.	.	26	9	6
Central America:											
La Selva (9)	lowland	.	2427	434	.	.	.	.	.	.	2.7
Barro Colorado Island (10)	lowland	4844	2725	414	229	154	83	47	16	4.6	3.4
Africa:											
Messa (11)	lowland	.	.	530	214	.	38	.	.	.	.
Okomu (11)	lowland	.	.	390	223	.	47	.	.	.	.

The mean density for trees between 1 and 2 *cm* dbh was 2861 ha^{-1}. Between 1 and 10 *cm* dbh the mean density was 6239 ha^{-1}. Mean density decreased through 1 *cm* class intervals in a slightly concave log-linear fashion (Figure 1). Density estimates for small trees are not often made in tropical forests, but field experience in the region and the few reports that have been published indicate that the densities at Pasoh are relatively high (Table 1).

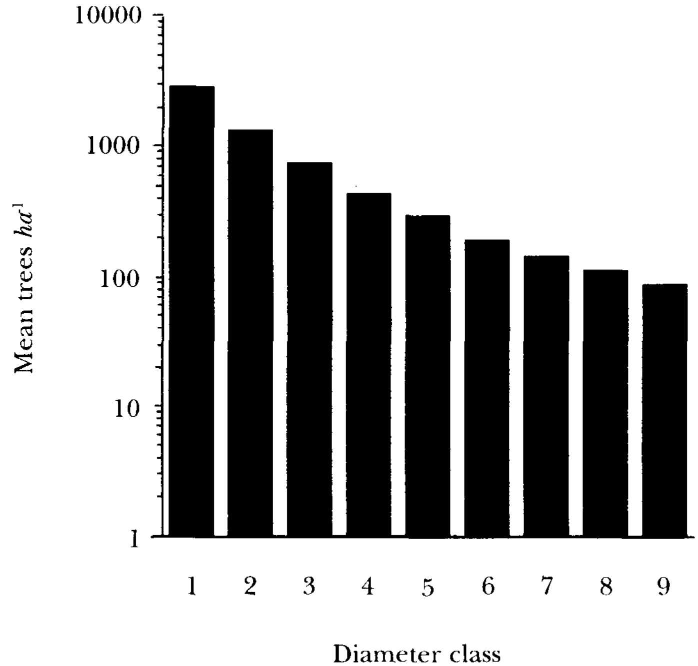

Figure 1. Density of trees 1 to 10 *cm* dbh, in 1 *cm* intervals, in the 50-*ha* plot, Pasoh Forest Reserve, Malaysia

Mean density of trees larger than 10 *cm* dbh was 530 trees ha^{-1}, which is similar to what has been found in many lowland forests in Malaysia. The density of trees above 30 *cm* dbh was somewhat low. In comparison with Sungei Menyala, for example, both forests had 530 trees ha^{-1} > 10 *cm* dbh, but Pasoh had only two-thirds the density of Sungei Menyala among trees > 40 *cm* dbh. The density of trees in the 10 to 15 *cm* dbh interval at Pasoh (about 250 trees ha^{-1}) must, therefore, be relatively high.

Mean density of trees classed at 10 *cm* dbh intervals decreased between 10 and 130 *cm* dbh in a very weakly concave log-linear fashion (Figure 2), whereas the density of trees > 130 *cm* dbh dropped abruptly. We found no evidence of the perturbed distribution pattern among diameter classes that was found, for example, in the storm forest of Kelantan, Malaysia (Wyatt-Smith 1954 and Table 1). At that site, trees of intermediate diameters were relatively few, 94 trees ha^{-1} between 20 and 40 *cm* dbh, and 108 trees ha^{-1} between 40 and 100 *cm* dbh.

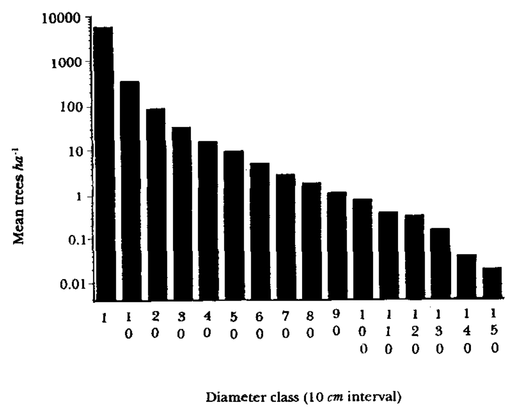

Figure 2. Density of trees 1 to 150 *cm* dbh, in 10 *cm* intervals, in the 50-*ha* plot, Pasoh Forest Reserve, Malaysia

Very large trees were few in number at Pasoh. Only four trees in the 50-*ha* plot exceeded 150 *cm* dbh, the largest was a chengal, *N. heimii* (Dipterocarpaceae), that measured 195 *cm* diameter at a height of 4 *m*. The standing bole of another long-dead chengal measured more than 2.3 *m* dbh. The number of very large trees in the 50-*ha* plot is low in comparison with some other tropical forests, and especially with the Malayan hill forests represented by Bukit Lagong (Wyatt-Smith 1966).

Basal area

Mean basal area of trees > 10 *cm* dbh was 25.2 m^2 ha^{-1}. This is lower than values for small lowland forest plot such as Sungei Menyala (32.5 m^2 ha^{-1}), and much lower than quality hill forest such as Bukit Lagong (41.7 m^2 ha^{-1}) (Manokaran 1988). The basal area for all trees > 1 *cm* dbh was 30.5 m^2 ha^{-1}.

The extent to which the forest is composed of small trees is emphasised by the large contribution they make to basal area (Figure 3).

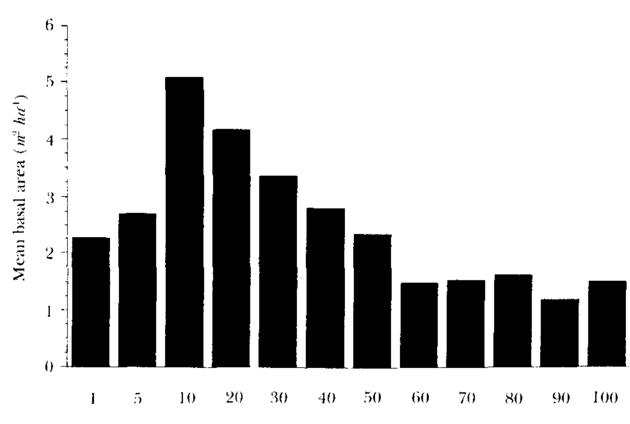

Figure 3. Basal area of trees in the 50-*ha* plot, Pasoh Forest Reserve, Malaysia (Note that values are on per *ha* basis and dbh intervals are uneven)

Heterogeneity

Stand structure was not perfectly uniform throughout the permanent plot, but varied from place to place. To examine variation in tree density, we calculated the density of trees 1 to 10 *cm* dbh for 1250 quadrats, each 400 m^2 in area. The quadrat density ranged between 106 and 474 trees, the median density was 243, and 50% of the quadrats had totals between 212 and 282 trees. The overall distribution was roughly normal (Shapiro-Wilk $W=0.97$, $p<W=0.0001$), and weakly skewed (skewness=0.56). Variation in basal area was similar; the distribution of values for 140 quadrats, each 2500 m^2, was roughly normal (Shapiro-Wilk $W=0.97$, $p<W=0.077$) and weakly skewed (skewness=0.44). The range was 5.16 to 10.93 m^2 and 50% of quadrats fell between 6.72 and 8.34 m^2.

The range of variation in structure was distributed throughout the plot rather evenly, bearing only a very weak relationship with topography. Density of small trees (1 to 10 *cm* dbh) showed an extremely weak but statistically significant negative correlation with ground slope of the quadrat ($r^2=0.02$ $p=0.0001$). Trees of intermediate size (10 to 30 *cm* dbh) showed no correlation between density and slope, but density of trees over 30 *cm* dbh was positively correlated with slope, though very weakly so ($r^2=0.03$, $p=0.0001$).

Figure 4 illustrates the distribution of all trees over 30 and 90 *cm* dbh. Comparison with the topographic map (Figure 5) indicates the rather homogeneous apportionment of 30 to 90 *cm* trees throughout the plot. Very large trees (over 90 *cm*) are evenly distributed throughout much of the plot, but are very sparse in the north west and south east corners, perhaps due to the wetter conditions there.

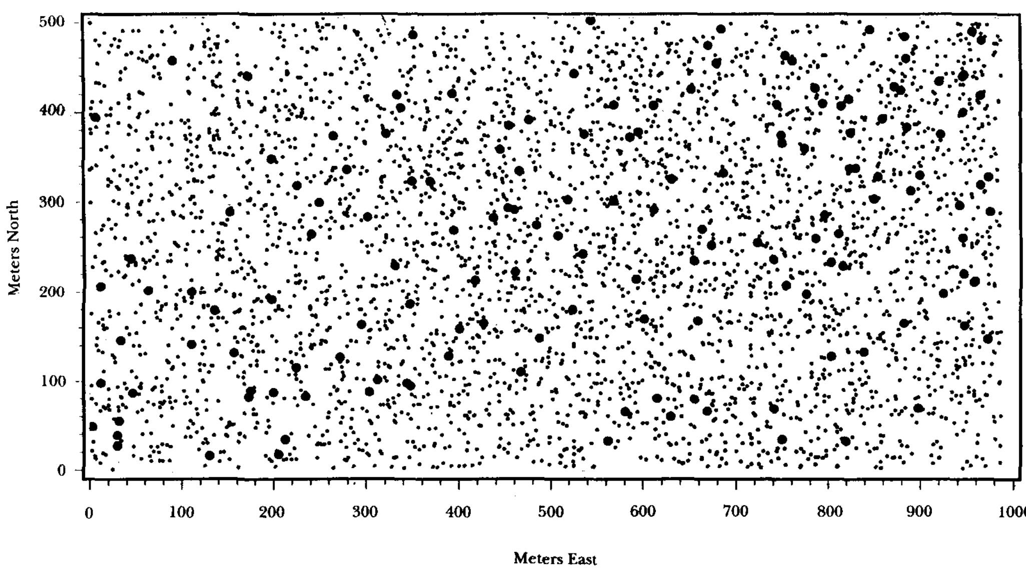

Figure 4. Map of all trees > 30 *cm* dbh (small dots) and 90 *cm* dbh (large dots) in the 50-*ha* plot, Pasoh Forest Reserve, Malaysia

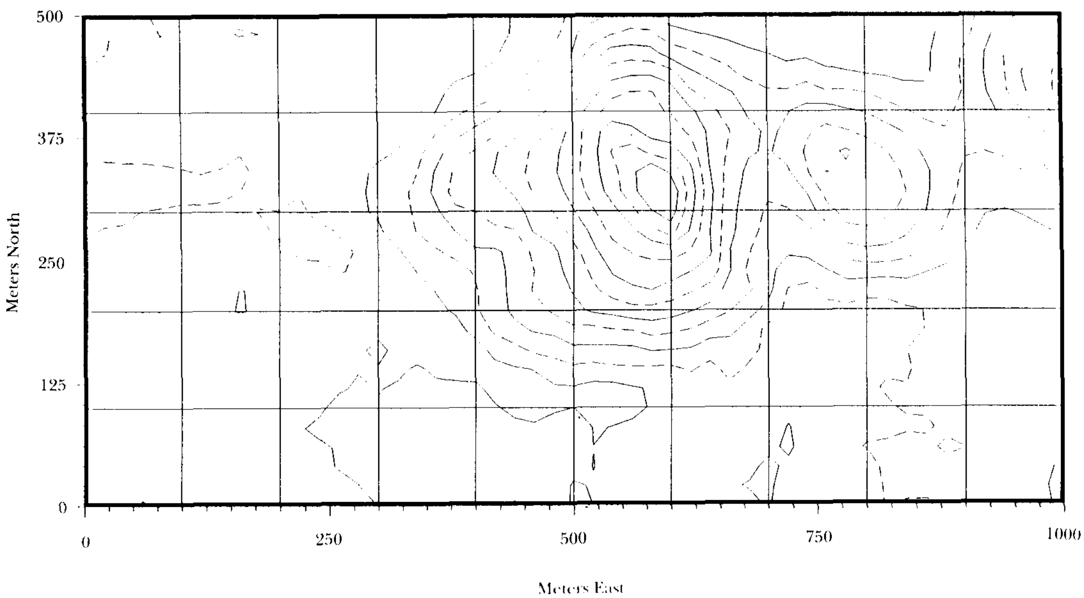

Figure 5. Topographic map of the 50-*ha* plot, Pasoh Forest Reserve, Malaysia (Contour intervals of 1 *m*)

The spatial distribution of small trees (1 to 2 *cm* dbh) is represented by the quadrat density of each 400 m^2 quadrat, illustrated as a grey tone map (Figure 6). The range of density values was distributed throughout the plot except for the most sparse and the most dense quadrats (white and black), which are found almost exclusively aggregated in the low flat ground.

One conspicuous patch of rather low density was located along the southern plot border about 200 to 300 *m* east of the origin. The square hectare that included this patch showed a density that is barely half the mean density for the plot, at 1 to 2 *cm* dbh, whereas the density of larger trees was consistently higher than the plot mean (Table 2). Field examination of this patch failed to determine conclusively the cause for the low number of trees in the 1 to 2 *cm* diameter class. Wild pigs were numerous in this part of the plot, and it appeared that they may have killed many small trees to build their nests, but further observation is needed.

Adjacent to the low density patch, about 500 to 600 *m* east of the origin, was an area where small trees were very numerous. The square hectare that includes this patch had density values that were consistently higher than mean values for the plot (Table 2). A field examination of this patch failed to indicate the cause, but the absence of large trees was conspicuous.

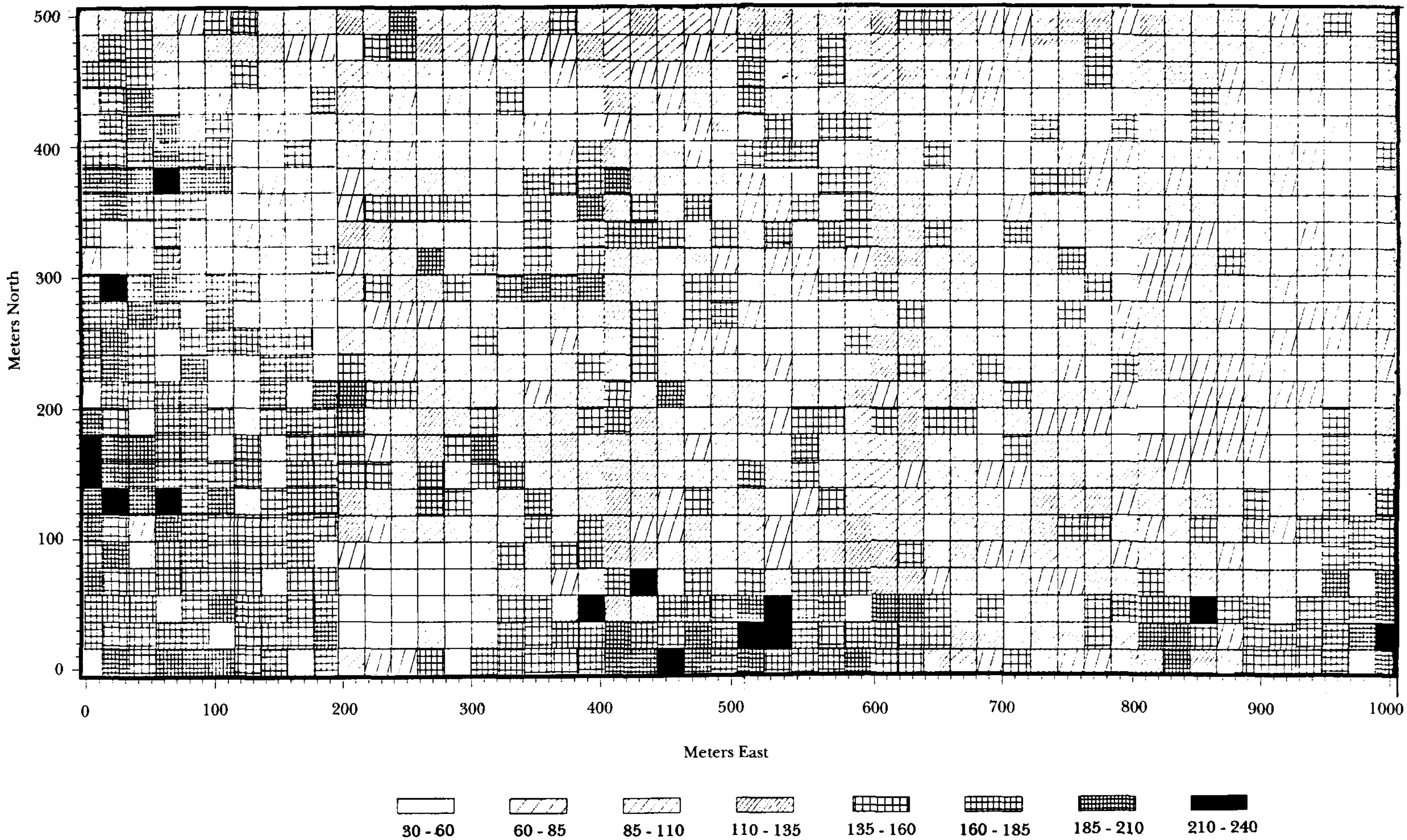

Figure 6. Density of trees 1 to 2 *cm* dbh in 1250 quadrats, each 400 m^2, in the 50-*ha* plot Pasoh Forest Reserve, Malaysia

Table 2. Comparison of stand structure for a low density patch and a high density patch with mean values for the 50-*ha* plot (Low density patch is defined as a square *ha* 200-300 *m* east, 0-100 *m* north; the high density patch is defined as a square *ha* 500-600 *m* east, 0-100 *m* north; *cf.* Figure 6)

DBH class (*cm*)	Mean values	Low density	High density
1-<2	2861	1200	3766
2-<3	1337	754	1611
3-<4	761	772	873
4-<5	442	486	433
5-<6	299	340	315
6-<7	197	222	205
7-<8	147	160	136
8-<9	115	140	134
9-<10	89	101	88
≥ 10	530	541	551

Discussion

The stand structure within the 50-*ha* plot conforms to general expectations for a lowland forest in the south-central region of the Malay Peninsula. The relatively high density of very small trees in the plot is likely related to the low density of larger trees; the canopy is rather open, the profile is irregular, the understorey is in many places well lit. It may be that the forest is regenerating on a relatively quick gap cycle and a rapid turnover may account for the rich stocking of saplings and treelets. This view would correspond with estimates of longevity among trees ≥ 10 *cm* dbh in four 2-*ha* plots at Pasoh. Based on 13 years observation, Manokaran (1988) calculated the annual mortality rate of trees ≥ 10 *cm* dbh to be 2.07%; that is comparable to figures of 2.02% at Sungei Menyala (Manokaran & Kochummen 1987), and 1.80 to 2.24% at La Selva, Costa Rica (Lieberman & Lieberman 1987).

Dawkins (1958) suggested that the basal area of tropical rain forests throughout the world probably ranges between 18 and 50 m^2 ha^{-1} (trees ≥ 10 *cm* dbh), which corresponds with the estimates of basal area by Swaine *et al.* (1987). Basal area in the 50-*ha* plot (25.2 m^2 ha^{-1}) is probably on the low side of Malayan forests, but it is very likely representative of conditions in the south-central Malay Peninsula. The rather low density of very large trees may also be typical of this relatively dry region.

The National Forest Inventory 1981 to 1982 (Anonymous 1985) indicated that Pasoh Forest included all three quality categories for primary forest: the eastern portion was considered "medium" quality (155 m^3 ha^{-1}), the central portion was considered "good" quality (160 m^3 ha^{-1}), and the western hills were considered "very good" (205 m^3 ha^{-1}). The 50-*ha* plot straddles the area labelled "good".

When we consider how Pasoh compares with other sites we should bear in mind that most published stand tables are based on very small plots, often no more than 0.25 *ha*, and usually chosen to exemplify a forest type rather than to incorporate a range of conditions. Some portions of the 50-*ha* plot show basal area in excess of 40 m^2 ha^{-1}, and some portions show dense stands of large trees, but these sites are balanced by the inclusion of rather more broken forest, especially the wet ground to the north east, and south central portions of the plot, and this depresses the overall mean values.

There is, nonetheless, some indication that Pasoh Forest has become more broken in recent time. Post felling reconnaissance of Pasoh in 1958 indicated that the southern compartments (now plantations) carried as much timber as any other forests of the red meranti-keruing type (Wyatt-Smith 1987). Furthermore, repeat census of four 2-*ha* plots at Pasoh indicate a 7.7% decline in basal area over the interval 1971 to 1984 (Manokaran 1988). This matches quite closely the results from three 4-*ha* plots in La Selva Research Station, Costa Rica, reported by Lieberman *et al.* (1985) where they found a 7.5% loss of basal area over the period 1969 to 1982. We might wonder if the receding borders of forest research sites have had an effect on the structure of the forest that remains. It is often supposed that decreased rainfall and increased wind associated with deforestation increases the damage to residual forest tracts, an opinion that is supported by the impressions of long-term observers of Pasoh, that tree falls are now more common than they previously were (P.S. Ashton, personal communication).

In Peninsular Malaysia, wind is usually not strong enough to damage the forest (Burgess 1969), the only known catastrophic wind damage being that in the north-east state of Kelantan where large lowland areas were flattened by a typhoon in 1880 (Browne 1949, Wyatt-Smith 1954). Elsewhere in Malaysia, wind damage is the very localised result of thunderstorms. Plot records show that at Sungei Menyala (2-*ha* plot of trees ≥ 10 *cm* dbh) there were two large windstorms that definitely contributed to tree falls, one in 1948 and the other in 1958. Of 76 trees that died between 1947 and 1951, 52 were uprooted, and nine were snapped during a single storm. Between 1957 to 1959, most of the 52 deaths recorded could be attributed to a windstorm (reported in Manokaran 1988). At Pasoh, data on wind damage is a necdotal; on July 13, 1982, an area of 1.2 *ha* outside of the 50-*ha* plot was damaged during a violent windstorm, while on April 15, 1987 violent gusts of wind, lasting no more than 20 *min*, accounted for numerous individual tree falls.

The heterogeneous distribution of small and large trees at Pasoh is not surprising in either its range or pattern. The different spatial scales at which heterogeneity can be seen derive from many different environmental factors that include topography, varying soils and water conditions, and the habits of pigs, elephants and termites.

Forests on the wet soils appear to be more broken, large trees are uncommon, and tip ups are numerous. Large tracts of swampy forest lie to the north and south of the 50-*ha* plot, but only a small portion of the plot is wet most of the year.

Old elephant wallows can still be found within the plot, and contribute in a very small way to the structural heterogeneity. Only a single elephant is known to remain in the reserve today, so this is not a likely source of disturbance in the future.

Pigs can be especially damaging to the understorey; by rooting they kill seedlings, and through nest building they eliminate large numbers of saplings.

The termite *Microcerotermes dubius* can destroy living trees and create conspicuous gaps in the forest (Tho 1982). Numerous infestations of this termite have been found at Pasoh.

Conclusions

Stand structure within the large scale permanent plot at Pasoh Forest Reserve is consistent with attributes of primary lowland forest in the Malay Peninsula and is probably characteristic of mean conditions in the lowland forest that once covered the south-central area. Some individual hectares of the 50-*ha* plot are well stocked with timber, but the mean basal area of 25.5 m^2 ha^{-1} indicates that the plot on the whole is not of the highest quality with regard to timber production. There is no evidence of large scale windthrows, fire or anthropogenic disturbance. The high density of small trees presents a favourable circumstance to view population dynamics of individual species. The good stocking ensures adequate sample size for most species, and suggests that significant changes can be observed in a relatively short time.

Acknowledgements

The large scale permanent plot at Pasoh Forest Reserve is an ongoing project of the Malaysian Government, initiated by the Forest Research Institute Malaysia, through its Director General, Salleh Mohd. Nor, under the leadership of N. Manokaran, P. S. Ashton and S. P. Hubbell. Supplemental funds are very gratefully acknowledged from the following sources: National Science Foundation (USA) BSR Grant INT-84-12201 to Harvard University through P. S. Ashton and S.P. Hubbell; Conservation, Food and Health Foundation, (USA) Inc.; United Nations, through the Man and the Biosphere program, UNESCO-MAB grants 217.651.5, 217.652.5, 243.027.6, 213.164.4, and also UNESCO-ROSTSEA grant 243.170.6.; and the continuing support of the Smithsonian Tropical Research Institute (USA), Barro Colorado Island, Panama.

References

ANONYMOUS. 1985. *Inventori hutan nasional II. 1981-1982 (National forest inventory).* Ibu Pejabat Perhutanan. Semenanjung Malaysia. Kuala Lumpur, Malaysia.

ASHTON, P.S. 1964. Ecological studies in the mixed dipterocarp forests of the Brunei state. *Oxford Forestry Memoirs 25.*

BROWNE, F.G. 1949. Storm forests in Kelantan. *Malayan Forester* 12:28-33.

BURGESS, P.F. 1969. Ecological factors in hill forests of the Malay Peninsula. *Malayan Nature Journal* 22:119-128.

DAWKINS, H.C. 1958. The management of natural tropical high-forest with special reference to Uganda. *Institute Paper Number 34.* Imperial Forestry Institute, Oxford.

KARTAWINATA, K., ROCHADI ABDULHADI & TUKIRIN PARTOMIHARDJO. 1981. Composition and structure of a lowland Dipterocarp forest at Wanariset, East Kalimantan. *Malaysian Forester* 44:397-406.

KOCHUMMEN, K.M., LAFRANKIE, J.V. & MANOKARAN, N. Floristic composition of Pasoh Forest Reserve, A lowland rain forest in Malaysia. *Journal of Tropical Forest Science* 3(1): 1 - 13.

LIEBERMAN, D., LIEBERMAN, M., PERALTA, R. & HARTSHORN, G.S. 1985. Mortality patterns and stand turnover rates in a wet tropical forest in Costa Rica. *Journal of Ecology* 73:915-924.

LIEBERMAN, D. & LIEBERMAN, M. 1987. Forest tree growth and dynamics at La Selva, Costa Rica (1969 - 1982). *Journal of Tropical Ecology* 3: 347 - 358.

MANOKARAN, N. & KOCHUMMEN, K.M. 1987. Recruitment, growth and mortality of tree species in a lowland dipterocarp forest in Peninsular Malaysia. *Journal of Tropical Ecology* 3: 315 - 330.

MANOKARAN, N. 1988. *Population dynamics of tropical forest trees.* Doctoral dissertation. Department of Plant Science, University of Aberdeen.

MANOKARAN, N., LaFRANKIE, J.V., KOCHUMMEN, K.M., QUAH, E.S., KLAHN, J., ASHTON, P.S. & HUBBELL, S.P. 1990. Methodology for the 50-*ha* research plot at Pasoh Forest Reserve. *Research Pamphlet Number 104.* Forest Research Institute Malaysia, Kepong, Malaysia.

MILLER, T.B. 1981. Growth and yield of logged-over mixed dipterocarp forest in East Kalimantan. *Malaysian Forester* 44:419-424.

POORE, M. 1968. Studies in Malaysian rain forest. I. The forest on triassic sediments in Jengka Forest Reserve. *Journal of Ecology* 56:143-196.

PROCTOR, J., ANDERSON, J., CHAI, P. & VALLACK, H. 1983. Ecological studies in four contrasting lowland rain forests in Gunung Mulu National Park, Sarawak. I. Forest environment, structure and floristics. *Journal of Ecology* 71:237-260.

RICHARDS, P.W. 1952. *The tropical rain forest.* Cambridge University Press, London.

RISWAN, S. 1987. Structure and floristic composition of a mixed dipterocarp forest, Lempake, East Kalimantan. Pp. 435-458 in Kostermans, A. (Ed.) *Proceedings of the third round table conference on Dipterocarp.* April 16 - 22, 1985. Samarinda, Indonesia.

SOEPADMO, E. & KIRA, T. 1977. Contribution of the IBP-PT Research Project to the understanding of Malaysian forest ecology. Pp. 63-94 in Sastry, C.B. Srivastra, P.B. & Abdul Manap, A. (Eds.), *A new era in Malaysian forestry.* Universiti Pertanian Malaysia Press, Serdang, Malaysia.

SWAINE, M.D., LIEBERMAN, D. & PUTZ, F.E. 1987. The dynamics of tree populations in tropical forest: a review. *Journal of Tropical Ecology* 3:359-366.

THO, Y.P. 1982. Gap formation by the termite *Microtermes dubius* in lowland forests of Peninsular Malaysia. *Malaysian Forester* 45:184-192.

WAN RAZALI MOHD. & ROSLAN ISMAIL. 1983. Tree-diameter distribution patterns in three topographic positions in a hill forest of Peninsular Malaysia. Pp. 11-23 in *Mensurational problems of forest inventory in southeast Asia. Special Publication Number 19.* BIOTROP, Bogor, Indonesia.

WYATT-SMITH, J. 1949. A note on tropical lowland evergreen rain forest in Malaya. *Malayan Forester* 12(2):58-64.

WYATT-SMITH, J. 1954. Storm Forest in Kelantan. *Malayan Forester* 17:5-11.

WYATT-SMITH, J. 1966. Composition and dynamic studies in lowland rainforest in two 5-acre plots. *Research Pamphlet Number 52.* Forest Research Institute, Kepong, Malaysia.

WYATT-SMITH, J. 1987. Manual of Malayan silviculture for inland forest: red meranti-keruing forest. *Research Pamphlet Number 101.* Forest Research Institute Malaysia, Kepong, Malaysia.