MANAGEMENT PLANNING FOR TEAK FORESTS

IN BURMA

BY

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A Substantial Essay

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ORIGINALITY OF THESIS

Except where specific acknowledgement is made this thesis is my original work.

1/5/81.

(Aung Kyaw Myint)

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ABSTRACT

Burma, with a population of 31.3 million in 1978 (Anon 1979), is endowed with rich natural forest resources which are significant in the national economy. Although more than half of the land area of the country is forested, further plantation establishment is necessary for local consumption as well as for export. The need for plantations is due to the uneven distribution of the population relative to the forests, the transportation difficulties and costs of extraction, and the efficiency of plantations in increasing the yield in the shortest time.

Teak forests in Burma have been managed successfully on a sustained yield basis for more than a century using traditional planning systems. Management planning can now be improved by the use of electronic computers for maintaining data and by developing growth and yield models for productive purposes.

Growth and yield models of plantation teak are developed using the data published by Laurie and Ram (1940), after conversion into metric units. The models relate top height to site index and age and basal area increment to age, site index and thinning index. A timber form factor function for estimating the stand volume was also developed. A simple simulation model was constructed utilizing the growth and yield models and the form factor function. Recommendations are advanced regarding the future development and applications of this model in management planning.

CHAPTER 1

GENERAL BACKGROUND

1.1 LOCATION

Burma is situated between latitudes 10° and 28° north and longitudes 93° and 103° east. The country extends about 2000 km in a north south direction and at its widest point 800 km east west. It has a coast-line over 1900 km long along the Bay of Bengal. The total area of the country is approximately 67.7 M ha of which 38.7 M ha (57.2 %) is under forests. Burma shares borders with Bangladesh and India in the west, China in the north, and Laos and Thailand in the east (see Figure 1.1).

1.2 GEOGRAPHY AND CLIMATE

There are a number of rivers in Burma all flowing north to south. The major rivers are the Irrawaddy, Sittang and Salween, and they are important for wood transportation in Burma (Ohn 1980). The Irrawaddy and the Sittang rivers originate in Burma, the Salween in Tibet. The Rangoon River which is much shorter than the major ones, has two tributaries namely the Myitmakha and the Pegu. The Myitmakha River starts from the western drainage of the Pegu Yoma, the Pegu River from the eastern drainage. They join at Rangoon before flowing into the sea as the Rangoon River (see Figure 1.1).

The Shan plateau in the eastern part of the country ranges from 1200 m to 2500 m in altitude and is connected with the Kachin hills of

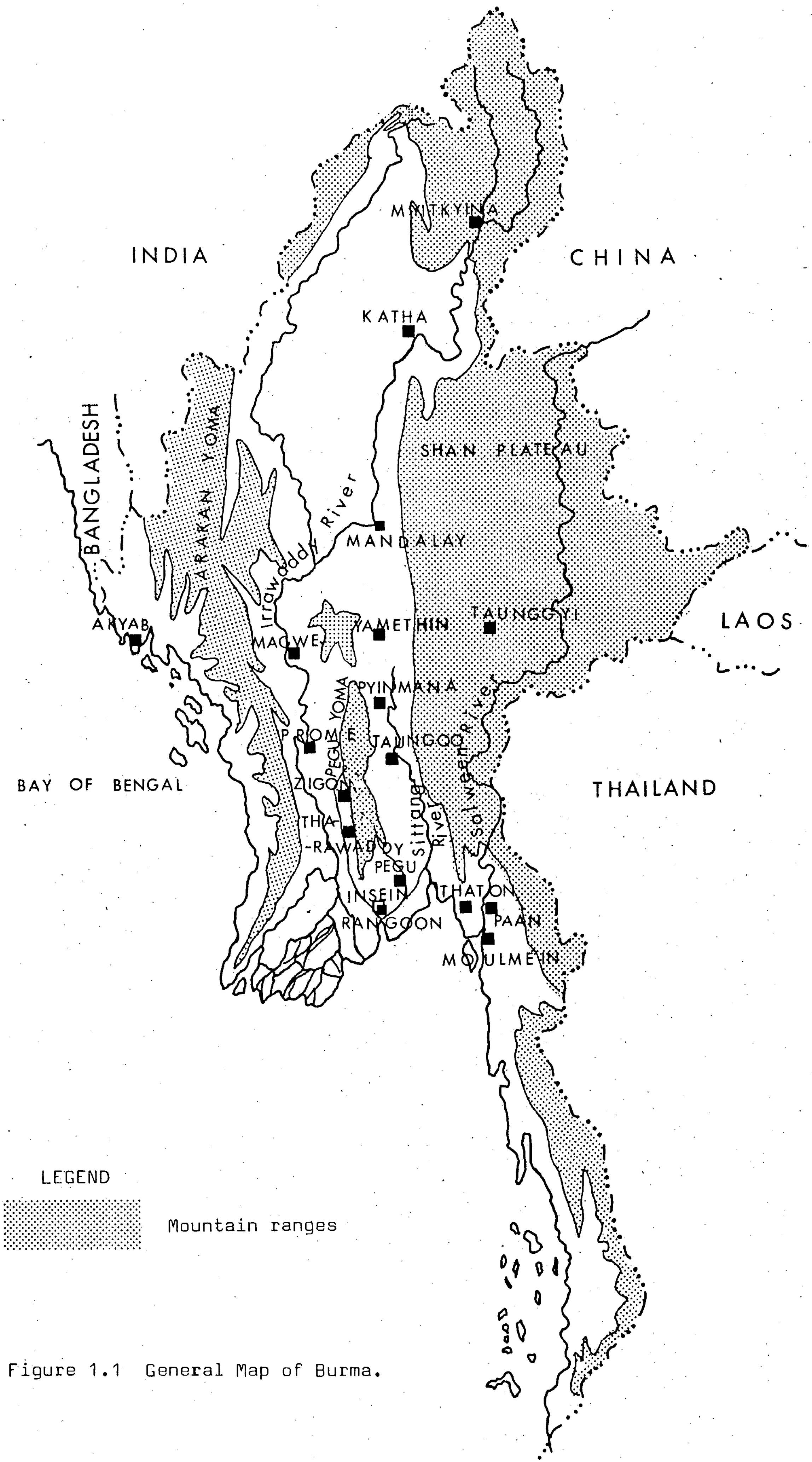


Figure 1.1 General Map of Burma.

northern Burma and with the hills of China. Kakhaborazi Mountain, the highest point of Burma, is approximately 6000 m above sea level and located in the far north. The Arakan Yoma Range is situated in the western part of the country lying north south and rises up to 3000 m. The Pegu Yoma, famous as the home of teak, lies in the centre with elevations generally below 610 m.

Rangoon is the capital of Burma. Mandalay and Moulmein, the second and third largest cities respectively, are located in the central and southern part of the country. The general map of Burma showing some cities, rivers and mountain ranges is given in Figure 1.1. There are three seasons in Burma - summer, monsoon and winter. The summer, the hot season, is from mid February to mid May; the monsoon, the rainy season, is from mid May to mid October; and the winter, the cold season, is from mid October to mid February. Usually the winter and the summer are dry, though there are occasional winter and summer rains. The areas in the east and west mountain ranges have the colder climates due to higher altitude. In general, over two thirds of the country can be categorized as having a tropical climate and one third a warm temperate climate. The country has a wide range of average annual rainfall zones, ranging from a few hundred mm to 6350 mm. Central Burma is known as the Dry Zone and has less than 760 mm of annual rainfall. The lower part of the country and the coastal strips have rainfall above 2540 mm, and the areas surrounding the Dry Zone together with the Shan Plateau range between 760 mm to 2540 mm (see Figure 1.2). Temperature generally ranges from 32° C to 38° C during the summer, 21° C to 30° C during the monsoon, and 10° C to 21° C during the winter. The Dry Zone may have temperatures as high as 42° C during summer.

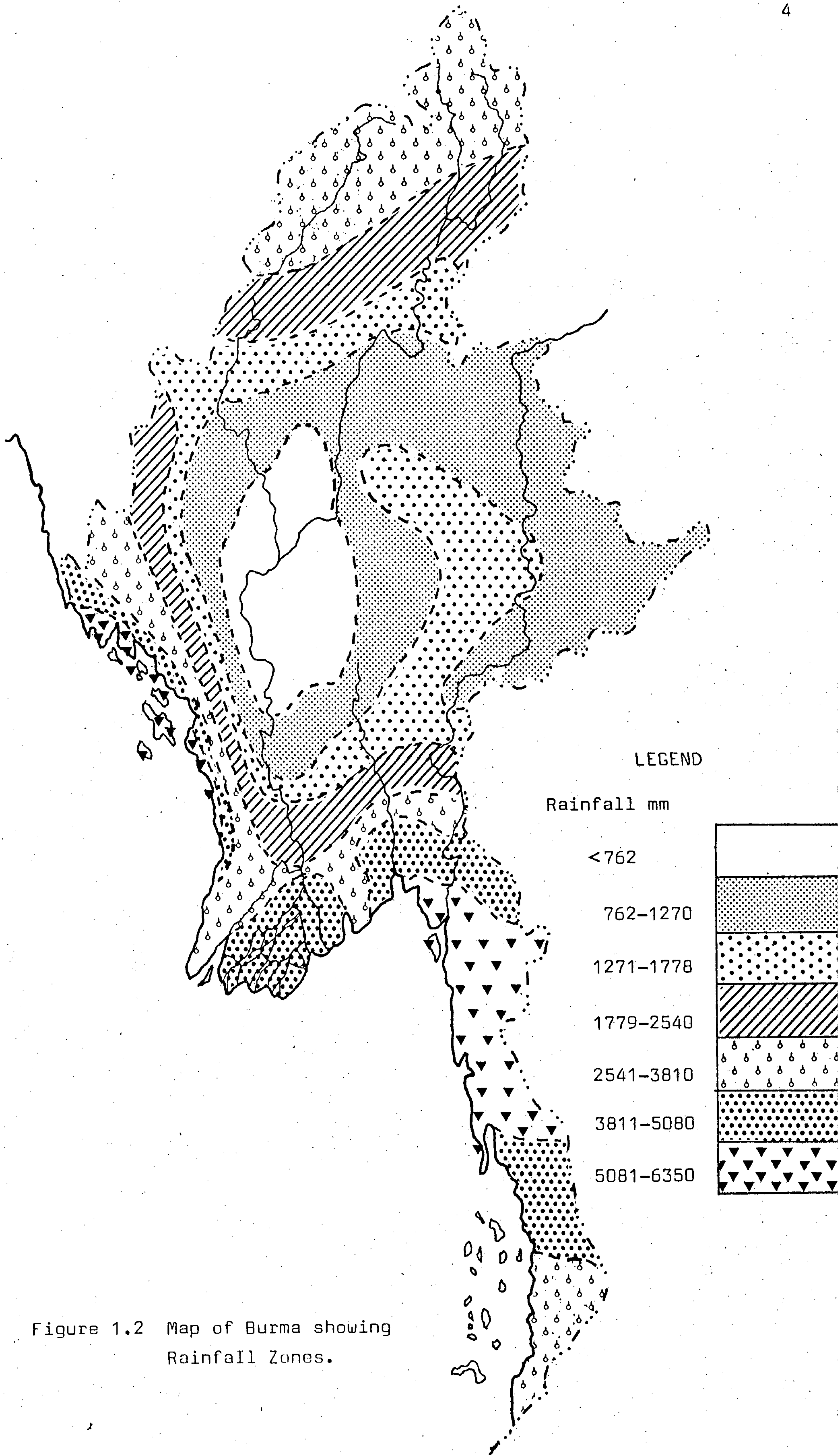


Figure 1.2 Map of Burma showing Rainfall Zones.

1.3 THE FORESTS OF BURMA

The total land area of approximately 67.7 M ha comprises forested land 57 per cent, agricultural land 28 per cent and other lands about 15 per cent. Government policy for forests calls for the reservation of at least 25 per cent of the country (Anon 1978a), but only 14 per cent has been achieved to date. Almost half of the agricultural land area is not in production but can be cultivated (see Table 1.1)

TABLE 1.1 LAND CLASSIFICATION

Classification	Area (ha)	Percentage of total land (%)
1. Forested land.	38,728,092	57.2
(a) Reserved	9,700,800	14.3
(b) Unreserved	29,027,292	42.9
2. Agricultural land.	18,550,272	27.5
(a) Under cultivation	9,992,692	14.8
(b) Cultivable but unused	8,557,580	12.7
3. Other land.	10,379,377	15.3
Total Land Area	67,657,741	100.0

Source : Anon. (1978b).

The forest types of Burma vary from tropical evergreen to dry thorny shrub forest (Kermode 1964). They include various tropical deciduous forests and temperate hill forests. There are six main forest types :-

1. Mixed deciduous forests.

2. Sub-tropical hill forests and alpine forests.

3. Evergreen forests.

4. Dry forests.

5. Deciduous dipterocarp forests or Indaing forests.

6. Tidal forests, beach and dune forests, and swamp forests.

The distribution of these forests is shown in Figure 1.3, and the proportion of each type given in Table 1.2.

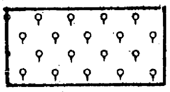
TABLE 1.2 FOREST TYPES

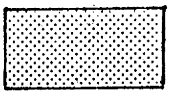
Forest type	Area (M ha)	Percentage of total forested land (%)
1. Mixed deciduous forests.	15.1	39
2. Sub-tropical hill forests and alpine forests.	10.1	26
3. Evergreen forests	6.2	16
4. Dry forests.	3.9	10
5. Deciduous dipterocarp or Indaing forests.	1.9	5
6. Tidal, beach and dune, and swamp forests.	1.5	4
Total Forest Area	38.7	100

Source : Kermode et al. (1957).

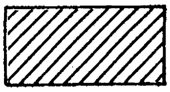
Legend to Figure 1.3

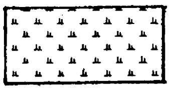
(1) Mixed Deciduous forests


- Moist Upper Mixed Deciduous forests

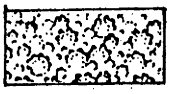

- Dry and Lower Mixed Deciduous forests

(2) Sub-tropical Hill and Alpine forests


- Sub-tropical Wet Hill and Hill Savannah forests

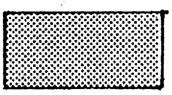

- Alpine forests

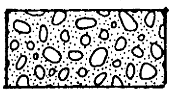
(3) Evergreen forests


- Tropical Wet Evergreen forests


- Tropical Semi-evergreen forests


(4) Dry forests


(5) Deciduous Dipterocarp *(Indaing)* forests


(6) Tidal, Beach and Dune, and Swamp forests

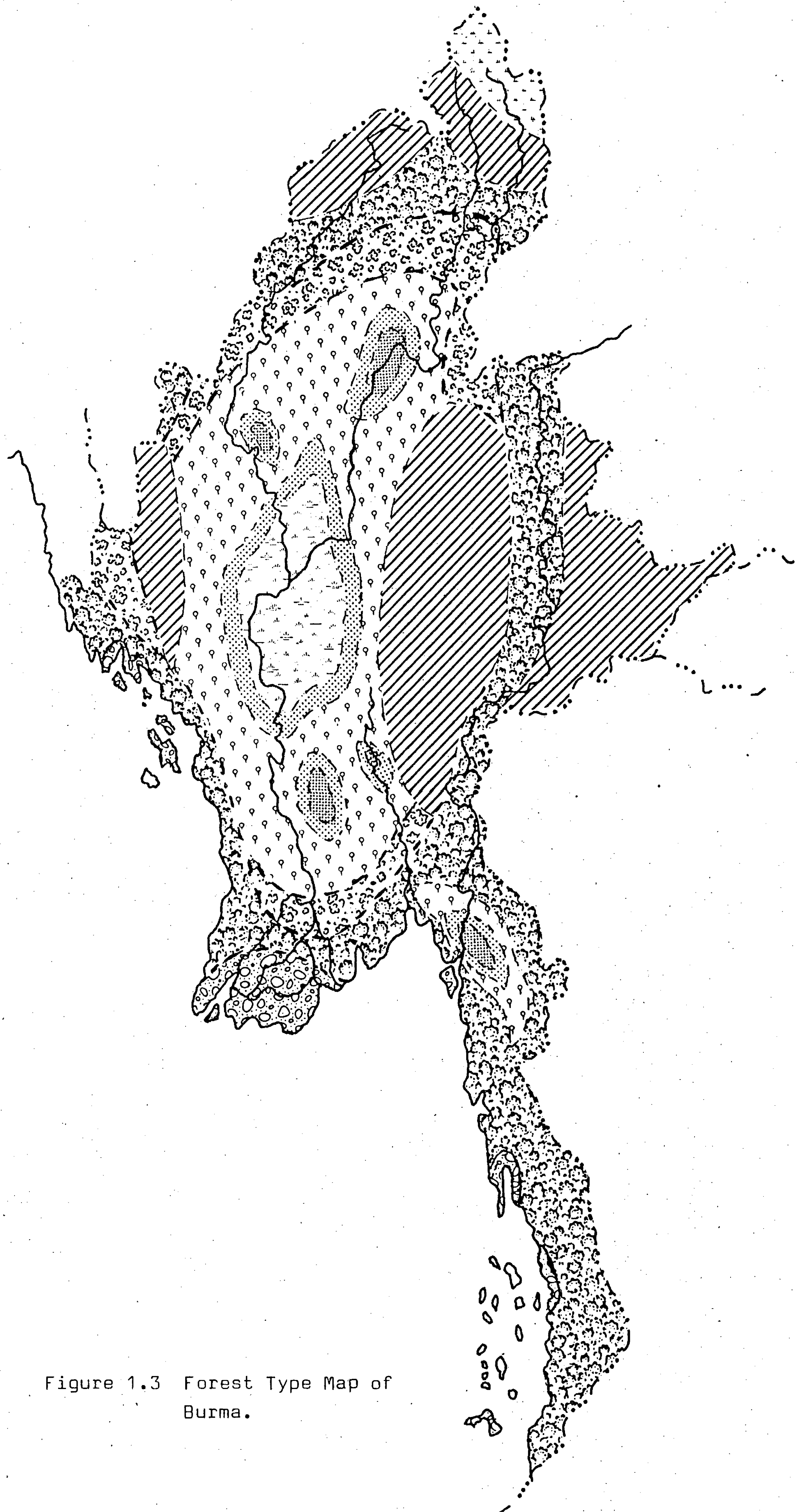


Figure 1.3 Forest Type Map of Burma.

The mixed deciduous forests are about 39 per cent of the total forested land (see Table 1.2) and are the most important as teak *Tectona grandis* Linn.f. trees grow naturally in them and comprise up to 10 per cent by number. The following section will give a brief description of the forests.

1.3.1 The Mixed Deciduous forests

These are economically the most important as teak and other commercial hardwoods are present. There are three sub-groups of the mixed deciduous forests :-

(1) Moist upper mixed deciduous (MUMD);

(2) Dry upper mixed deciduous (DUMD);

(3) Lower mixed deciduous (LMD).

Both moist and dry upper mixed deciduous forest types are found on well drained hill slopes and on the top of the ridges. The lower mixed deciduous forest occurs on low-lying flat areas, usually with alluvial soils and near streams. Usually mixed deciduous forests are found in the regions with an annual precipitation of 1500 mm to 2030 mm.

The typical tree species of the moist upper mixed deciduous forests associated with teak, are pyinkado (*Xylia dolabriformis*, D.C.), binga (*Mitragyna rotundifolia*, O.Ktze.), didu (*Samalia insignis*, Schott. and Endl.), letpan (*Salmalia malabarica*, Schott. and Endl.), padauk (*Pterocarpus macrocarpus* Kurz.), and yemane (*Gmelina arborea*, Roxb.). Generally teak grows vigorously and is more or less the dominant species. Typical bamboo species are kyathaungwa (*Bambusa polymorpha*, Munro.) and tinwa (*Cephalostachyum pergracile*, Munro.) and are useful for identification.

Dry upper mixed deciduous forests can be found on the hills with a drier and stiff soil where the quality of teak is poor. Typical associate species of teak, in this type of forest are hnaw (*Adina cordifolia*, Hook. f.), in (*Dipterocarpus tuberculatus*, Roxb.), ingyin (*Pentacme siamensis*, Kurz.), padauk (*Pterocarpus macrocarpus*, Kurz.), pyinkado (*Xylia dolabriformis*, Benth.), taukkyan (*Terminalia tomentosa*, W. and A.), and thitya (*Shorea oblongifolia*, Thw.). It is common to identify this type of forest by the presence of the bamboo species myinwa (*Dendrocalamus strictus*, Nees.) which grows and survives on the hard, stiff and dry soils.

Teak in the lower mixed deciduous forests is usually associated with tree species like leza (*Lagerstroemia tomentosa*, Presl.), and yon (*Anogeissus acuminata*, Wall.). Although teak grows faster in this forest type than in other mixed deciduous types it is usually defective due to the occurrence of flutes and hollows. Climbers are found more abundantly in this forest type although the absence of any bamboo is also a characteristic.

1.3.2 Sub-tropical Hill forests and Alpine forests

These forests constitute about 26 per cent of the total forested area (see Table 1.2) and are located above 900 m in altitude (see Figures 1.1 and 1.3). These forests may be sub-divided into three groups as follows :-

(1) Sub-tropical wet hill forests;

(2) Sub-tropical hill savannah forests;

(3) Alpine forests.

Generally the sub-tropical wet hill forests occur above the 900 m altitude with heavy annual rainfall (see Figure 1.2) and while found pure on the Arakan Yoma and the Chin hills are mixed with the sub-tropical hill savannah forests on the Shan plateau where the rainfall is lower. The most common tree species of the sub-tropical wet hill forest type are htinshu (Pinus merkusii, Jungh.), htinshu (Pinus kesiya, Royle. ex Gordon.), laukya (Schima wallichii, Choisy.), maibau (Alnus nepalensis, Don.), thitcha (Castanopsis spp.), and thite (Quercus spp.).

The sub-tropical hill savannah forests are dry hill forests and typical tree species present are thitsi (Melanorrhoea usitata, Wall.), in (Dipterocarpus tuberculatus, Roxb.), thitya (Shorea oblongifolia, Thw.), and ingyin (Pentacme siamensis, Kurz.).

The alpine forests are mostly pine forests and usually at very high altitude (see maps in Figures 1.1 and 1.3), with very high rainfall (see map in Figure 1.2). The forests have little commercial importance because of severe weather conditions and difficult extraction. Resin tapping from the pine forests on the Shan plateau and from the Chin hills is the only economic activity, apart from fuel wood extraction and clear felling for shifting cultivation. However these forests are important for soil conservation and protection of watersheds.

1.3.3 Evergreen forests

These forests occur in the areas where the annual rainfall is above 2000 mm. They fall mainly into two sub-groups, i.e. :-

(1) Tropical wet evergreen;

(2) Tropical semi-evergreen.

The tree species common in the tropical wet evergreen forests are kanyin (Dipterocarpus spp.), kaunghmu (Anisoptera scaphula, Roxb., Pierre.), kokko (Albizzia lebbek, Benth.), pyinkado (Xylia dolabriformis Benth.), taungthayet (Swintonia floribunda, Griff.), thingadu (Parashorea stellata, Kurz.), thingan (Hopea odorata, Roxb.), thikado (Cedrela toona, Roxb.), thitpok (Tetrameles nudiflora, R.Br.), and sagawa (Michelia champaca, Linn.). Generally these forests are characterised by the dense mass of undergrowth of various canes and climbers.

The tropical semi-evergreen forests are found further inland than the wet evergreen, where the rainfall is less, and they are characterised by evergreen tree species mixed with the deciduous tree species (see Figure 1.3). Sometimes, even in the deciduous forest type zone, these tropical semi-evergreen forests can be identified in patches along the river sides and in very moist areas, and they are usually termed riverine evergreen forests. In addition to the evergreen tree species, other species found are yemane (Gmelina arborea, Roxb.), didu (Salmalia insignis, Schott. and Endl.), letpan (Salmalia malabarica, Schott. and Endl.). The typical bamboo species found in both types of evergreen forest are wabo (Dendrocalamus brandisii, Kurz.), wabomyetsangye (Dendrocalamus hamiltonii, Nees. ex Arn.), waphyu (Dendrocalamus membranaceus, Munro.), and waphugyi (Gigantochloa macrostachaya, Kurz.).

1.3.4 Dry forests

This type of forest occurs in the Dry Zone where annual rainfall is typically below 760 mm and is not always a forest as expected. Thorny bushes and stunted vegetation are commonly found on the ground due to repeated and heavy cuttings. These forests may be sub-divided into the following groups :-

(1) Than - dahat forests;

(2) Thorn forests.

The characteristic tree species in all of the dry forests are than (Terminalia oliveri, Brandis.), dahat (Tectona hamiltoniana, Wall.), and sha (Acacia catechu, Willd.). Most of the species are of no commercial value other than for fuel wood but sha (Acacia catechu, Willd.) is widely used for manufacturing cutch. Starting in the early 1960's plantations of the red gum eucalypt (Eucalyptus camaldulensis) have been established in these areas. The adaptability of the species to the Dry Zone soil and climate has been previously established in young test plots, and fairly rapid rates of growth have been obtained.

1.3.5 Indaing forests

This type of forest is edaphic occurring typically on poor gravelly or lateritic soils. Although the type is only 5 per cent of the total forested land (see Table 1.2), it has some important features because the occurrence of in (Dipterocarpus tuberculatus, Roxb.) may be as high as 80 per cent by number. Natural regeneration of in (Dipterocarpus tuberculatus, Roxb.) can be achieved uniformly and abundantly. Most importantly, the timber of this species has a high demand for local consumption as well as plywood.

1.3.6 Tidal, Beach and Dune, and Swamp forests

These forests constitute about 4 per cent of the total forest area and occur mostly in the tidal limits of the Irrawaddy delta (see Figure 1.3). The characteristic species are mainly mangroves including kanazo (Heritiera fomes, Buch.) and kyana (Xylocarpus moluccensis, Lam.)

and used for fire wood, although they can also produce pulping material for paper and paperboards.

1.4 POPULATION

The population of Burma is approximately 31.4 million (1978) with an annual growth rate of 2.24 per cent (see Table 1.3). The urban and rural population are 7.61 M and 23.76 M respectively.

TABLE 1.3 POPULATION IN BURMA (1978)

Region	Population		
	Urban	Rural	Total
1. Kachin State	162,042	605,671	767,713
2. Kayah State	28,538	91,377	119,915
3. Karen State	86,018	651,561	737,579
4. Chin State	40,856	314,517	355,373
5. Sagaing Division	427,081	3,057,313	3,484,394
6. Tenasserim Division	186,144	614,215	800,359
7. Pegu Division	682,928	2,866,717	3,549,645
8. Magwe Division	456,534	2,486,837	2,943,371
9. Mandalay Division	1,078,546	3,019,644	4,098,190
10. Mon State	416,273	1,044,577	1,460,850
11. Arakan State	275,990	1,623,700	1,899,690
12. Rangoon Division	2,478,580	1,083,710	3,562,290
13. Shan State	531,539	2,417,879	2,949,418
14. Irrawaddy Division	764,536	3,880,776	4,645,312
Total Population	7,614,835	23,755,264	31,374,099

Source : Anon. (1979).

In Table 1.3 Saggaing, Pegu, Magwe, Mandalay, Rangoon and Irrawaddy Divisions are the most thickly populated and highly accessible. Most of the forests in these Divisions were cleared under population pressure.

As the forested area of the country is approximately 38.7 M ha, the overall forest area per capita is 1.23 ha, but the regional forest area per capita varies from 0.06 ha to 9.30 ha (Table 1.4) due to uneven distribution of population. More forests may be needed in the densely populated regions.

TABLE 1.4 FOREST AREA PER CAPITA

Region	Total land area M ha	Forested land area M ha	Forest area per capita ha
1. Kachin State	8.9	2.0	2.59
2. Kayah State	1.2	1.0	8.84
3. Karen State	3.0	2.2	2.99
4. Chin State	3.6	3.3	9.30
5. Sagaing Division	9.5	5.6	1.62
6. Tenasserim Division	4.3	3.7	4.65
7. Pegu Division	3.9	2.0	0.56
8. Magwe Division	4.5	2.0	0.68
9. Mandalay Division	3.7	1.3	0.32
10. Mon State	1.2	0.6	0.39
11. Arakan State	3.7	1.9	0.98
12. Rangoon Division	1.0	0.2	0.06
13. Shan State	15.6	11.8	4.01
14. Irrawaddy Division	3.5	1.1	0.23
Total Burma	67.6	38.7	1.23

Source : Anon. (1979).

It is clear that the most thickly populated Divisions, mentioned earlier, have very low forest area per capita. Development of plantations in these areas is most appropriate due to the accessibility, internal demands and transportation of timber.

1.5 NATIONAL ECONOMY

Burma is primarily an agricultural country and the economy is largely dependent upon agricultural production, particularly rice. Values of the net output for the nation from 1969 to 1975 are shown in Table 1.5 below.

TABLE 1.5 NATIONAL INCOME (1969 - 1975)

(Million Kyats at 1969-70 prices)

Sectors	Years					
	1969-70	1970-71	1971-72	1972-73	1973-74	1974-75
Goods	5162	5509	5564	5248	5512	5524
Agriculture	2713	2896	2954	2765	3023	2963
Forestry	736	804	824	715	803	794
Live stock and fishery	258	283	277	272	236	272
Mining	111	149	137	139	120	117
Processing and manufacturing	1071	1107	1107	1081	1054	1098
Power	61	67	65	72	89	89
Construction	212	203	200	204	187	191
Services	2295	2340	2477	2653	2637	2803
Trade	2519	2539	2600	2637	2663	2760
Net Output	9976	10388	10641	10538	10812	11087

Source : Anon. (1977).

Export of rice has been the major source of foreign exchange earnings since pre-war. However, forestry has become more and more important as the export earnings from timber, especially teak, increased. The changing trends are shown in Table 1.6. The export of forest products contributed only 6 per cent in 1940, 9 per cent in 1960, but rising to more than 25 per cent in 1967 and 1974. This suggests that forestry will become even more important in the national economy in the future.

TABLE 1.6 EXPORT EARNINGS BY COMMODITY (1940 -1975)

(Million Kyats)

Commodity	Years			
	1940-41	1960-61	1967-68	1974-75
Agricultural products	281	769	307	524
Forest products	32	94	156	232
Mineral and gems	62	36	20	103
Other exports	180	116	39	54
Total Exports	555	1015	522	913

Source : Anon. (1969, 1977).

While hardwood species are most important for domestic consumption, particularly for firewood and sawn timber, the teak forests are still very important for domestic purposes as well as exports. This study is directed toward the management of the teak forests. There are insufficient data readily available to enable a detailed analysis of the natural teak forests from a management point of view but the results of the analysis of the available data of Burmese teak plantations are presented.

CHAPTER 2

DEVELOPMENT OF THE FOREST DEPARTMENT AND PLANNING

2.1 DEVELOPMENT OF THE FOREST DEPARTMENT

The historical development of scientific forest management and the development of the Forest Department in Burma have been described by Blanford (1925, 1956) and Kyi (1959). Teak extraction was allowed on a contract system in the Tenasserim Province soon after the British occupation in 1826 (Blanford 1925). At that time, there was neither a forest organization nor any regulation on cutting. As a result the teak forests in Tenasserim were overcut and the stocking of teak reduced gradually. In 1841, attempts to control the cuttings and to conserve the teak were made by prescribing a girth limit for extraction. Due to the lack of a proper forestry organization it was not very effective.

The Province of Pegu was annexed by the British in 1852. Dr. McClelland was appointed as Superintendent of Forests for the Pegu Province soon after annexation. In 1856, Dr. Brandis, a scientifically trained forester, founded the Forest Department following his appointment as Superintendent of Forests for the Pegu Province. He divided the Pegu Province into six Forest Divisions (Blanford 1925). The Forest Department consisted of one Conservator and six Deputy and Assistant Conservators in 1868. The forests of the Lower Burma were later managed under two Conservatorships. By 1880 the Department consisted of two Conservators, seven Deputy Conservators, seven Assistant Conservators and four Sub-Assistant Conservators. Upper Burma was annexed in 1885, and Lower and Upper Burma were amalgamated in 1895. The Forest Department was expanded for the management of the forests of

Upper Burma. At first the forests of Upper Burma were organized under one Conservatorship, and later another additional Conservatorship was created. By that time all the Conservatorships were independent of each other. In 1900, the country was divided into four forest circles each administered by a Conservator namely Pegu, Tenasserim, Northern and Southern (Blanford 1956). In the year 1904-05 the post of Chief Conservator of Forests was created on the recommendation of the Conservators, and Beadon Bryant was appointed as the first Chief Conservator (Kyi 1959).

The Forest Department grew gradually. Barrington (1925) reported the strength of the Forest Department in 1925 to be one Chief Conservator, seven territorial Conservators, two Conservators for the Working Plans and Utilization Circles respectively, thirty-eight territorial Divisional Forest Officers and seven specialist Divisional Forest Officers for research and planning. Blanford (1956) noted that during the period 1920 to 1930 the Burma Forest Department reached its zenith.

The organization strength of the Forest Department in the 1920's and at present (1979) are shown in Table 2.1. The Forest Department is an organization under the Ministry of Agriculture and Forests. The Director-General, formerly the Chief Conservator of Forests, as the head of department is responsible to the Minister. The organization chart of the Department is shown in Figure 2.1.

Compared to the strength of 1927, the Forest Department is understrength (Table 2.1), and a reorganization of the department is in progress to strengthen it.

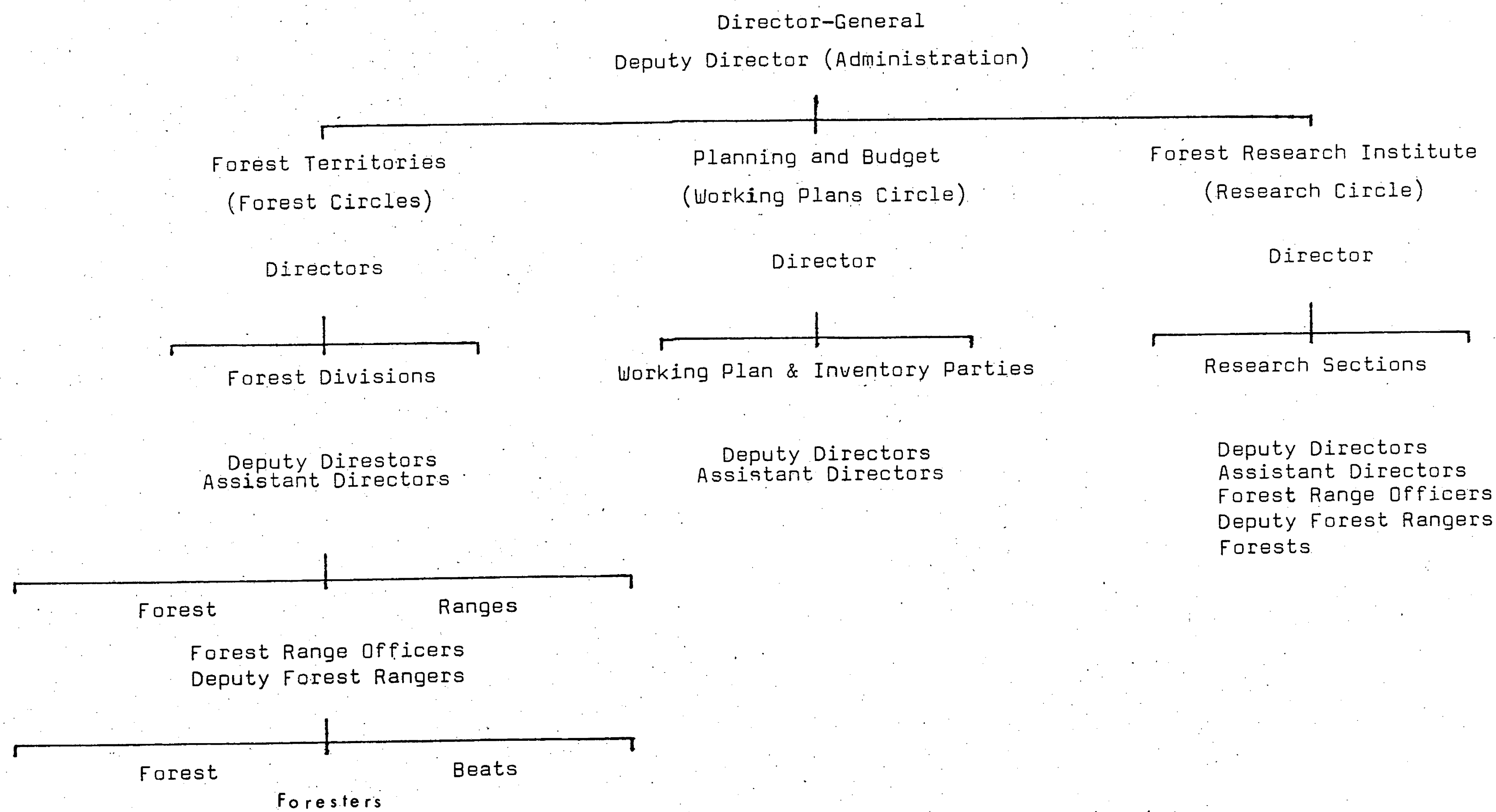


Figure 2.1 Organization Chart of Burma Forest Department.

TABLE 2.1 FOREST DEPARTMENT IN BURMA

Post	Sanctioned strength 1927	Sanctioned strength 1979
Director-General (Chief Conservator of Forests)	1	1
Director (Conservator of Forests)	9	8
Deputy Director (Deputy Conservator of Forests) (Divisional Forest Officer)	75[©]	44
Assistant Director (Assistant Conservator of Forests) (Extra Assistant Conservator of Forests)	78[®]	94
Township Forest Officer (Forest Ranger)	225	218
Deputy Township Forest Officer (Deputy Ranger)	432	414
Forest Beat Officer/Forester	1988	1624
Total	2808	2403

Source : Watson (1927), Anon. (1979).

Note : Exclude 26[©] and 30[®] reserve posts (see Watson 1927).

2.2 WORKING PLANS

2.2.1 Background of Working Plans

All the forests in Burma were orginally the property of the king, and teak had been prescribed as a royal tree (Hoe 1969). King Mindon permitted extraction from some of the forests in Tenasserim by British private companies but there were numerous disagreements between the Burmese authorities and the British companies about the extraction of teak.

When the Tenasserim Province was annexed by the British the private companies were allowed to continue timber extraction under a revenue system. At that time there were no management plans for the forests. Teak was cut down freely all over the forests of Tenasserim. Brandis wrote the first working plan for the Pegu forests in 1857. He adopted a sustained yield approach to the harvesting of teak which was based on growth projections of the growing stock.

The British government declared all forested land to be at the disposal of the Crown. The Forest Act empowered the government to reserve a forest. The reservation of the forests became the major work of the Department followed by ground survey for mapping. It was also necessary to measure the growing stock of a forest before a working plan was prepared. The working plans were prepared for the individual forests. In 1920 the Working Plans Circle was formed, after which working plans were prepared for the whole Forest Division combining the separate individual forest working plans. A manual on the preparation of working plans was also published (Anon 1961).

The forests are managed under various working circles some of which may overlap. The working circles are formed on the basis of their accessibility classifications and the nature and availability of the forest products. The following is a list of working circles common in the working plans (Anon 1961) :

i Teak Selection Working Circle (T.S.W.C.);

ii Teak Eradication Working Circle (T.E.W.C.);

iii Hardwood Supply Working Circle (H.S.W.C.);

iv Local Supply Working Circle (L.S.W.C.);

v Fuelwood Working Circle;

vi Cutch Working Circle;

vii Plantation Working Circle.

Teak is accessible throughout the forest as the logs can be floated easily two years after girdling. All the teak bearing forests are grouped under the Teak Selection Working Circle. Teak is a reserved tree species all over Burma, and it cannot be removed without authority. Teak Eradication Working Circles were formed covering cultivated and private lands, whereas the Forest Department eradicates teak. For the extraction of non-teak hardwood and other forestry products, the accessibility classification is important. The accessibility classifications are listed below :

<u>Class</u>

A : Areas that are currently accessible.

B : Areas that are likely to be accessible in the near future.

C : Areas that are likely to be accessible in the distant future.

The class A and B forests can be grouped under the Hardwood Supply Working Circle. The Local Supply Working Circle is always constituted of class A forests. The plantations also need to be highly accessible for efficient management, and usually the class A and B forests can be grouped. The accessibility of the non-teak hardwood forests in Burma is shown in Table 2.2.

TABLE 2.2 ACCESSIBILITY CLASSIFICATION OF NON-TEAK HARDWOOD FORESTS IN BURMA

(Sq km)

State / Division	Reserve forests A	B	C	Total	Unclassed forests A	B	C	Total
Kachin	2003	647	1283	3933	4229	3521	6961	14711
Kayah	-	-	-	-	1756	1963	6880	10599
Karen	1817	611	1222	3650	9801	2683	5394	17878
Chin	834	77	397	1308	1165	1222	3306	5693
Sagaing	5038	2359	9915	17312	19049	8005	11489	38523
Tenasserim	4698	3557	-	8255	13177	7187	7944	28308
Pegu	3104	1526	4706	9336	2602	927	2983	6512
Magwe	2315	1335	2707	6357	7086	1404	1590	10080
Mandalay	3391	1408	1942	6741	2505	413	753	3671
Mon	915	530	-	1445	3845	-	-	3845
Arakan	712	178	-	890	12578	2485	2193	17256
Rangoon	413	73	154	640	-	-	-	-
Shan	2485	4617	-	7102	39683	46656	50497	136836
Irrawaddy	1655	765	712	3132	2874	-	761	3635
Total	29380	17683	23038	70101	120350	76466	100751	297567

Source : Working Plans Department, Forest Department, Burma.

2.2.2 Teak Yield Regulation in Burma

Calculation and prescription of the yield is the most important part of a working plan. The original Brandis' method of yield calculation was based on the number of trees of certain exploitable size (Brasnett 1953). The main features of the Brandis' method were summarized by Kyi (1962) as :

i Estimation of the stock by survey;

ii Adoption of a girth limit of approx. 2.1 m (7');

iii Estimation of the rate of growth of teak;

iv Adoption of a thirty years felling cycle;

v Estimation of the survival percentages by size classes.

Kyi (1962, p23) also noted that "Brandis' method is not one of high precision. It never was claimed to be one. But it is sound, simple and flexible". Carron (1968) showed certain underlying assumptions in the method of yield regulation are not fufilled, such as the uniformity in the distribution and rate of growth of trees in a specific girth class. However, apart from these weaknesses the Brandis' method of yield regulation has been practised successfully in managing for a sustained yield in Burma. The following are the main achievements of the Brandis' method (Kyi 1961) :

i Matching the harvest with the average annual rate of promotion of trees into the group of exploitable girth limit and over;

ii Staggered liquidation of the surplus stock in the exploitable girth limit and over, as in the case of the virgin natural forest;

iii Prompt and successful institution of organized forestry;

iv Reservation and division of reserves into compartments;

v Establishment of sequence of compartments to be tackled;

vi Collection and building up of data on the growing stock and growth rate of teak;

vii Development of silvicultural techniques;

viii Development of working plans progressively;

ix Growth and building up of a forest service and its tradition.

The various developmental stages of teak yield regulation have been summarized by Kyi (1961). Teak growing stock was estimated by subjective linear valuation surveys covering about 10 % of the selected compartments during the period 1856 to 1880. From 1880 onwards, starting with Thonze reserve forest working plan, the intensity of these surveys was raised from 10 % to 25 %. Some application of the yield calculation method based on basal area was made during the period 1920 to 1930. During the period 1930 to 1940 a definite decision was made concerning the method of yield calculation. The linear valuation surveys were no longer carried out and yield was calculated directly from the enumeration record of trees left standing at the time of girdling operations. The Brandis' method was no longer practised.

Starting from 1962 random sampling methods were applied in measuring the growing stock of the forest (Tin et.al. 1973). These surveys provided reliable estimates for efficient management planning (Kyaw 1978).

The silvicultural system practised in the teak forests is the polycyclic selection system better known as the Burma Selection System. The possibility of changing from the selection system to the uniform system had been tested in 1910 (Gale 1978). Due to difficulties in getting uniform natural regeneration and the high rate of expenditure incurred for tending operations, the attempts were given up. The Burma Selection System with the number of trees as the yield control is still practised. The yield of teak in Burma is 246,800 trees of exploitable girth and over as in 1979 (see Table 2.3).

TABLE 2.3 ANNUAL ALLOWABLE CUT OF TEAK IN BURMA

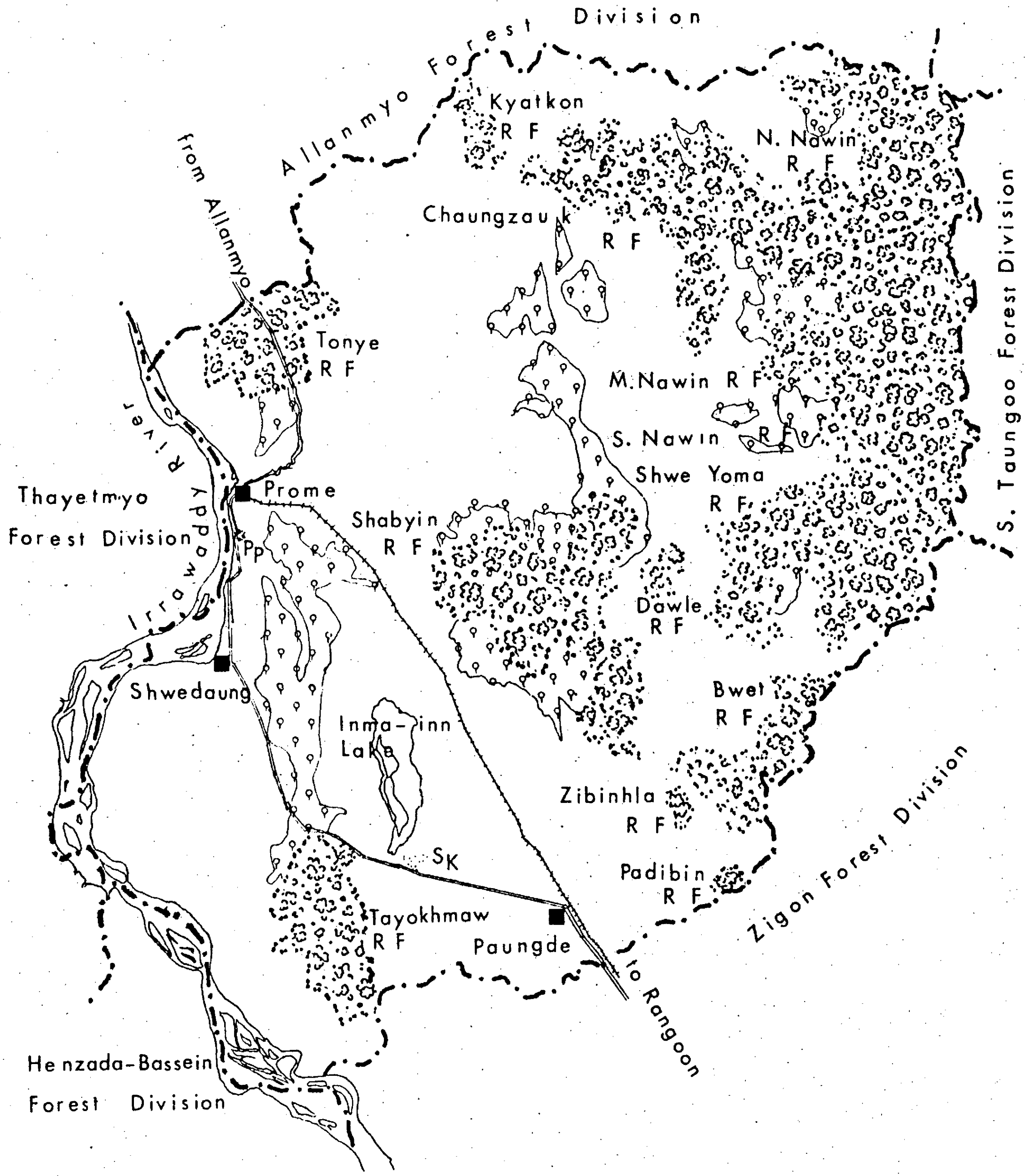
State / Division	Annual allowable cut of teak (yield trees)
1. Kachin State	20,500
2. Kayah State	5,340
3. Karen State	7,000
4. Chin State	3,900
5. Sagaing Division	61,530
6. Pegu Division	52,070
7. Magwe Division	40,770
8. Mandalay Division	23,960
9. Mon State	220
10. Rangoon division	3,670
11. Shan State	26,190
12. Irrawaddy Division	1,650
Total Burma	246,800

Source : Anon. (1979).

2.2.3 Working Plan for Prome Forest Division

Prome Forest Division is one of the eight Forest Divisions in the Pegu Forest Circle. It has the Allanmyo Forest Division in the north, the South Taungoo Forest Division in the east, the Zigon Forest Division in the south and the Thayetmyo Forest Division in the west (Figure 2.2).

Figure 2.2 Map of Prome Forest Division showing Reserved and Unclassed forests.



LEGEND

R F – Reserved Forests

Unclassed Forests

Forest Division Boundary

PP = Prome Plantation R F

SK = Shwe Kyundaw R F

The physical location of towns, the unclassed forests and the reserved forests are shown in Figure 2.2. A list of working plans, formerly the individual forest plans and later the divisional plans, are shown in Table 2.4. The constitution of the area of Prome Forest Division can be given as follows (Kyi 1969) :

1) Reserved Forests	132,439 ha
2) Unclassed Forests	129,737 ha
3) Other areas	250,364 ha
Total	512,540 ha

Note : Excluded is 139,451 ha of Thayetmyo Forest Division on the west bank of the Irrawaddy River, amalgamated to Prome Forest Division in 1974.

The reserve forests (132,439 ha) can be identified as the Hills and Plains reserves. The working circles were formed according to the accessibility of the reserves as summarized below (see Table 2.5 for detail) :

Working Circle	Number of reserves
Teak Selection W.C.	7
Commercial Supply W.C.	8
Local Supply W.C.	6
Cutch W.C.	5
Plantation W.C.	2

TABLE 2.4 WORKING PLANS OF PROME FOREST DIVISION

Area dealt with	Period	Author
Shwele W. C. (Shwele, Bwet, Dawle, and Kyaukgyitaung reserves)	1892-93 to 1921-22	H. Carter
Nawin forests (North Nawin and Chaungzauk reserves)	1892-93 to 1922-23	J. Messer
Plains reserves	1921-22 to 1930-31 (Superseded by Vorley's plan)	J.M.D. Mackenzie
Whole Division	1925-26 to 1934-35	J.S. Vorley
Whole Division	1930-31 to 1939-40	J.S. Vorley
Whole Division	1940-41 to 1954-55 (Owing to efflux of time redrafted by Garthwaite)	A.F.R. Brown
Whole Division	1946-47 to 1958-59	P.F. Garthwaite and U Ba Than
Whole Division	1959-60 to 1968-69	U Hla Pe
Whole Division	1969-70 to 1978-79	U Soe Kyi

Source : Kyi (1969).

TABLE 2.5 ALLOTMENT OF AREAS TO WORKING CIRCLES (PROME FOREST DIVISION)

(Area in ha)

Reserves / Unclassed forests	TSWC	HSWC	LSWC	CuWC	PlWC	TEWC	Total
Hills reserves							
Kyatkon		1819					1819
Chaungzauk	18192	(18192)		(10087)			18192
Olezwe	1559	(1559)		(1559)			1559
North Nawin	15404	(1831)					15404
Middle Nawin	15990	(15577)		(3082)			15990
South Nawin	14181	(13089)					14181
Shwele Yoma	21972	(21673)		(7619)			21972
Bwet	6997	(6997)		(3722)			6997
Shabyin			18737				18737
Dawle			1015				1015
Plains reserves							
Zibinhla			500				500
Pandinbin			352				352
Tayokhmaw			9519				9519
Shwekyundaw					103		103
Prome Plantation					32		32
Tonye		6067					6067
Unreserved							
Unclassed forests	129737						129737
Other areas						250364	250364
Total Prome Forest Division	224032	7886 (78918)	30123	(26069)	135	250364	512540

TSWC = Teak Selection Working Circle; HSWC = Hardwood Supply Working Circle; LSWC = Local Supply Working Circle; CuWC = Cutch Working Circle; PlWC = Plantation Working Circle; TEWC = Teak Eradication Working Circle.

Figures in bracket are overlapped areas.

Source : Working Plans Department, Burma Forest Department.

All the Hills reserves except three are under the Teak Selection Working Circle. Most of these reserves are easily accessible and included in the Commercial Supply Working Circle overlapping with the Teak Selection Working Circle.

However, the Middle Nawin, the North Nawin, and the South Nawin reserves are only partly accessible for hardwood extraction, especially the North Nawin. Some portions of the Hill reserves are also under the Cutch Working Circle (cutch is extracted from sha, <u>Acacia catechu</u> Willd.). The Plains reserves are very accessible and are located close to the villages. Four out of the six Plains reserves are managed for the Local Supply Working Circle. The remaining two Plains reserves were planted with teak under the Plantation Working Circle (see Table 2.5). Prome Plantation reserve is a small area located very close to Prome, where a second rotation teak plantation had been established after the first rotation crop had been cut at the age of 80 years.

There are also some old plantations in the Hills reserves which occur in small patches. They are no longer treated as the plantations due to difficulties in management. These small patches of plantation were formed for the purpose of supplementing the scarce natural regeneration and they were by no means intended to be managed under a clear felling system.

2.3 TEAK PLANTATIONS IN BURMA

The first teak plantation was established as early as 1856 by a Karen called U Panhee, who was a taungya cutter, as a personal present to Brandis. Brandis foresightedly remarked, after (Blanford 1956) :

> "This, if the people can ever be bought to do it, is likely to become the most efficient mode of planting teak in this country; "

Currently this method of artificial regeneration, "taungya" is well accepted in the world. In Burma changing concepts in the development of teak plantations have occured. During the period 1856 to 1910 teak plantations were formed only on a small scale. From 1918 an area of 3000 acres (approx. 1200 ha) was planted annually (Gale 1961). By 1936 the plantation programs were almost stopped when it was believed that soil erosion in teak plantations was serious. As a matter of fact, the teak plantations had never been formed in large contiguous blocks.

TABLE 2.6 TEAK PLANTATIONS IN BURMA

Period	Area (ha)
Actual planting	
1895 to 1941	36,929
1947 to 1962	1,230
1962 to 1971	9,255
1972 to 1980	16,006
Plan for planting	
1981 to 1990	109,265
1991 onwards	12,100 ha annually

Source : Forest Department, Burma.

The extent of teak plantations established up to 1962 is given in

Table 2.6. As the productivity of the teak plantations is very high compared to the yield from natural forest and the rotation is shorter, it is very desirable to replace the natural teak forests with plantations. With the approval of the Ministry of Agriculture and Forests, the Forest Department is undertaking a substantial program to establish teak plantations up to 12,100 ha per annum by 1990 (see Table 2.6). It is also to be noted that the teak plantations will be managed by a clear felling system with artificial regeneration.

2.4 THE NEED FOR GROWTH AND YIELD MODELS

The use of electronic data processing in forestry science has progressed with developments in the electronic digital computers and the application of management information systems (Leech 1977).

Computer applications in Burmese forestry were reported by Ohn and Myint (1977). Although computers are not used for all management planning systems, they are effectively utilized for the processing of resource surveys or forest inventories. The results obtained are very important for management planning in the natural teak forests.

The development of teak plantations involves relatively high capital investment. Therefore it is important to manage these plantations, especially for large scale plantations, under optimum strategies to achieve the maximum benefits (Buongiorno and Teeguarden 1978).

Traditional approaches of applying yield tables in managing plantations have been superceded by growth and yield models developed by appropriate computer based simulation models (Australian Forestry Council 1978). Examples are the development of growth and yield models by Leech (1973, 1978) and the development of a computer data processing aid for management planning of radiata pine plantations in South Australia by Lewis et al. (1976). Furthermore, once the flexible computer based simulation models have been constructed, estimates of growth can be predicted and management strategies optimised with the help of computers. However, the final decision lies with the decision-maker who is supplied with the optimum results for his formulated costs and constraints for various possible strategies.

At present, models for natural teak forests are not applied in Burma. The only available yield table for plantations is that published by Laurie and Ram (1940) which is for both India and in Burma, as there was a lack of sufficient sample plot measurement data for Indian teak. It is not proved that the growth characteristics of teak plantations in India and Burma are the same, therefore the Laurie and Ram (1940) yield tables may not be directly applicable to Burmese plantations. The development of growth and yield models for both natural teak forests and for plantation teak in Burma is therefore necessary. In this study models are developed for plantation teak.

CHAPTER 3

TOP HEIGHT FUNCTIONS FOR BURMESE PLANTATION TEAK

3.1 GENERAL

3.1.1 Definition of Top Height

Top height in Burmese teak plantations is defined as the height of the tree with a diameter equal to the mean of the diameters of the hundred largest trees (by diameter) per acre (approximately 247 trees per ha). One of the alternative definitions for top height is the average height of the one hundred tallest trees per acre but measurements would be much more difficult. The one hundred largest diameter trees are usually the tallest trees in the plantations.

3.1.2 Review of Previous Research

Laurie and Ram (1940) developed a yield and stand table for teak plantations in India and Burma. These tables are the only published yield tables available in Burma. Graphical methods were applied in constructing the tables. Because sufficient data were not available for the highest and lowest site quality classes, neither Baur's method (Spurr 1952) nor the single mean tree method described by Griffith and Prasad(1949) could be applied in constructing these tables. Site quality classifications were therefore based on the top height trends of four arbitrarily divided groups of all sample plot data, so bias is unavoidable (Laurie and Ram 1940). Neither the least squares method nor any other regression method was applied in constructing the yield tables.

Ohn (1967) pointed out that the number of trees per acre (stocking density) and average diameter relationships in Burmese teak plantations provide sufficient control of thinning operations irrespective of site quality classification or thinning strategy. He also pointed out that Laurie and Ram's (1940) tables underestimated the growth of Burmese teak plantations, and demonstrated the application of the number per acre and the average diameter table for the control of thinning instead of the yield tables as directed (Anon 1944) in the Departmental Instructions.

Myint (1967) and Ohn and Myint (1968) reported the results of investigation of the average diameter growth of teak plantations in Burma. These attempts resulted in regression relationships relating the average diameter to the number of stems per acre, average height and age.

Tint and Schneider (1980) developed growth and yield models for plantation teak based mainly on the average diameter growth. They constructed a computer-orientated simulation model for predicting the growth and yield of plantation teak.

This study is based on data from Laurie and Ram (1940) as very little other data are available. Keogh (1979) reported the growth and yield models developed for plantation teak in Trinidad, El Salvador, and Jamaica. His models only predict the growth of teak plantations up to an age of thirty years. Other studies on the growth and yield of teak are based on young plantations subject to first thinnings at various intensities (Prombubpa 1974, Lowe 1976). Thaiutsa and Kaitpraneet (1976) reported the thinning guides based on relationships involving age, average diameter at breast height, and the density of plantation teak. However, his study was based on only 13 sample plots.

3.1.3 Objectives of the Present Study

The objectives of the present study are as follows :-

1) To estimate and select the best model for predicting the growth and yield of Burmese teak plantations;

2) To develop models for simulating the growth of teak plantations under various management strategies as a possible basis for optimising the yield.

3.2 BASIC DATA

The data used in the present analysis consist of the sample plot measurement records reported by Laurie and Ram (1940). There are 326 sample plots of which 221 are in Burma and the rest in India. These sample plots were established in teak plantations of various ages with varying past treatments and initial spacings. The majority of the plots were measured at five year intervals except for a few measured at four to ten years. Most plots were measured two or three times, the maximum number of measurements being four. The data covered thirteen Forest Divisions. The distribution of sample plots by Forest Divisions in Burma is shown in Table 3.1.

TABLE 3.1 NUMBER OF SAMPLE PLOTS BY FOREST DIVISIONS

Forest Division	No of sample plots	No of sample plots: No of measurement(s) per plot 1	2	3	4	No of total measurements
Ataran	10	3	7	-	-	17
Insein	28	4	22	2	-	54
Katha	13	4	6	3	-	25
Magwe	13	-	6	7	-	33
Myitkyina	4	-	2	2	-	10
Prome	23	6	6	11	-	51
Pyinmana	25	2	3	6	14	82
Tharrawaddy	27	5	13	9	-	58
Thaton	19	1	5	13	-	50
Thaungyin	5	2	2	1	-	9
Taungoo	4	1	2	1	-	8
Yamethin	4	-	1	2	1	12
Zigon	46	14	22	10	-	88
Total	221	42	97	67	15	497

Source : Laurie and Ram (1940).

The original data were recorded in Imperial units. Metric conversion has been made and the resulting data in metric units are listed in Appendix I.

The distribution of sample plots and frequency of measurement by site quality classification are shown in Table 3.2. It will be noted that the majority of Burmese sample plots were site quality II and III.

TABLE 3.2 DISTRIBUTION OF SAMPLE PLOTS BY SITE QUALITY

Forest Division	Number of sample plots by SQ I	SQ II	SQ III	SQ IV	SQ V	Total	No of total measurements
Ataran	4	4	2	-	-	10	17
Insein	-	4	23	1	-	28	54
Katha	1	5	5	2	-	13	25
Magwe	-	-	2	9	2	13	33
Myitkyina	1	3	-	-	-	4	10
Prome	2	9	12	-	-	23	51
Pyinmana	2	17	6	-	-	25	82
Tharrawaddy	-	14	11	2	-	27	58
Thaton	-	6	13	-	-	19	50
Thaungyin	1	1	3	-	-	5	9
Taungoo	-	4	-	-	-	4	8
Yamethin	-	4	-	-	-	4	12
Zigon	-	25	11	9	1	46	88
Total Plots	11	96	88	23	3	221	-
Measurements	19	233	194	46	5	-	497

Source : Laurie and Ram (1940).

The distribution of sample plot measurements by age groups is summarized in Table 3.3. Most of the sample plot measurements were made in stands aged less than 50 years.

TABLE 3.3 FREQUENCY OF MEASUREMENT BY AGE GROUPS

Age group	Frequency of measurements
1 - 10	71
11 - 20	118
21 - 30	88
31 - 40	116
41 - 50	68
51 - 60	29
61 - 70	5
71 - 80	2
Total	497

Source : Laurie et al. (1940).

3.3 MODELS SELECTED

Leech (1978) discussed a number of growth and yield models including models developed by von Bertalanffy and Mitscherlich. The general form of the growth model developed by von Bertalanffy (1941, 1942) is sigmoidal or S-shape. On the other hand Mitscherlich's (1910) model is an exponential growth model without inflexion points.

1) von Bertalanffy's model :

$$H = \frac{n}{p}\left[1 - e^{-p(1-m)(A-Ao)}\right]^{\left(\frac{1}{1-m}\right)} \qquad (1)$$

2) Mitscherlich's (1910) model :

$$H = \frac{n}{p}\left[1 - e^{-p(A - Ao)}\right] \qquad (2)$$

where H denotes top height in metres;

A denotes age in years;

Ao is the intercept, that is the age at which top height is indicated as zero;

n,p,m denote the coefficients.

The intercept Ao of these models is practically zero for the top height of teak, thus equation (2) can be rewritten as

$$H = \frac{n}{p}\left[1 - e^{-pA}\right] \qquad (2\ A)$$

These models are simple, flexible and also possess the desired form and a minimum of parameters to estimate. Ferguson (1979) used von Bertalanffy's (1941, 1942) model for estimation of the top height function, and Mitcherlich's (1910) model for gross basal area function, for A.C.T. pine plantations. As data from plantation teak are scanty (Table 3.1) it was considered important to select models with as few parameters as possible to be estimated.

Equation (2 A) can be written as

$$H = \frac{n}{p} - \frac{n}{p} e^{-p A}$$

and

$$n \, e^{-p A} = n - p H \qquad (3)$$

By differentiating (2 A) with respect to A, we get

$$H' = n \, e^{- p A} \qquad (4)$$

where H' is the differential of top height, and

by equating (3) and (4) we get

$$H' = n - p H \qquad (5)$$

By similar differentiation of equation (1), we can show

$$H' = n H^{m} - p H \qquad (6)$$

The parameters n, p, and m of the equations (1), (2) and (2 A) can be estimated by fitting the differentials as shown in equations (5) and (6).

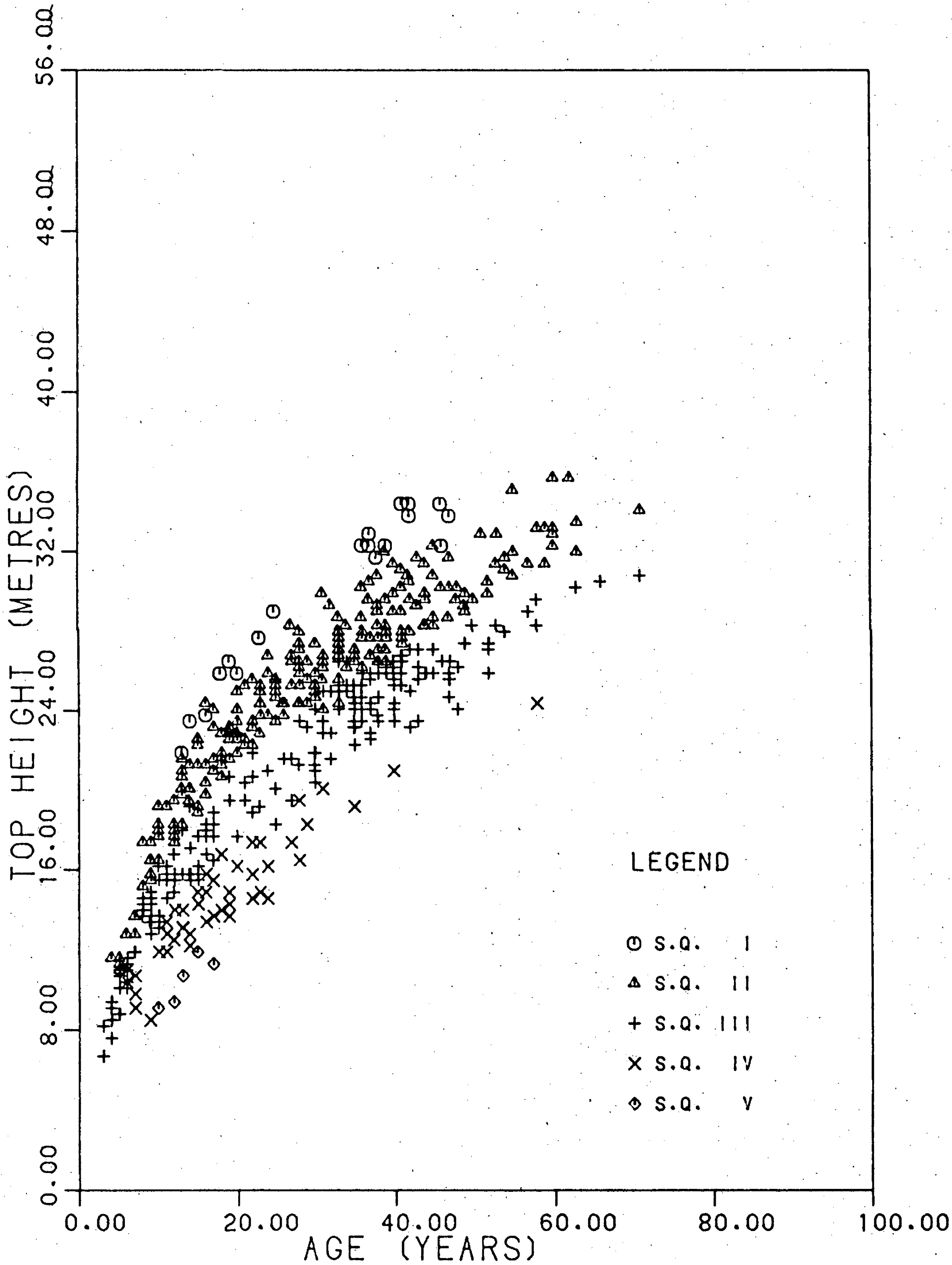
3.4 TOP HEIGHT FUNCTIONS

3.4.1 Top Height Functions by Forest Divisions

Top height measurements for all 221 Burmese sample plots were plotted against age within the old site quality classifications (Figure 3.1).

FIGURE 3.1

TOP HEIGHT OVER AGE OF PLANTATION TEAK



The sample plot measurements for each individual Forest Division varied from 8 to 88 (Table 3.1). There were insufficient measurements to utilize the two stage GLS approach (Miles et al. 1978, Ferguson 1979).

Top height functions were therefore fitted to the pooled data from all plots and the parameters of models (1) and (2 A) estimated using program NLPE (Bard 1967) for each Division separately. The results are summarized in Appendix II and indicate that the parameter m of model (1) which represents the point of inflexion was not significantly different from zero at the 95 % probability level. The results also confirm that the data for individual Divisions could not be fitted separately because there were too few observations and the resulting regressions are clearly not significantly different from one another. Thus all the data for all Divisions were pooled within each site quality class and model (2 A) fitted. The results were again unsatisfactory (see Appendix II for parameters) partly because the old site quality classification seems to be inappropriate and partly because the available data are not evenly distributed over site qualities.

It was therefore decided to re-estimate model (2 A), with the pooled data and also including the site index variable.

3.4.2 Top Height Functions by Rainfall Regions

Gyi (1972) pointed out that the intensity and distribution of rainfall of a region were important for the growth of teak plantations. A climogram of each Division was prepared by plotting the mean monthly temperature against the monthly rainfall. Forest Divisions were then classified into groups with similar climograms, based on the 1979 meteorological data, and shown in Figures 3.2 to 3.4.

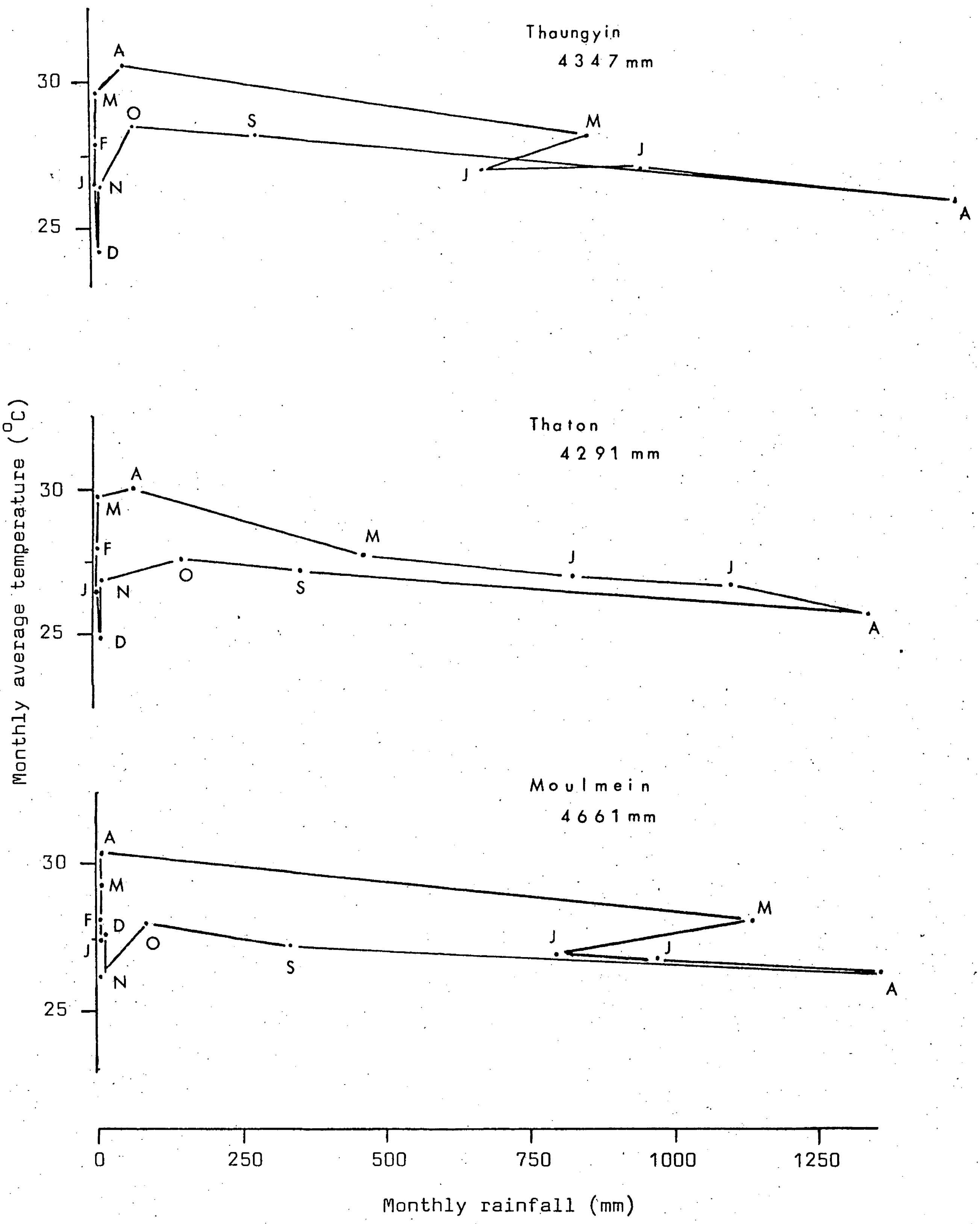


Figure 3.2 Climograms (1979) for heavy rainfall regions.

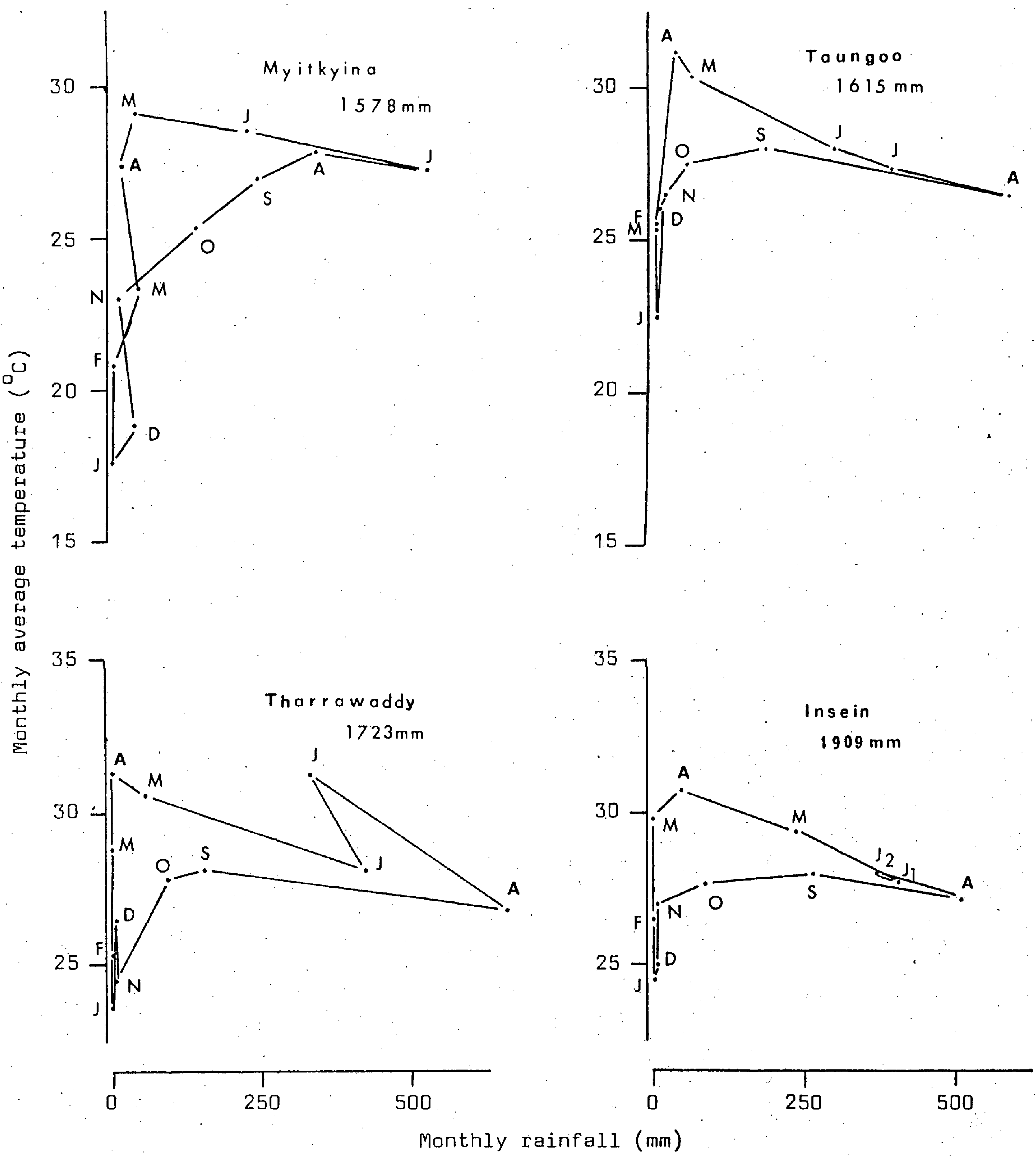


Figure 3.3 Climograms (1979) for medium rainfall regions.

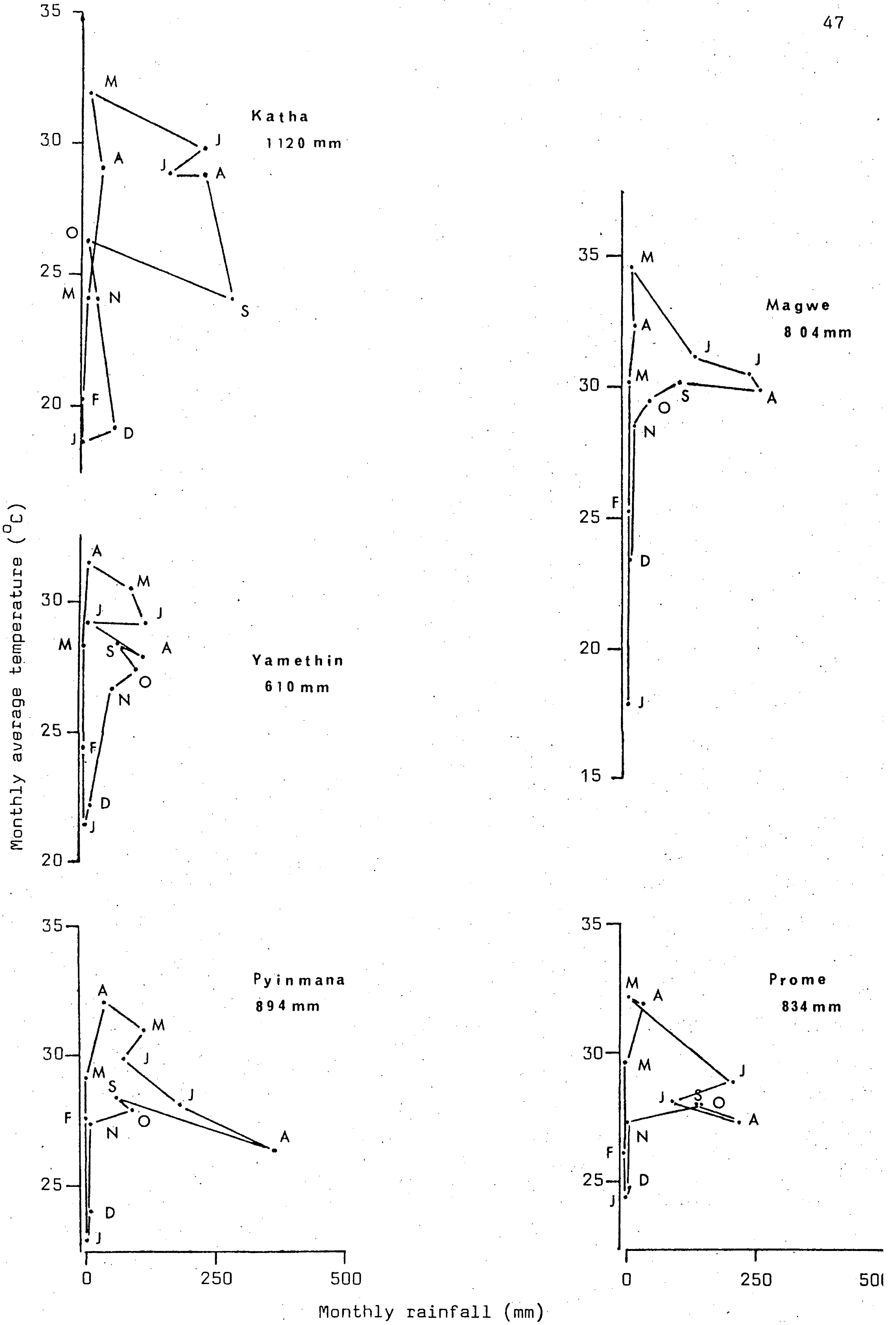


Figure 3.4 Climograms (1979) for light rainfall regions.

Forest Divisions were grouped into three rainfall regions as follows :-

I Heavy rainfall region

1. Thaungyin Forest Division
2. Thaton F.D.
3. Moulmein F.D.

II Medium rainfall region

1. Myitkyina Forest Division
2. Taungoo F.D.
3. Tharrawaddy F.D.
4. Insein F.D.

III Light rainfall region

1. Katha Forest Division
2. Yamethin F.D.
3. Pyinmana F.D.
4. Magwe F.D.
5. Prome F.D.

Top height at specific age was adopted as the site index for teak. Tint and Schneider (1980) adopted the age of 80 years as the specified age. Carron (1968) suggested using an age of two thirds the rotation age. Teak plantations are expected to have a rotation of 80 to 100 years and an age between 40 to 60 years could thus be adopted.

The majority of the sample plots span ages of 20 to 50 years (Table 3.3). Two possible ages, 20 or 40 years, were selected as standard age for site index. Graphs of top height against age were prepared for each Forest Division and values of top height at age 20 or 40 interpolated for the sample plot covering ages 20 or 40 years. These values providing starting estimates of site index for each plot for each of two definitions of site index.

Earlier regressions indicated that model (2 A) was more appropriate to the data :-

$$H = \frac{n}{p} [1 - e^{-p A}] \qquad (2\ A)$$

It can also be expressed in the differential form :

$$H' = n e^{- p A} \qquad (4)$$

According to the definition, site index (S) is the top height at a specified age. If the age is 20 years, then

$$S = \frac{n}{p} [1 - e^{-p\ 20}] \qquad (7)$$

and by transposing (7), we get

$$n = \frac{p\ S}{(1 - e^{-p\ 20})}$$

By substituting n in (2 A) and (4) we get

$$H = \frac{S\ (1 - e^{-p A})}{(1 - e^{-p\ 20})} \qquad (8)$$

$$H' = \frac{p\, S\, (e^{-p A})}{(1 - e^{-p\, 20})} \qquad (9)$$

By transposing (8) we can get a relationship for estimating site index :

$$S = \frac{H\, (1 - e^{-p\, 20})}{(1 - e^{-p A})} \qquad (10)$$

Similarly, the relationships for an age of 40 years can be obtained as follows.

$$H = \frac{S\, (1 - e^{-p A})}{(1 - e^{-p\, 40})} \qquad (11)$$

$$H' = \frac{p\, S\, (e^{-p A})}{(1 - e^{-p\, 40})} \qquad (12)$$

$$S = \frac{H\, (1 - e^{-p\, 40})}{(1 - e^{-p A})} \qquad (13)$$

These models involve only one parameter to estimate. The values of the differentials of top height (H') were approximated by the values of the periodic mean annual increment.

The mean annual increments in top height for the sample plots were plotted against age for each rainfall region to see the relationships (Figures 3.5, 3.6 and 3.7). Annual increment was negatively related to age.

FIGURE 3.5

MEAN ANNUAL HEIGHT INCREMENT
HEAVY RAINFALL REGION

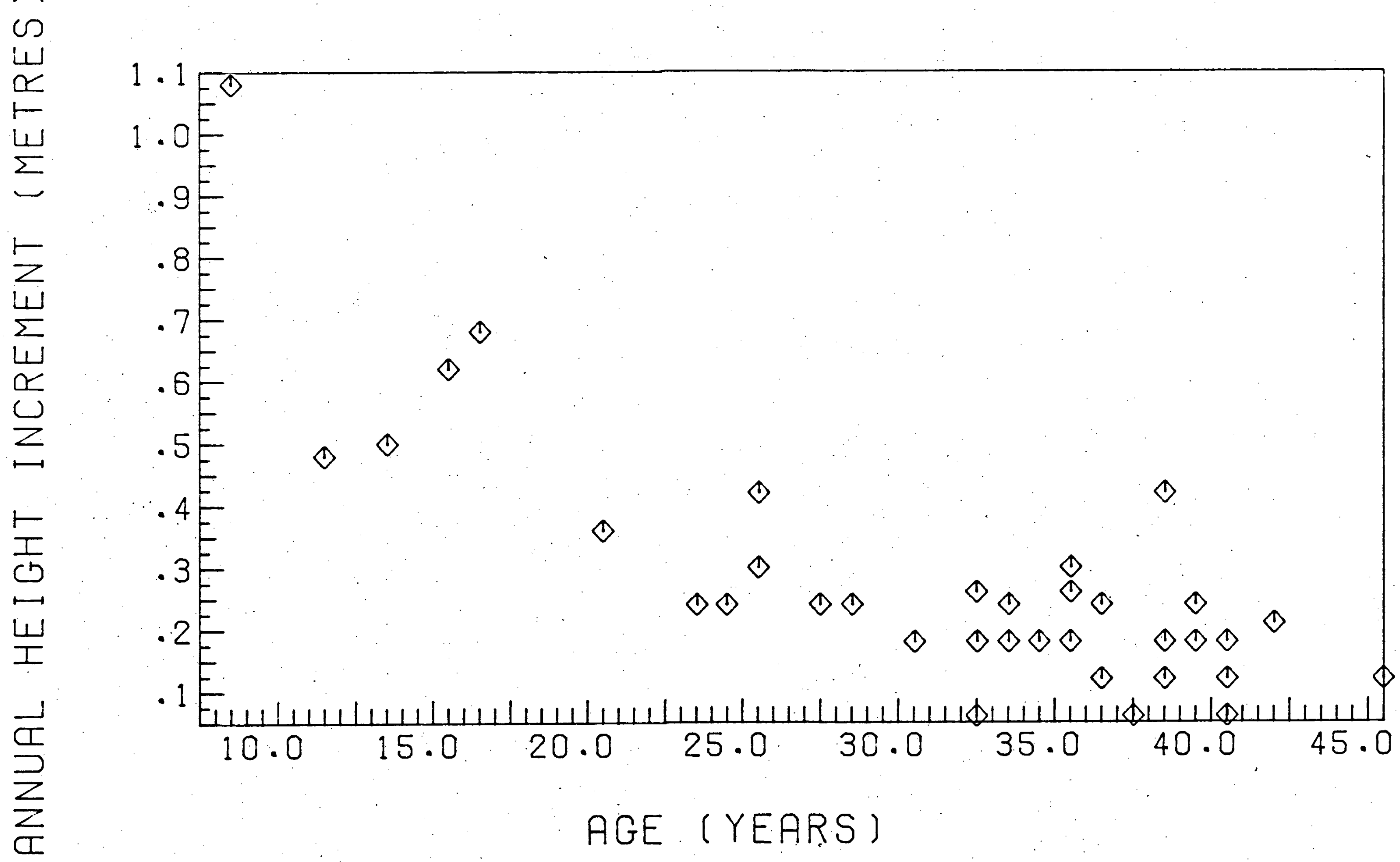


FIGURE 3.6

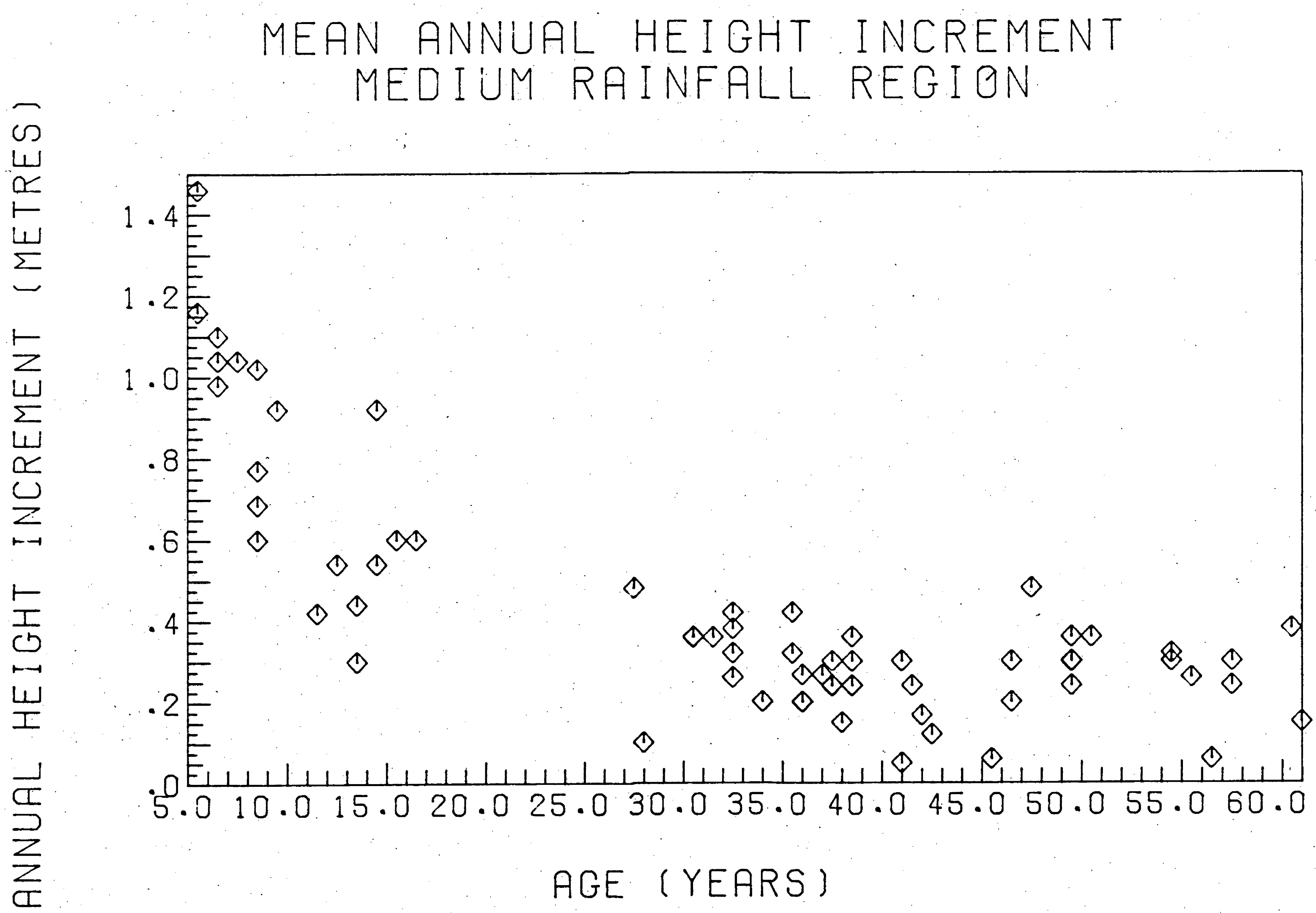
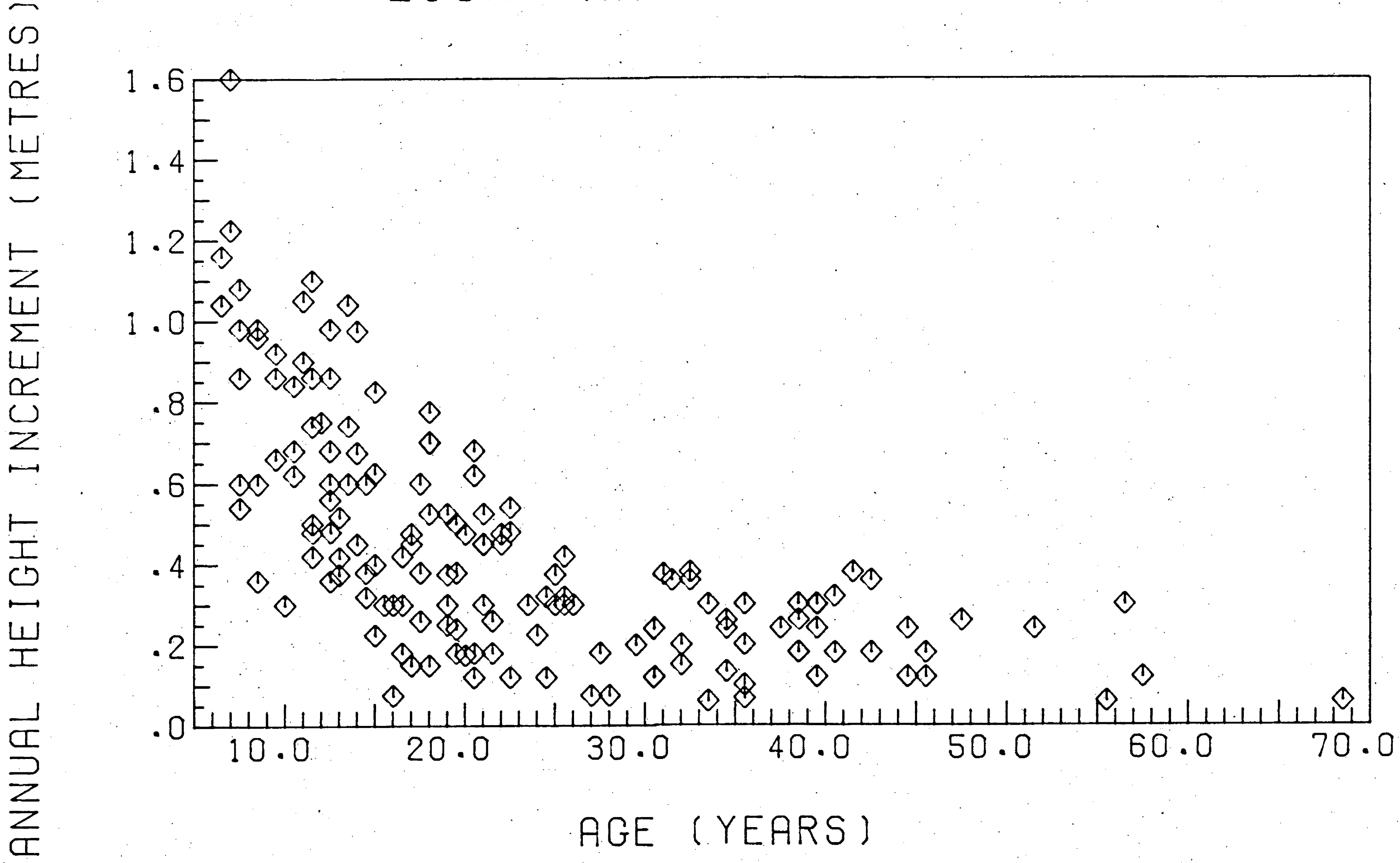

MEAN ANNUAL HEIGHT INCREMENT
MEDIUM RAINFALL REGION
ANNUAL HEIGHT INCREMENT (METRES)
1.4
1.2
1.0
.8
.6
.4
.2
.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
AGE (YEARS)

FIGURE 3.7

MEAN ANNUAL HEIGHT INCREMENT
LIGHT RAINFALL REGION



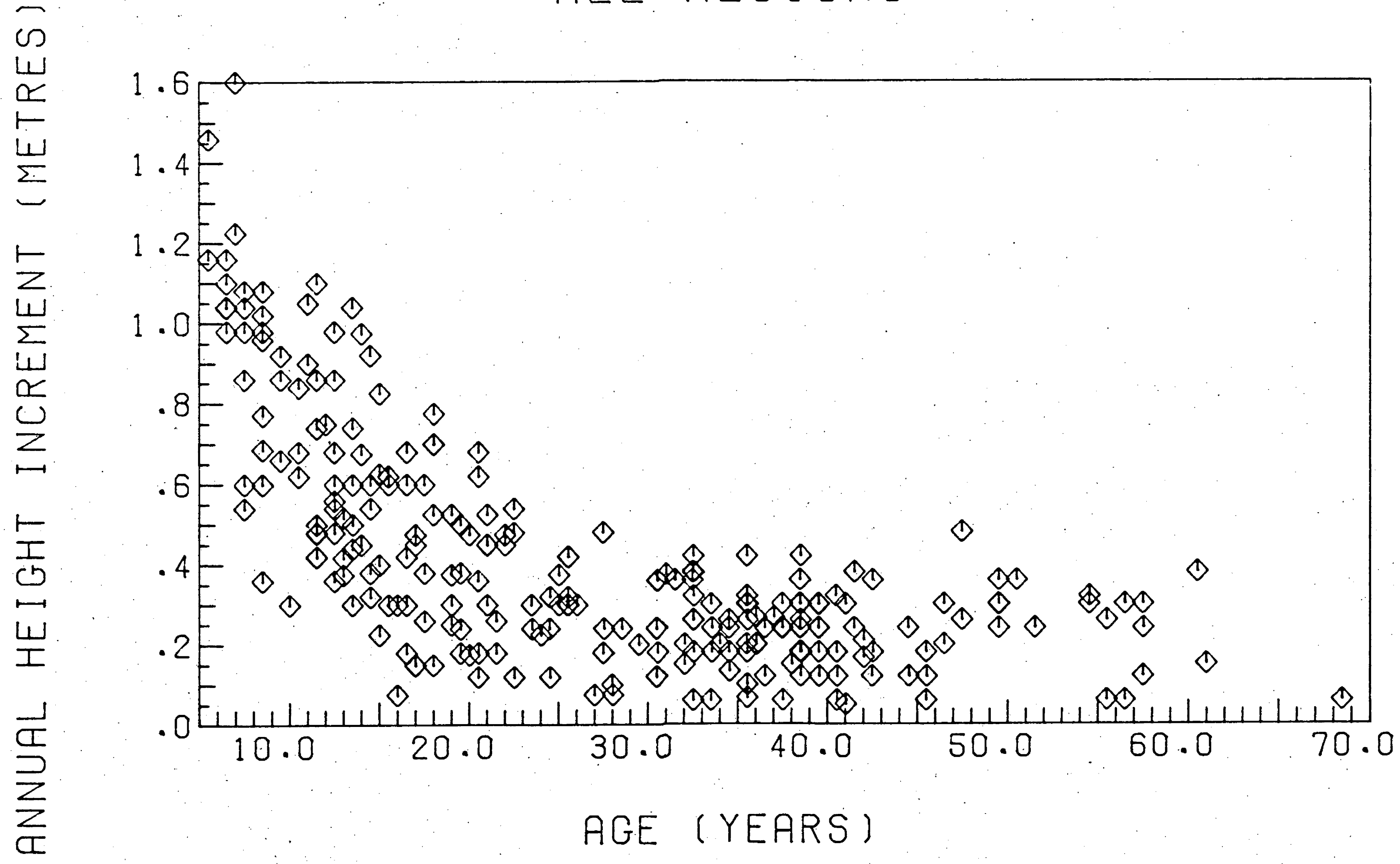
Models (9) and (12) were fitted using NLPE (Bard 1967) for each rainfall region. In the initial run, only the measurements where the site index values could be interpolated from the graph (Figure 3.1) were included. The resulting estimate of the parameter p was then used to estimate the site index values of all sample plots. Using the resulting site index values, a new estimate of the parameter p was made. This process was repeated until the value of the parameter p converged.

The results for the parameter p after convergence are summarized in Appendix III. The resulting top height functions for a base age of 20 years implied that asymptotic values of top height were reached by about age 40 years. This behaviour is not consistent with the annual height growth as plotted in Figures 3.5 to 3.7 for there is still significant height growth at older ages. Equation (12) with a base age of 40 years was more appropriate in that there is a gradual height increment even at older ages. Nevertheless, at this stage both models were retained pending tests on the differences between rainfall regions.

Significance tests were made for differences between the top height functions for the three rainfall regions for both Models (8) and (11) as shown in Appendix III. The difference between the regional top height functions with the base age 20 years was not significant. Therefore a general function for all regions should be developed. On the other hand the difference between the regional top height functions with a base age of 40 years was found highly significant (Appendix III). However as the available data were not evenly distributed between the rainfall regions, it is suggested that the regional top height functions should be developed only when sufficient data becomes available in the future. In both cases it is to be noted that teak appears to grow best in the medium rainfall region, because the parameter p, which represents

FIGURE 3.8

MEAN ANNUAL HEIGHT INCREMENT
ALL REGIONS



decay rate, is the lowest for that region (Appendix III). Finally, because of the lack of data for each rainfall region, it was decided to develop a general top height function for all the regions.

3.4.3 A General Top Height Function

The functions for the base age 20 for the three rainfall regions were not significantly different and a general function for base age 20 for all the plantations in Burma was therefore computed. The same procedure as discussed in Section 3.4.2 was adopted. Annual top height growth is plotted against age for all rainfall regions in Figure 3.8. Model (9) was fitted to the data for a base age of 20 years as before :-

$$H = \frac{S\,(1 - e^{-0.0985\ A})}{(1 - e^{-0.0985 \times 20})} \qquad (14)$$

the parameter p = 0.0985
(0.0041)

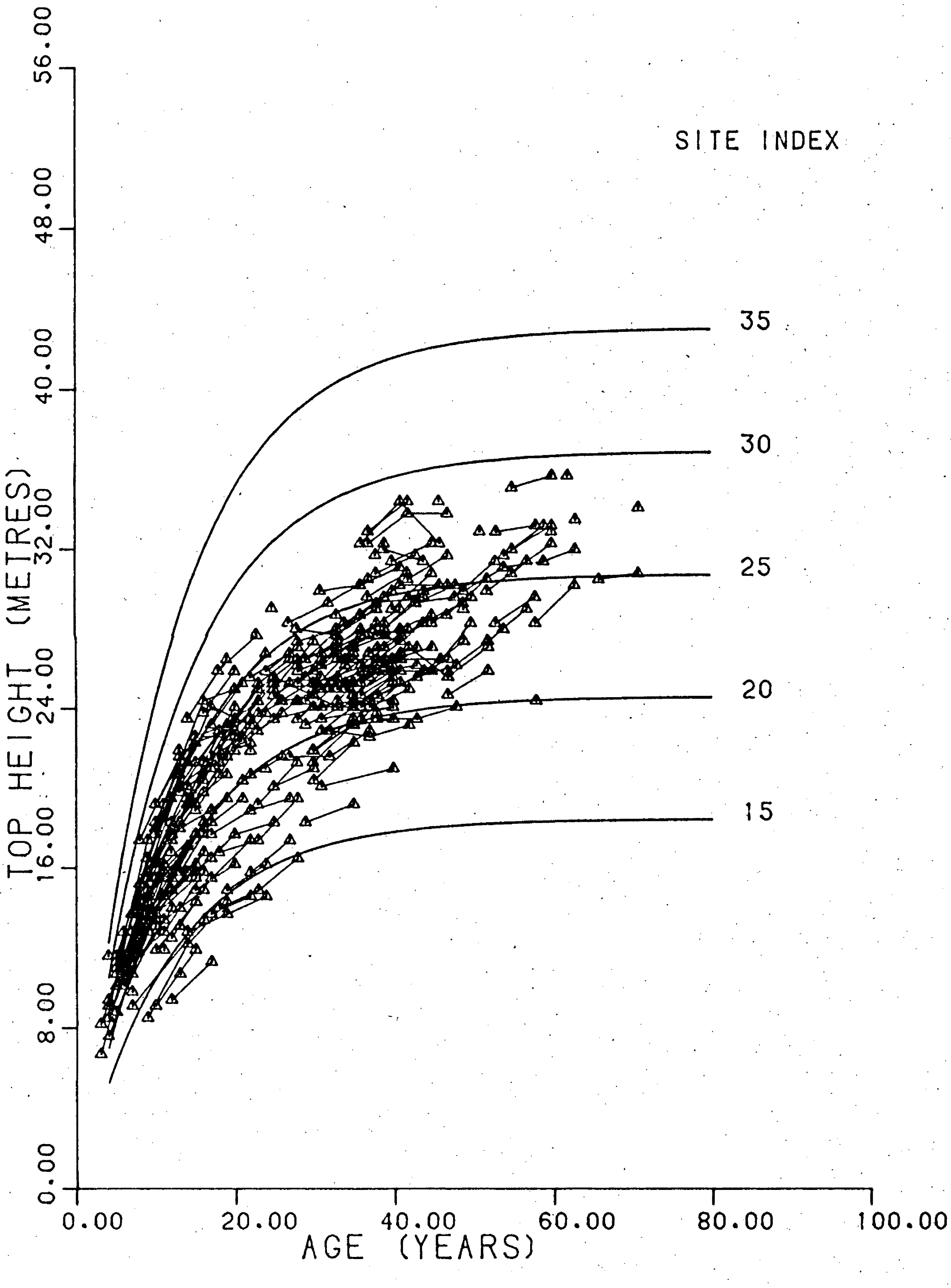
S.E. of regression = 0.1813

Top height curves for various levels of site index were plotted in Figure 3.9 based on the above relationship. Asymptotic values were approached by 40 years of age. Thus the model was rejected.

FIGURE 3.9

SITE INDEX CURVES FOR BURMA PLANTATION TEAK

SITE INDEX AGE 20 YEARS



Although the functions for base age 40 years for the three rainfall regions were significantly different (Appendix III), the available data were not evenly distributed between the rainfall regions and, as suggested previously, it seems advisable to develop regional top height functions only when sufficient data become available. In this study a general function for base age 40 years for all the plantations was therefore computed.

The results for the top height function using a base age of 40 years is given below :-

$$H = \frac{S\,(1 - e^{-0.0338\ A})}{(1 - e^{-0.0338\ \times\ 40})} \qquad (15)$$

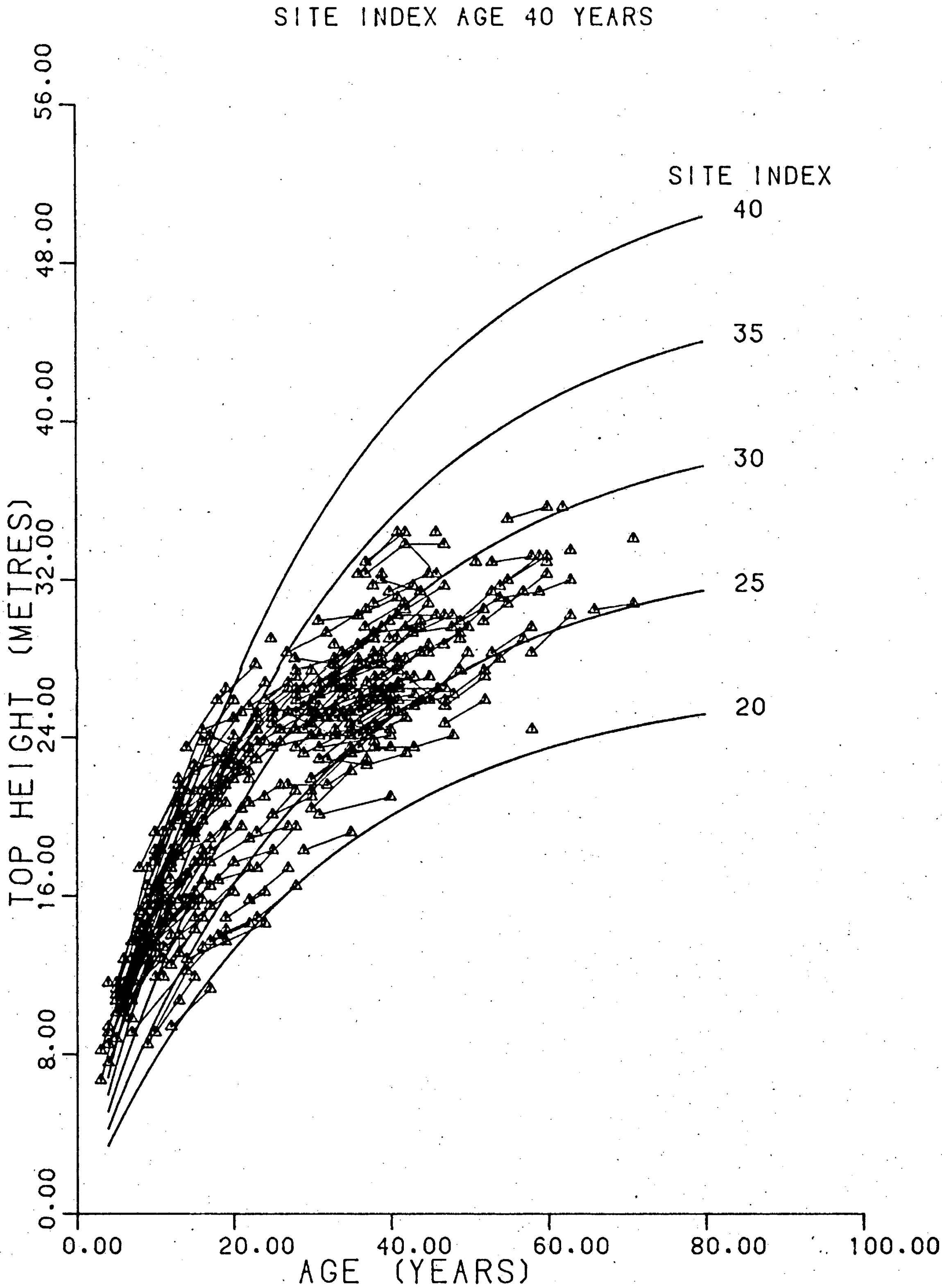
the parameter p = 0.0338
(0.0029)

S.E. of regression = 0.317

Top height curves for various levels of site index based on an age of 40 years are plotted in Figure 3.10. The annual height growth at older ages corresponds with the trends plotted in Figure 3.8. The equation (15) shown above was therefore accepted as the top height function for Burma plantation teak.

FIGURE 3.10

SITE INDEX CURVES FOR BURMA PLANTATION TEAK



CHAPTER 4

BASAL AREA AND VOLUME FUNCTIONS OF BURMESE PLANTATION TEAK

4.1 BASAL AREA FUNCTIONS

Ferguson (1979) reported research on basal area growth in radiata pine plantations. After the research of Ferguson (op cit.) Mitscherlich's (1910) growth model was chosen for fitting the basal area growth of plantation teak. The model is simple, flexible and involves only two parameters to be estimated. The model is as shown below.

$$B = \frac{n}{p}\left[1 - e^{-p(A - Ao)}\right] \qquad (16)$$

where B denotes gross basal area in sq m per ha;

A denotes age in years;

Ao is the intercept, or the age at which the gross basal area is indicated as zero;

n and p denote parameter and constant.

The gross basal area of the plot was not available because past records of thinning were not available. Therefore the parameters were estimated by fitting the differential of the gross basal area as follows.

By differentiating equation (16) we get

$$B' = n \left[e^{-p(A - Ao)} \right] \qquad (17)$$

where B' denotes annual gross basal increment in sq m per ha

By assuming that the asymptotic value (n/p) of a crop varies directly with its site index, and also that the parameter p is constant for various site indices, we get

$$n = b\ S$$

where b is a constant and S denotes the site index.

By substituting the value of n in (17) we get

$$B' = b\ S\ [\ e^{-p(A - Ao)}\ ] \qquad (18)$$

Equation (18) can be further simplified as

$$B' = b^{*}\ S\ [\ e^{-p\ A}\ ] \qquad (19)$$

where $b^{*} = b\ e^{-pAo}$

By studying the basal area data it was found that the intercept Ao was constant with a value of 2 (approx.).

The mean annual basal area increment was computed from the sample plot data. Most data were from measurements at 5 year intervals and the mean basal area increment therefore applies to the mid period of the intervals of 5 years. The resulting mean annual basal area increments were plotted against mid-age as shown in Figure 4.1.

FIGURE 4.1

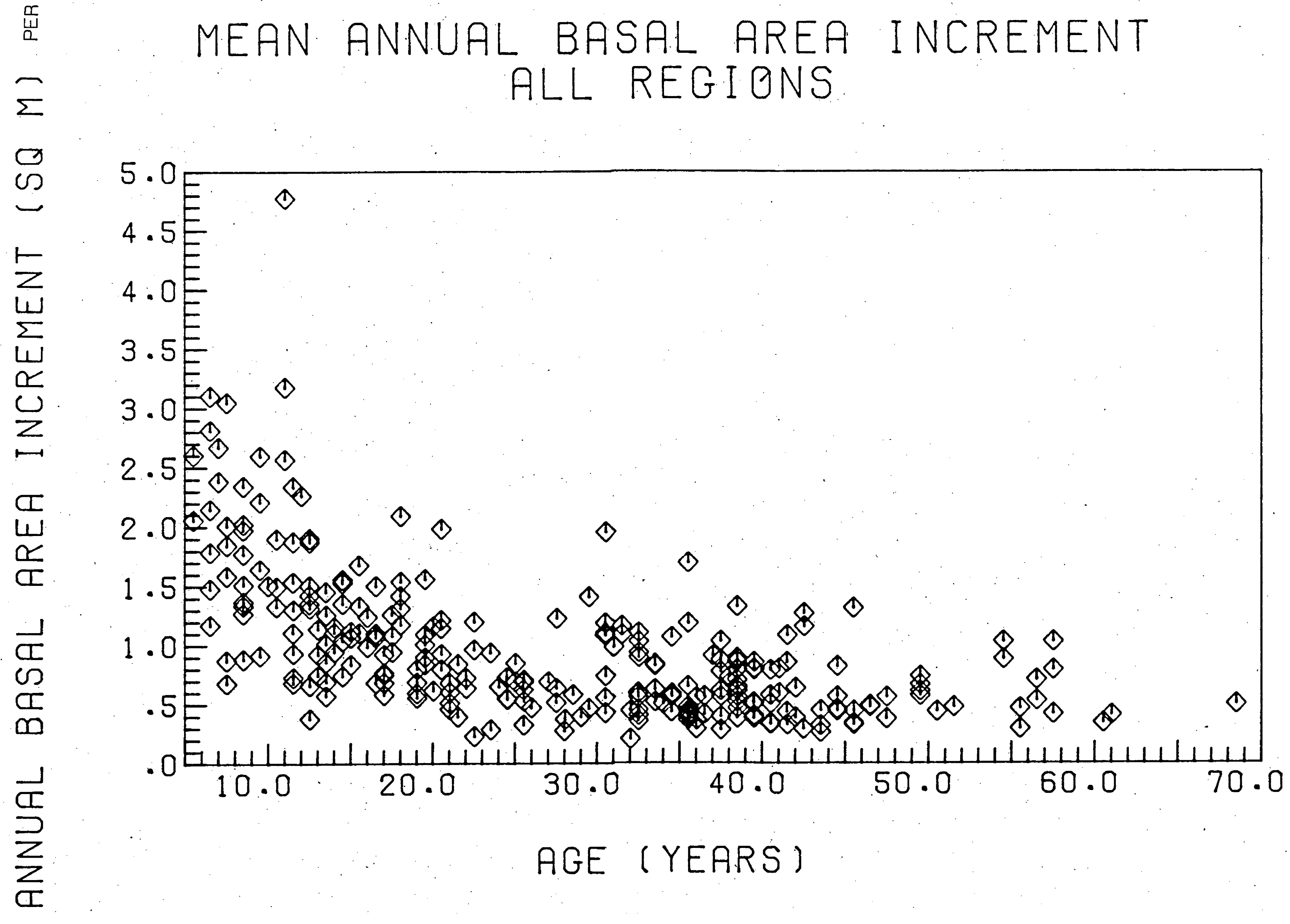

MEAN ANNUAL BASAL AREA INCREMENT
ALL REGIONS
ANNUAL BASAL AREA INCREMENT (SQ M) PER HA
AGE (YEARS)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0

Figure 4.1 shows a clear relationship between the annual basal area increment and age.

Equation (19) was fitted by using NLPE (Bard 1967) resulting in the following function :-

$$B' = 0.0604 \quad S \quad e^{-0.0273 \quad A} \qquad (20)$$

where $b^{*} = 0.0604$
(0.0026)

$p = 0.0273$
(0.0022)

S.E. of regression = 0.3933

The function (20) above is acceptable having coefficients which are significantly different from zero at the 95 % probability level. However, function (20) does not include an allowance for a response to thinning operations. Teak is a light demanding species, and is very sensitive to competition. Ohn (1967) suggested heavier thinnings than C grade were needed such that about 60 % of the basal area was left after thinning. He also pointed out that crops on lower site qualities can have higher growth rates than the higher site quality crops due to heavier thinnings. The underlying assumption that the same rate of growth occurs in both the thinned and unthinned crops in the above function is therefore weak. The inclusion of a thinning index in the basal area growth model was therefore investigated further.

If thinning index is defined as the ratio of the basal area left after thinning to the basal area before thinning, and if T denotes that thinning index such as T = 1.0 when there is no thinning, then it can be incorporated in the model (19) as shown below.

$$B' = b^{*} S \left[e^{-p\left(\frac{A}{T}\right)} \right] \qquad (21)$$

where T is the thinning index and all other symbols are as defined in (19).

$$\text{or } B' = b^{*} S \left[e^{-p(A\,T)} \right] \qquad (22)$$

where all the symbols are as in (21) above.

Model (21) was used by Ferguson (1979) for growth models for radiata pine plantations. As the thinning index T is a reverse factor determining the rate of decay, it implies that the growth rate of pine plantations is slower when more severe thinnings are applied. It also corresponds to the characteristics of pine when there is a definite shock period after thinning. Unlike pine, teak plantations are very responsive to thinnings. Older crops respond very quickly to thinning, the heavier the thinning the faster the rate of growth obtained. No shock period following thinning has appeared. Hence model (22) seems more appropriate than the model (21) for teak plantations. To confirm this hypothesis, both models (21) and (22) were fitted using NLPE (Bard 1967).

The results for model (21) gave a standard error of regression 0.461 which is approximately 18 percent higher than (20). Model (22) on the other hand resulted in a standard error of 0.348 which is about 11 percent lower than (20). Therefore the model equation (22) was accepted, the results obtained are shown below.

$$B' = 0.0611 \; S \; e^{-0.037 \; A \; T} \qquad (23)$$

where $p = 0.037$
(0.0024)

$b^{*} = 0.0611$
(0.0021)

S.E. of the regression = 0.348

Annual basal area increments for various levels of site index and no thinning were plotted in Figure 4.2 based on function (23). Annual gross basal area increment declines with age in Figure 4.2.

The effect of various intensities of thinning on the annual basal area increment for a plantation with a site index of 20 metres is shown in Figure 4.3.

FIGURE 4.2

ANNUAL BASAL AREA INCREMENT BY AGE OF PLANTATION TEAK IN BURMA

FOR VARIOUS SITE INDICES

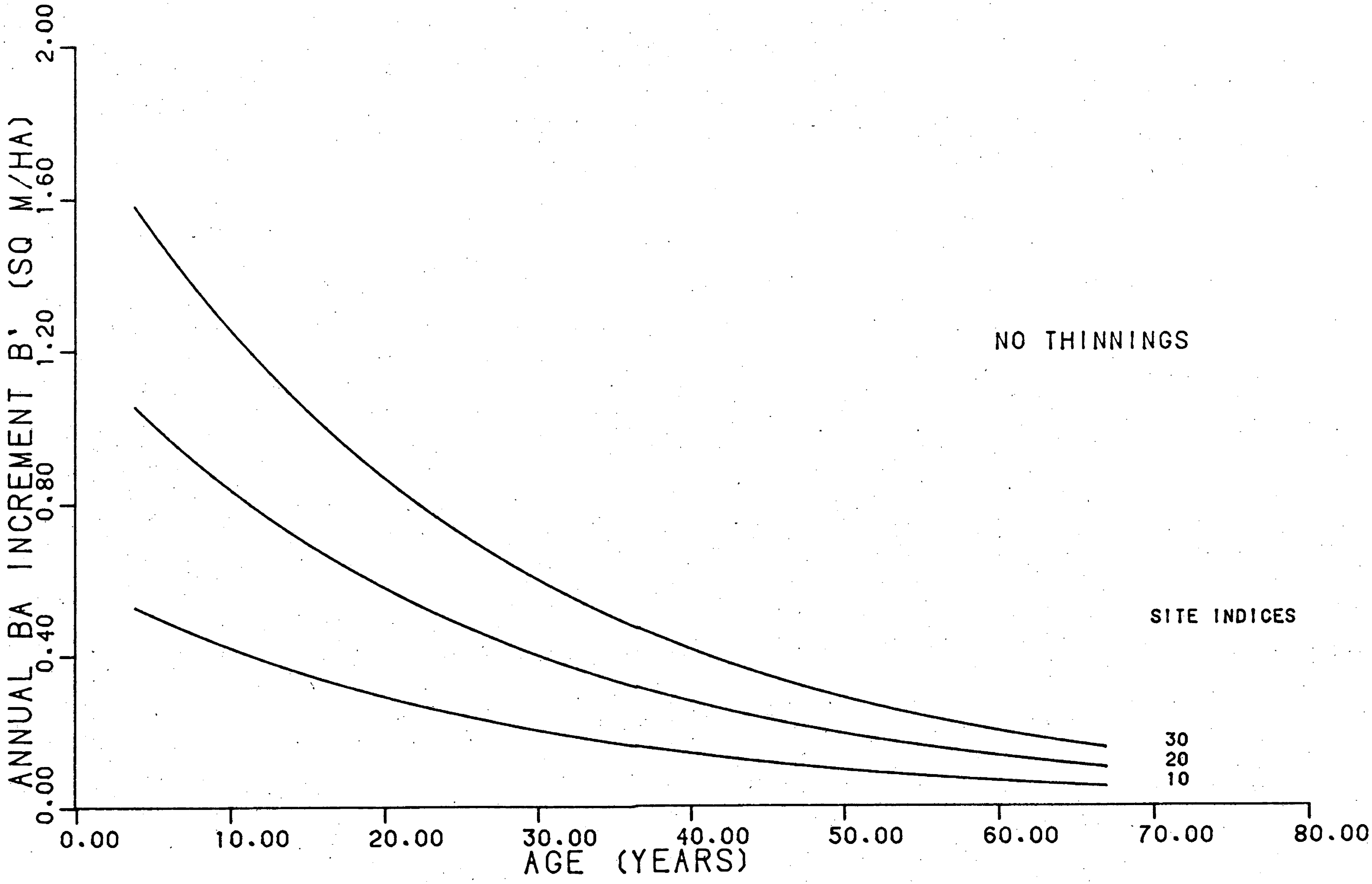
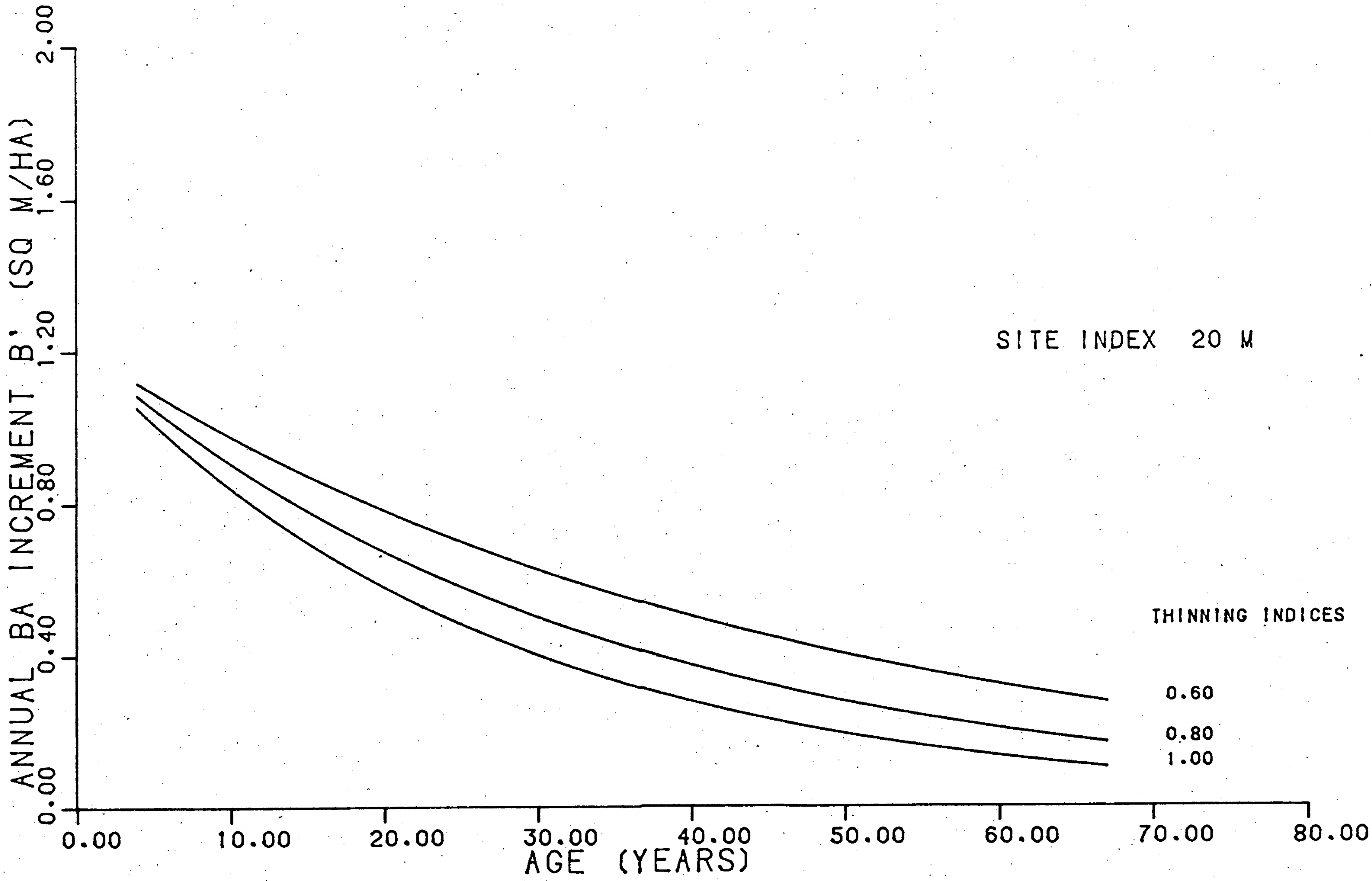


FIGURE 4.3

ANNUAL BASAL AREA INCREMENT BY AGE OF PLANTATION TEAK IN BURMA

FOR DIFFERENT THINNING INTENSITIES



In Figure 4.3 the basal area increment at age 50 is 0.25 sq m per ha for a thinning index 0.8 and 0.45 sq m per ha for a heavier thinning index of 0.6. Basal area increment of a site index 30 m crop at the age of 50 years with no thinning (Figure 4.2) is about the same as the basal area increment for a site index 20 m crop when thinned to the thinning index of 0.8 at the same age. At age 50 years, a site index 20 m crop thinned to 0.6 thinning index (Figure 4.3) has a much higher basal area increment than a site index 30 m crop with no thinning. These findings seem sensible because heavier thinning intensities of 60% have been advocated in order to achieve faster rates of growth in Burma teak plantations (Ohn 1967).

Because of the nature of data used in this study, the basal area increment obtained by the relationship (23) is to be applied for predictions over a 5 year interval. If there are no thinnings in the next 5 years then the annual basal area increment is to be reduced to the rate of growth without thinning. To prevent the sharp drop in increment rates, the averages have been taken after the period of 5 years if there is no thinning.

4.2 STAND VOLUME FUNCTIONS

Laurie and Ram (1940) developed a crop form factor to calculate the volume of the main crop. Although they were satisfied with the form factors of the main crop, they were not able to develop the appropriate form factors for the thinnings due to high variation in the data. They had to make rough estimates of the form factors for estimating the volume of thinnings. The same approach was taken in the present study as no other data were available.

The form factor of the main crop volume to a diameter limit of 8" over bark (approx. 20 cm) was plotted against site quality and age in Figure 4.4. Site qualities SQ I, SQ II, SQ III, and SQ IV correspond to roughly site indices of 35 m, 30 m, 26 m and 20 m respectively. Thus form factor seems to be a function of site index and age, and the following functions were fitted using GLIM (Baker and Nelder 1978).

$$F = a + bS + cA \qquad (24)$$

$$F = a + bS + cA + dA^2 \qquad (25)$$

$$F = a + bS + cA + dA^2 + eA^3 \qquad (26)$$

$$F = a + bS + cA + fS^2 \qquad (27)$$

$$F = a + bS + cA + dA^2 + fS^2 \qquad (28)$$

$$F = a + bS + cA + gSA \qquad (29)$$

$$F = a + bS + cA + dA^2 + gSA \qquad (30)$$

For equations (24) to (30), the symbols represent :

F = form factor;

S = site index in metres with base age 40 years;

A = age of plantation;

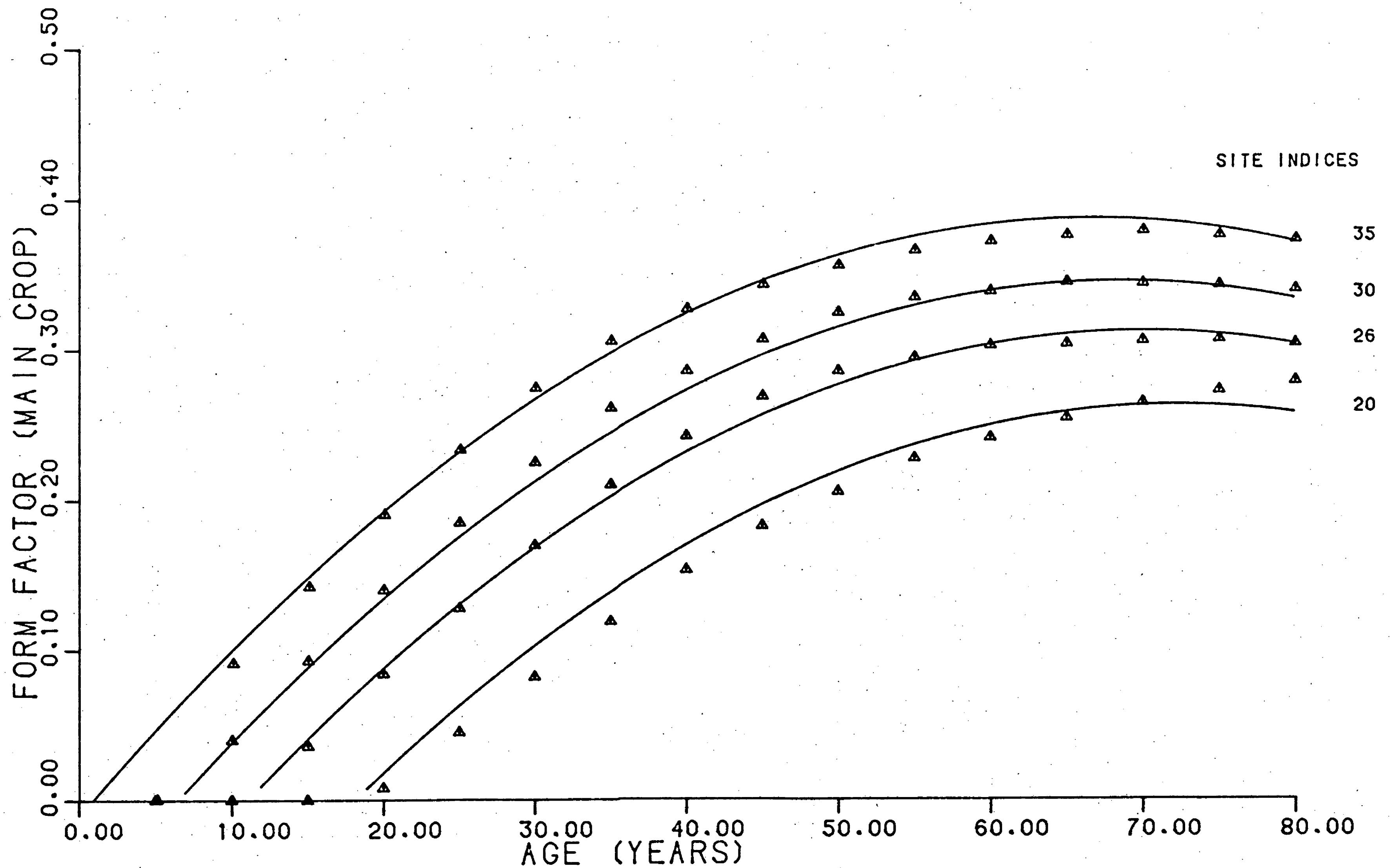
a, b, c, d, e, f, & g are constant and coefficients.

The function (30) gave the best fit based on the residual sum of squares (see Appendix IV). The parameters for other regressions from (24) to (30) are also listed in Appendix IV.

FIGURE 4.4

STEM TIMBER FORM FACTOR (MAIN CROP) OF PLANTATION TEAK IN BURMA

FOR VARIOUS SITE INDICES



The function (30) is accepted for estimating the volume of the crops. The estimates for the accepted function (30) can also be shown below.

$$F = -0.466 + .013\,S - .000068\,S\,A + .0143\,A - .0000897\,A^2 \qquad (31)$$
$$\quad (0.021) \quad (.0006) \quad (.0000136) \quad (.0005) \quad (.0000036)$$

S.E. of the regression = .00158

The relationship of form factor to age and site index is plotted in Figure 4.4 based on equation (31).

4.3 MORTALITY

There is no literature reporting on mortality in teak plantations. Laurie and Ram (1940) did not mention mortality, and it is assumed that there was no mortality when thinnings were carried out at short intervals. Unsound teak trees, including the diseased and suppressed trees, are felled during thinning and included in thinning yields rather than mortality. Tint and Schneider (1980) adopted the mortality rates of natural forests in their study of plantation teak but these seem inappropriate. For example a teak plantation with an initial spacing of 6' X 6' (approx. 2m X 2m) was found in Zigon Forest Division. The plantation had been left untreated due to the out-break of World War II and when found it was 60 years old but the planted trees had all survived although they were very small. Thus in this study, mortality was assumed to be zero. Future studies of mortality, especially in younger stands, would be desirable to confirm this assumption and to provide data from which a mortality function might be developed.

CHAPTER 5

MANAGEMENT PLANNING BASED ON COMPUTER SIMULATION MODELS

5.1 COMPUTER SIMULATION MODELS FOR TEAK PLANTATIONS

Computer simulation models are now widely used for management planning of plantations in Australia (Australian Forestry Council 1978, Myint 1979). A simulation model for management planning of pine plantations in New South Wales has been reported by McMullan (1978) and Wilson (1978). The APM Forests Pty. Ltd. also developed computer simulation models (Hall 1974, Dargavel et al. 1975, and Turner et al. 1977). Management planning of the softwood plantations of the Victorian Forests Commission with the aid of computer simulation models is also reported (Gibson et al. 1971, Opie 1972, Wild 1979 and Tregonning and Aeberli 1979). Simulation models were also developed by Leech (1973, 1978) for management planning in South Australia as reported by Lewis et al. (1976).

The growth and yield models developed in Chapter 3 and Chapter 4 can be used to construct a stand simulation model. The top height function, equation 15 (Chapter 3), can be used for estimating site index as well as for predicting the top height at any age. A simple computer program has been prepared which tabulates the top height for various ages and given site index as shown in Table 5.1. A copy of the program is attached in Appendix V. Annual basal area increment of a plantation can be estimated by means of equation 23 (Chapter 4) given the values of thinning intensity to be used and site index. Basal area at any age can thus be derived by summing annual increments and adding

TABLE 5-1

TOP HEIGHT BY SITE INDEX OF PLANTATION TEAK

IN BURMA

AGE	TOP HEIGHT (METRES)														
	SITE INDEX														
	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5
5	1.6	2.1	2.6	3.1	3.7	4.2	4.7	5.2	5.8	6.3	6.8	7.3	7.9	8.4	8.9
10	2.9	3.9	4.8	5.8	6.8	7.7	8.7	9.7	10.6	11.6	12.6	13.5	14.5	15.5	16.4
15	4.0	5.4	6.7	8.0	9.4	10.7	12.1	13.4	14.8	16.1	17.4	18.8	20.1	21.5	22.8
20	5.0	6.6	8.3	9.9	11.6	13.3	14.9	16.6	18.2	19.9	21.5	23.2	24.9	26.5	28.2
25	5.8	7.7	9.6	11.5	13.5	15.4	17.3	19.2	21.2	23.1	25.0	26.9	28.9	30.8	32.7
30	6.4	8.6	10.7	12.9	15.0	17.2	19.3	21.5	23.6	25.8	27.9	30.1	32.2	34.4	36.5
35	7.0	9.4	11.7	14.0	16.4	18.7	21.1	23.4	25.7	28.1	30.4	32.8	35.1	37.4	39.8
40	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5
45	7.9	10.5	13.2	15.8	18.4	21.1	23.7	26.4	29.0	31.6	34.3	36.9	39.5	42.2	44.8
50	8.3	11.0	13.8	16.5	19.3	22.0	24.8	27.5	30.3	33.0	35.8	38.5	41.3	44.0	46.8
55	8.5	11.4	14.2	17.1	19.9	22.8	25.6	28.5	31.3	34.2	37.0	39.9	42.7	45.5	48.4
60	8.8	11.7	14.6	17.6	20.5	23.4	26.4	29.3	32.2	35.1	38.1	41.0	43.9	46.9	49.8
65	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0	39.0	42.0	45.0	48.0	51.0
70	9.2	12.2	15.3	18.3	21.4	24.4	27.5	30.6	33.6	36.7	39.7	42.8	45.8	48.9	51.9
75	9.3	12.4	15.5	18.6	21.7	24.8	27.9	31.0	34.1	37.3	40.4	43.5	46.6	49.7	52.8
80	9.4	12.6	15.7	18.9	22.0	25.2	28.3	31.5	34.6	37.8	40.9	44.0	47.2	50.3	53.5

the value to the initial basal area. The volume of timber can be predicted by the form factor relationship, equation (31), (Chapter 4). Because insufficient data were available, the volume of thinnings could not be estimated accurately. Based on the natural teak volume tables for sound and unsound trees (Silviculturist 1917), the form factor for the volume of thinnings was assumed to be 80 % of that for the main crop. However, the volume function of the thinnings requires further research.

A simple computer simulation model for teak plantations in Burma has been prepared, based on the functions estimated and presented in earlier Chapters and as shown in Appendix VI. The computer program requires the following information to be provided to initiate a simulation run :-

(1) Age in years.
(2) Thinning index.
(3) Initial basal area in sq m per ha.
(4) Top height in m.
(5) Site index.

The first three data fields must be supplied, and either top height in field 4 or site index in field 5 must be given. Following the first record, successive records describing the age and thinning index of the next thinning must be supplied. Stands comparable in initial specification with site qualities I and III of the yield tables by Laurie and Ram (1940) have been simulated by the program and the results are reproduced in Tables 5.2 and 5.3 respectively. Total basal area at age 80 years by the yield tables of Laurie and Ram, (1940) for site qualities I and III are equivalent to 65.8 and 43.6 sq m per ha, so the agreement between the yield tables and the simulation model is fairly close (Tables 5.2 and 5.3).

TABLE 5-2 Simulation of a S.Q.I plantation with old thinning strategy.

GROWTH AND YIELD OF PLANTATION TEAK IN BURMA

SITE INDEX = 35.0 (METRES)

AGE	TOP HEIGHT	FINAL CROP		MAIN CROP		THINNINGS		CUMULATIVE THINNING YIELD		GRAND TOTAL YIELD	
		B.A.	VOL.	B.A.	VOL.	B.A.	VOL.	B.A.	VOL.	B.A.	VOL.
YR	M	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA
10	14	20.6	27.0	13.6	19.1	7.0	7.9	7.0	7.9	20.6	27.0
15	20	21.4	58.3	15.8	45.5	5.6	12.8	12.6	20.7	28.4	66.2
20	24	22.4	98.2	17.9	81.9	4.5	16.4	17.0	37.0	34.9	118.9
25	28	23.3	144.0	20.0	127.4	3.3	16.6	20.3	53.6	40.3	181.1
30	30	24.4	194.4	22.0	178.5	2.4	15.9	22.7	69.5	44.7	248.0
35	33	25.6	245.5	23.3	227.5	2.3	18.0	25.0	87.5	48.3	315.0
40	35	26.2	291.7	24.1	272.8	2.1	19.0	27.1	106.5	51.3	379.2
45	37	26.6	331.6	24.7	312.8	1.9	18.8	29.0	125.3	53.7	438.1
50	38	26.8	363.8	24.9	343.2	1.9	20.7	30.9	146.0	55.8	489.1
55	39	26.6	385.7	24.8	363.8	1.9	21.9	32.7	167.9	57.5	531.7
60	40	26.2	397.4	24.4	374.9	1.8	22.6	34.6	190.5	59.0	565.3
65	41	25.6	399.5	23.8	376.8	1.8	22.7	36.4	213.1	60.2	590.0
70	42	24.9	392.9	23.1	370.6	1.7	22.3	38.1	235.5	61.2	606.0
75	42	24.0	377.9	22.1	353.3	1.9	24.6	40.0	260.0	62.1	613.4
80	43	22.8	359.7	22.8	359.7	.0	.0	40.0	260.0	62.8	619.7

TABLE 5-3 Simulation of a S.Q.III plantation with old thinning strategy.

GROWTH AND YIELD OF PLANTATION TEAK IN BURMA

SITE INDEX = 26.0 (METRES)

AGE	TOP HEIGHT	FINAL CROP		MAIN CROP		THINNINGS		CUMULATIVE THINNING YIELD		GRAND TOTAL YIELD	
		B.A.	VOL.	B.A.	VOL.	B.A.	VOL.	B.A.	VOL.	B.A.	VOL.
YR	M	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA
10	11	14.2	.0	9.2	.0	5.0	.0	5.0	.0	14.2	.0
15	14	15.0	8.3	11.7	6.7	3.3	1.5	8.3	1.5	20.0	8.3
20	18	16.5	24.5	13.7	21.0	2.8	3.4	11.1	5.0	24.7	26.0
25	20	17.6	45.2	15.1	40.0	2.5	5.2	13.5	10.2	28.7	50.2
30	23	18.4	68.3	16.4	62.1	2.0	6.1	15.6	16.3	31.9	78.4
35	24	19.0	92.2	17.3	85.4	1.7	6.8	17.3	23.1	34.6	108.5
40	26	19.5	115.4	18.2	108.9	1.4	6.6	18.6	29.6	36.8	138.5
45	27	20.0	137.0	18.6	129.2	1.4	7.8	20.0	37.4	38.6	166.6
50	28	20.1	154.7	18.9	147.2	1.2	7.5	21.3	44.9	40.1	192.1
55	29	20.2	168.9	18.9	160.7	1.2	8.2	22.5	53.1	41.4	213.8
60	30	20.0	177.9	18.6	167.8	1.4	10.1	23.9	63.2	42.5	231.0
65	30	19.5	181.2	18.3	172.4	1.2	8.8	25.0	72.0	43.4	244.5
70	31	19.1	181.0	17.7	170.7	1.3	10.3	26.4	82.3	44.1	253.1
75	31	18.4	175.4	17.1	165.5	1.3	10.0	27.7	92.3	44.8	257.8
80	32	17.6	168.8	17.6	168.8	.0	.0	27.7	92.3	45.3	261.0

In practice 10 year thinning intervals are adopted for younger plantations and a 20 year interval for older plantations, together with heavier thinning intensities than those used in the yield tables. A less frequent thinning and heavier thinning intensity with a thinning index of 0.85 was also simulated for a site quality I plantation and the results are summarized in Table 5.4. At age 80 years, the main crop has a basal area of 36.1 sq m per ha (Table 5.4) compared to 22.8 sq m per ha (Table 5.2) for the yield table regime. The volume of the main crop and total yield also increased. Although not shown in the tables, the number of trees per hectare retained in a heavier thinning regime is of course less than that in the lighter thinnings and thus the individual size of the trees in the main crop is larger than in the case of the heavier thinning regime, as would be expected.

This simulation model may be useful in estimating the yields likely to result from different regimes. Development of a similar but improved model is a pre-requisite to any development of optimisation models for planning.

5.2 SIMULATION MODELS FOR NATURAL TEAK FORESTS

Building simulation models for natural teak forests is more complex than for plantation teak. Natural teak forests are usually managed on a polycyclic basis and the teak trees are mixed with many other tropical species. The variation in site productivity and species composition is also very high. Most importantly, little is known about the growth characteristics in relation to the site productivity, the natural environment, or to the treatment. Nevertheless, Tint and Schneider (1980) developed a simulation model for natural teak forests in Burma.

TABLE 5-4 Simulation of a S.Q.I plantation with more heavier thinning strategy.

GROWTH AND YIELD OF PLANTATION TEAK IN BURMA

SITE INDEX = 35.0 (METRES)

AGE	TOP HEIGHT	FINAL CROP		MAIN CROP		THINNINGS		CUMULATIVE THINNING YIELD		GRAND TOTAL YIELD	
		B.A.	VOL.	B.A.	VOL.	B.A.	VOL.	B.A.	VOL.	B.A.	VOL.
YR	M	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA	SQ M/HA	CU M/HA
10	14	20.6	28.1	17.5	24.6	3.1	3.5	3.1	3.5	20.6	28.1
20	24	30.2	134.2	25.7	117.6	4.5	16.6	7.6	20.1	33.3	137.6
30	30	34.8	274.0	29.6	240.1	5.2	33.9	12.8	54.0	42.4	294.1
40	35	36.1	395.8	30.7	346.9	5.4	49.0	18.3	102.9	48.9	449.8
60	40	38.1	568.2	32.4	497.9	5.7	70.3	24.0	173.2	56.4	671.1
80	43	36.1	569.6	36.1	569.6	.0	.0	24.0	173.2	60.1	742.8

Their simulation model is applicable to the inventory data from natural teak forests and is used to determine the yield or annual allowable cut.

At present the inventory data for natural teak forests is derived from two sources :-

(1) Random sampling surveys; and

(2) Complete enumeration during girdling operations.

Random sampling surveys are well developed in Burma (Tin et al. 1973), and the growing stock and species composition of a forest at a certain year can be estimated with reasonable precision for the large areas involved in regional planning. However, these inventories are not precise for small areas of forest; for example, a compartment, a group of compartments or even a felling series. On the other hand, the complete enumeration of teak trees left at the time of girdling provides excellent data for teak in a compartment or part thereof. However, these enumeration data are recorded only at the time of girdling operation, which usually is only once in a thirty year felling cycle. Furthermore, the entire growing stock is not enumerated, smaller teak and all other species being unrecorded. At present these enumeration data are used as the basis for management planning within a Forest Division.

Simulation models for natural teak forests will play an important part in planning once a fully computer-based planning system has been developed. A computer system for processing random sampling survey data of natural teak forests has been already developed (Myint 1976) but management strategies cannot be simulated on inventory data for natural teak forests until simulation models are formulated and developed. The enumeration data could also be automated by designing a computer data file and storing the records, so that they will be applicable for control of management operations at the Divisional or even the forest reserve level.

Moser and Hall(1969) and Moser (1972) showed how to develop growth and yield models for uneven-aged stands. Leary (1970) also identified various systems of stand dynamics and illustrated some models based on systems of differential equations. These methods should be considered in developing the growth and yield models for natural teak forests in Burma.

Consideration should be given to the interim enumeration of teak trees five or ten years after girdling in conjunction with other silvicultural operations at those times. At those times, data should be collected for site classification and species composition. Such data would be very useful for analysis of the growth characteristics of natural teak forest as well as for general management purposes.

5.3 POSSIBLE OPTIMISATION MODELS

In the management of plantations which are far more capital intensive than natural forests, it is important to select the best set of silvicultural regimes while satisfying the various constraints on demand and resources. Optimisation models for the purpose have been illustrated by Ware and Clutter (1971) and Curtis (1962). Dargavel (1978) reported on an optimisation model developed for the pine plantations of APM Forests Pty. Ltd. in Victoria. An optimisation model for yield scheduling in the pine plantations of New South Wales has also been developed by Wilson (1976, 1979). Optimisation models for management of natural forest stands were also reported by Loucks (1964), Paine (1966), Nautiyal and Pearse (1967), and Campbell et al. (1979).

Optimisation models can be developed for both even aged and uneven aged forests. Once the basic growth and yield simulation models are developed, optimisation models can readily be formulated. These models can be very helpful for national level planning. Furthermore, even if the forests are managed under multiple goals and for multiple products, optimisation models can still be developed using the goal programming approach as reported by Navon (1971), Bell (1975), Field (1973, 1978), Rustagi (1976, 1978), and USDA (1977).

Optimisation models involve substantial data processing and may be quite costly. The optimal solutions, however, may lead to much greater efficiencies in terms of economics or production.

The following recommendations are advanced for future research and development of optimisation models directed toward improving the planning of the management of teak forests of Burma :-

(1) Further research is needed to refine growth and yield models for both artificial as well as natural teak forests.

(2) The inventory and enumeration data should be processed by computer and the necessary programs for these developed.

(3) The enumeration system should be restructured to incorporate

further data collection at periodic intervals after a girdling operation.

(4) Simulation models should be applied for regional level planning as they are less costly and simpler than optimisation models.

(5) Optimisation models should be developed for national level forest management planning for the data for national models are available and many practices, for example exploitable girth limits, are standardized nationally. Computers are only accessible at head offices, and this is the main factor which hinders the development of regional optimisation models.

5.4 REVIEW

The computer simulation model (Appendix VI) developed for teak plantations in Burma shows promising results for the future management of the plantations. The model, presented in Chapters 3 and 4, i.e. functions (15), (23) and (31), incorporates site variations and allows for the intensity of thinning. It predicts top height and basal area growth and estimates stand timber volume at any age. The variables required for the control of simulation are very simple and readily obtained by field measurements.

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APPENDIX I
BURMA PLANTATION TEAK SAMPLE PLOT DATA

Average diameter	Number per ha	Top height	Age	Basal area per ha	Volume per ha	Plot Id.			
cm	no	m	yr	sq m	cu m				
28.7	269	29.0	25	17.31	130.08	1	1	1	1
33.5	175	29.6	37	15.59	124.69	1	3	2	2
36.3	124	30.8	42	12.90	133.86	1	3	2	3
22.6	361	25.9	18	14.49	44.43	1	4	1	4
26.7	264	27.7	23	14.65	82.78	1	4	1	5
35.3	158	31.7	38	15.68	157.93	1	5	1	6
22.4	373	24.4	26	14.53	43.94	1	6	2	7
24.4	301	25.6	31	14.10	63.33	1	6	2	8
10.7	1025	13.4	9	9.14	.00	1	7	3	9
13.5	665	15.8	14	9.64	.00	1	7	3	10
41.1	153	34.4	46	20.41	259.74	1	9	1	11
16.0	512	19.5	14	10.26	3.50	1	11	2	12
19.8	346	22.9	19	10.63	18.26	1	11	2	13
20.1	356	19.2	23	11.39	22.60	1	12	3	14
23.1	314	21.3	28	13.13	46.81	1	12	3	15
23.1	329	22.9	23	13.87	46.60	1	13	2	16
25.9	287	24.4	28	15.20	74.94	1	13	2	17
21.3	408	21.9	30	14.72	34.64	2	1	3	18
24.6	237	23.2	35	11.39	45.27	2	1	3	19
21.3	373	21.9	30	13.31	32.68	2	2	3	20
25.1	232	23.5	35	11.57	50.45	2	2	3	21
21.3	403	21.3	30	14.37	34.01	2	3	3	22
24.4	250	23.2	35	11.73	48.63	2	3	3	23
30.0	250	27.4	52	17.63	125.46	2	4	3	24
33.5	163	29.0	57	14.28	122.03	2	4	3	25
35.1	215	29.9	52	20.66	180.46	2	5	2	26
39.1	143	31.4	57	17.40	172.69	2	5	2	27
35.6	175	28.7	47	17.47	153.87	2	7	2	28
38.9	143	30.5	52	17.06	171.43	2	7	2	29
31.0	198	25.9	47	14.92	117.62	2	8	3	30
34.0	163	27.4	52	15.01	141.69	2	8	3	31
29.2	230	25.6	47	15.40	105.17	2	9	3	32
32.5	158	27.1	52	13.25	115.03	2	9	3	33
28.2	225	24.7	47	14.12	80.68	2	10	3	34
31.0	173	25.9	52	13.02	101.39	2	10	3	35
31.7	230	29.3	43	18.30	143.65	2	11	2	36
37.1	138	29.6	48	15.06	155.27	2	11	2	37
39.9	131	31.4	53	16.41	195.29	2	11	2	38
29.7	255	27.1	39	17.54	121.75	2	12	2	39
33.0	168	28.3	44	14.46	121.19	2	12	2	40
35.8	153	29.3	49	15.47	144.56	2	12	2	41
25.7	292	23.5	36	14.60	83.27	2	13	3	42
28.7	208	25.3	41	13.43	99.50	2	13	3	43
24.6	299	24.7	36	14.33	65.63	2	14	3	44
27.9	203	25.9	41	12.42	79.98	2	14	3	45
31.0	183	26.5	41	13.68	105.80	2	15	3	46
23.1	346	24.1	36	14.53	59.41	2	16	3	47
27.9	215	25.3	41	13.15	82.29	2	16	3	48
26.9	250	25.3	36	14.07	86.14	2	17	3	49
30.7	168	26.8	41	12.49	100.41	2	17	3	50
24.1	361	25.3	35	16.62	73.82	2	18	3	51
27.2	222	26.5	40	12.86	76.06	2	18	3	52
25.1	304	25.3	35	14.92	69.97	2	19	3	53
29.0	195	26.5	40	12.90	87.68	2	19	3	54
24.4	321	24.7	35	15.06	61.93	2	20	3	55
27.4	227	26.2	40	13.61	80.26	2	20	3	56
24.6	279	24.7	35	13.15	55.00	2	21	3	57
27.2	200	25.9	40	11.71	66.82	2	21	3	58
36.1	166	28.3	53	16.97	151.49	2	38	3	59
37.6	153	29.6	58	17.17	174.79	2	38	3	60
29.0	203	26.5	40	13.38	95.23	2	39	3	61
30.5	183	27.1	45	13.43	111.12	2	39	3	62
29.5	215	25.9	44	14.58	95.44	2	40	3	63
31.7	188	27.4	49	14.81	116.01	2	40	3	64
38.9	151	28.3	58	17.84	183.61	2	41	3	65
40.6	138	30.2	63	17.98	186.41	2	41	3	66
30.2	203	24.4	58	14.42	95.16	2	42	4	67
31.5	198	25.9	45	15.36	107.34	2	43	3	68
33.3	183	28.3	50	15.93	133.09	2	43	3	69
30.5	217	23.8	38	16.00	102.16	2	44	3	70
36.6	128	28.0	54	13.43	127.84	2	45	3	71

APPENDIX I (contd.)
BURMA PLANTATION TEAK SAMPLE PLOT DATA

Average diameter	Number per ha	Top height	Age	Basal area per ha	Volume per ha	Plot Id.			
cm	no	m	yr	sq m	cu m				
10.7	818	12.8	6	7.21	.00	3	15	2	72
10.2	927	13.7	8	7.64	.00	3	21	3	73
13.7	586	14.9	12	8.52	.00	3	21	3	74
16.3	470	16.5	17	9.83	4.90	3	21	3	75
13.2	929	16.5	9	12.86	.49	3	22	2	76
17.8	529	20.1	13	13.09	8.89	3	22	2	77
21.8	358	21.6	18	13.45	33.10	3	22	2	78
13.0	838	16.2	10	11.11	.00	3	23	3	79
17.5	497	19.2	14	11.89	9.94	3	23	3	80
19.8	343	20.7	19	10.72	22.32	3	23	3	81
22.9	252	23.2	29	10.42	39.88	3	24	3	82
25.7	198	24.4	35	10.15	56.19	3	24	3	83
17.3	395	18.3	29	9.39	7.28	3	25	4	84
18.5	346	19.2	35	9.25	12.46	3	25	4	85
27.2	200	25.3	30	11.62	64.30	3	26	2	86
32.8	171	26.5	39	14.35	107.90	3	26	2	87
21.1	240	22.9	31	10.38	36.39	3	27	3	88
27.9	208	25.6	40	12.67	68.50	3	27	3	89
25.9	173	23.5	31	9.07	47.58	3	28	3	90
30.7	158	24.1	40	11.91	77.25	3	28	3	91
20.3	267	20.1	31	8.68	16.37	3	29	4	92
23.9	242	21.0	40	10.84	37.30	3	29	4	93
19.0	465	21.9	13	13.27	23.02	3	30	1	94
18.5	494	20.1	13	13.20	13.08	3	31	2	95
17.3	549	20.1	14	12.83	8.96	3	32	2	96
7.1	1606	9.1	10	6.36	.00	4	1	5	97
10.2	1090	11.9	15	8.72	.00	4	1	5	98
8.1	1374	12.5	12	7.00	.00	4	2	4	99
11.7	1035	15.5	17	10.93	.00	4	2	4	100
14.2	838	17.4	22	13.41	.00	4	2	4	101
6.6	1779	9.4	12	5.88	.00	4	3	5	102
8.9	1497	11.3	17	9.46	.00	4	3	5	103
9.4	1102	12.8	14	7.83	.00	4	4	4	104
12.4	887	13.7	19	10.72	.00	4	4	4	105
13.5	848	14.6	24	12.21	.00	4	4	4	106
13.7	642	14.9	19	9.53	.63	4	5	4	107
16.5	549	16.2	24	11.57	4.48	4	5	4	108
10.4	934	14.0	18	8.15	.00	4	6	4	109
13.2	692	14.9	23	9.92	.00	4	6	4	110
15.2	551	16.5	28	9.94	.00	4	6	4	111
13.7	657	16.8	18	9.73	.84	4	7	4	112
16.3	465	17.4	23	9.55	2.10	4	7	4	113
17.5	378	19.5	28	9.04	4.83	4	7	4	114
6.3	2098	8.5	9	6.89	.00	4	8	4	115
9.4	1278	12.2	14	8.88	.00	4	8	4	116
11.9	833	14.3	19	9.18	.00	4	8	4	117
10.2	1063	14.9	15	8.70	.00	4	9	4	118
13.0	761	16.2	20	10.12	.00	4	9	4	119
10.7	828	15.8	15	7.48	.00	4	10	3	120
13.7	605	17.7	20	8.84	1.19	4	10	3	121
14.5	524	18.3	25	8.72	2.31	4	10	3	122
14.5	605	17.7	17	10.06	1.33	4	11	3	123
17.5	512	18.9	22	12.26	9.87	4	11	3	124
19.3	408	19.5	27	11.78	17.35	4	11	3	125
11.4	1021	13.7	17	10.42	.00	4	13	4	126
13.5	875	14.6	22	12.60	.00	4	13	4	127
12.7	907	15.8	22	11.62	.00	4	14	4	128
14.2	694	17.4	27	11.20	.00	4	14	4	129
24.4	395	25.0	25	18.53	76.41	5	6	2	130
28.2	232	27.4	30	14.49	91.17	5	6	2	131
17.3	482	19.5	12	11.36	8.33	5	9	2	132
22.4	306	24.1	17	12.10	33.17	5	9	2	133
26.7	245	23.2	22	13.54	54.51	5	9	2	134
12.2	796	13.7	7	9.44	.00	5	11	2	135
16.8	531	18.3	12	11.80	7.28	5	11	2	136
21.1	378	21.0	17	13.38	20.22	5	11	2	137
23.9	336	23.5	14	14.99	58.08	5	21	1	138
29.2	257	26.5	19	17.19	115.10	5	21	1	139
17.3	403	22.9	32	9.60	6.02	6	5	3	140
19.8	306	22.6	37	9.41	12.32	6	5	3	141
21.8	269	23.2	42	10.01	21.83	6	5	3	142
26.9	222	26.2	31	12.63	67.24	6	6	2	143
31.0	185	27.7	36	14.03	102.72	6	6	2	144
34.3	146	29.0	41	13.48	112.66	6	6	2	145
31.5	178	32.9	37	13.91	120.49	6	7	1	146

APPENDIX I (contd.)
BURMA PLANTATION TEAK SAMPLE PLOT DATA

Average diameter	Number per ha	Top height	Age	Basal area per ha	Volume per ha	Plot Id.			
cm	no	m	yr	sq m	cu m				
35.8	153	34.4	42	15.43	155.62	6	7	1	147
32.3	188	32.3	37	15.50	145.75	6	8	1	148
36.3	158	33.8	42	16.35	173.88	6	8	1	149
40.6	126	33.8	47	16.14	193.82	6	8	1	150
25.7	222	26.8	37	11.50	60.74	6	9	2	151
28.4	193	28.0	42	12.21	80.26	6	9	2	152
31.2	190	30.8	38	14.65	120.77	6	10	2	153
33.3	146	31.7	43	14.26	136.03	6	10	2	154
19.0	311	23.5	38	8.86	12.73	6	11	3	155
20.8	292	23.5	43	10.01	22.81	6	11	3	156
22.6	272	24.1	48	10.77	35.90	6	11	3	157
27.9	225	28.7	36	13.73	86.42	6	12	2	158
31.0	213	30.2	41	16.07	122.94	6	12	2	159
32.5	178	30.2	46	14.78	134.14	6	12	2	160
15.2	462	21.0	24	8.40	1.54	6	13	3	161
14.2	588	20.1	25	9.25	.49	6	14	3	162
16.0	514	21.0	30	10.26	3.99	6	14	3	163
21.1	336	25.0	23	11.57	28.55	6	15	2	164
23.6	242	26.5	28	10.61	38.62	6	15	2	165
25.9	203	27.1	33	10.67	53.74	6	15	2	166
20.3	348	25.6	37	11.34	23.79	6	16	3	167
23.9	267	27.1	42	11.85	48.49	6	16	3	168
25.9	235	25.6	47	12.51	56.96	6	16	3	169
26.9	235	29.9	31	13.20	78.09	6	17	2	170
30.7	171	30.2	36	12.76	94.74	6	17	2	171
33.8	138	31.1	41	12.37	103.07	6	17	2	172
20.8	348	24.1	30	11.80	24.77	6	18	3	173
23.1	277	24.1	35	11.55	35.97	6	18	3	174
25.7	220	25.3	40	11.27	50.45	6	18	3	175
17.0	413	21.6	27	9.39	4.62	6	19	3	176
19.0	351	21.6	32	10.10	10.15	6	19	3	177
21.1	314	22.9	37	10.88	23.16	6	19	3	178
24.6	272	28.3	27	13.09	57.17	6	20	2	179
30.7	183	29.3	32	13.61	97.96	6	20	2	180
36.3	136	30.5	37	14.10	126.51	6	20	2	181
37.8	148	30.5	66	16.67	173.60	6	21	3	182
40.6	121	30.8	71	15.66	171.01	6	21	3	183
44.4	91	34.1	71	14.33	168.91	6	22	2	184
34.3	195	32.0	39	18.02	151.21	6	23	2	185
36.3	166	31.4	44	17.13	173.88	6	23	2	186
14.2	484	16.8	12	7.67	.00	6	24	3	187
9.7	811	11.9	7	5.81	.00	6	29	3	188
7.9	1359	11.0	5	6.66	.00	6	30	3	189
7.1	1606	9.1	4	6.34	.00	6	31	3	190
36.6	146	32.3	39	15.29	150.02	7	1	1	191
28.4	203	26.5	34	12.95	81.24	7	2	3	192
20.3	376	22.3	21	12.19	19.87	7	3	2	193
23.9	245	23.8	26	10.93	41.42	7	3	2	194
20.1	408	22.9	20	13.04	24.00	7	4	3	195
23.6	282	25.6	25	12.28	47.23	7	4	3	196
26.4	245	24.1	33	13.31	62.28	7	4	3	197
22.1	358	22.9	20	13.61	36.04	7	5	2	198
26.4	235	25.3	25	12.76	66.89	7	5	2	199
29.0	208	25.6	29	13.64	76.13	7	5	2	200
32.8	178	27.1	33	15.13	106.99	7	5	2	201
18.0	447	18.9	15	11.32	11.20	7	10	2	202
22.4	343	21.9	20	13.41	37.16	7	10	2	203
24.6	306	23.8	24	14.67	58.71	7	10	2	204
21.1	385	23.8	16	13.38	31.07	7	11	1	205
25.1	289	25.9	20	14.35	60.81	7	11	1	206
15.0	561	19.2	11	10.01	3.08	7	12	2	207
19.8	427	24.4	16	13.11	21.83	7	12	2	208
23.4	324	25.0	20	13.87	52.97	7	12	2	209
25.4	259	26.8	24	13.13	70.46	7	12	2	210
13.7	714	18.0	10	10.65	.70	7	13	2	211
18.0	452	22.3	15	11.59	11.48	7	13	2	212
19.8	393	22.9	19	12.17	19.52	7	13	2	213
21.3	341	25.0	23	12.05	36.32	7	13	2	214
13.7	736	17.7	10	11.07	.14	7	14	2	215
18.8	425	22.6	15	11.89	11.97	7	14	2	216
21.6	356	23.2	19	12.90	30.16	7	14	2	217
23.4	292	25.0	23	12.37	44.71	7	14	2	218
14.0	717	18.3	10	11.13	1.82	7	15	2	219
18.0	499	21.3	15	12.63	17.07	7	15	2	220
19.8	440	23.2	19	13.64	29.25	7	15	2	221

APPENDIX I (contd.)
BURMA PLANTATION TEAK SAMPLE PLOT DATA

Average diameter	Number per ha	Top height	Age	Basal area per ha	Volume per ha	Plot Id.
cm	no	m	yr	sq m	cu m	
21.3	339	24.4	23	12.14	38.20	7 15 2 222
13.7	818	19.2	10	12.01	.00	7 16 2 223
18.3	487	22.6	15	12.70	13.99	7 16 2 224
20.3	390	22.6	19	12.65	24.28	7 16 2 225
22.4	306	24.4	23	11.87	38.20	7 16 2 226
13.0	877	15.8	9	11.39	.00	7 17 2 227
18.3	563	20.1	14	14.72	13.92	7 17 2 228
21.1	430	21.3	18	14.97	31.21	7 17 2 229
24.1	257	23.2	22	11.78	44.64	7 17 2 230
13.5	702	15.8	9	10.12	.00	7 18 2 231
18.8	512	21.3	14	14.30	17.98	7 18 2 232
21.3	405	21.6	18	14.51	32.40	7 18 2 233
23.1	279	22.3	22	11.66	33.66	7 18 2 234
13.2	600	17.4	8	8.31	.00	7 19 2 235
18.3	415	21.6	13	10.93	9.31	7 19 2 236
21.6	329	23.2	17	12.01	25.61	7 19 2 237
23.9	267	25.3	21	12.12	38.48	7 19 2 238
10.9	885	14.6	8	8.38	.00	7 20 3 239
14.7	645	18.0	13	11.04	2.03	7 20 3 240
17.5	516	18.9	17	12.37	10.01	7 20 3 241
19.6	390	20.4	21	11.75	20.22	7 20 3 242
10.9	1003	15.2	8	9.44	.00	7 21 2 243
15.5	591	18.3	13	11.29	3.08	7 21 2 244
18.3	516	21.6	17	13.66	13.99	7 21 2 245
19.8	390	22.6	21	12.21	20.71	7 21 2 246
12.7	853	15.8	13	10.74	.00	7 22 3 247
14.5	682	18.3	17	11.34	.70	7 22 3 248
16.0	479	19.5	21	9.69	4.83	7 22 3 249
10.9	979	13.7	7	9.39	.00	7 23 2 250
16.3	687	18.0	12	14.03	5.81	7 23 2 251
18.5	539	19.8	16	14.53	17.00	7 23 2 252
22.1	418	22.6	20	15.91	45.06	7 23 2 253
9.1	1297	12.8	7	8.45	.00	7 24 2 254
14.5	662	17.4	12	10.90	.07	7 24 2 255
16.8	470	21.3	16	10.51	6.72	7 24 2 256
20.3	368	24.1	20	12.03	26.10	7 24 2 257
15.0	741	17.7	12	13.20	.00	7 25 2 258
17.5	551	20.4	16	13.36	13.92	7 25 2 259
22.4	356	23.5	20	13.87	41.35	7 25 2 260
8.6	1342	11.3	6	8.08	.00	7 26 3 261
13.7	694	16.2	11	10.12	.00	7 26 3 262
15.5	596	17.7	15	11.34	3.36	7 26 3 263
17.5	521	19.5	19	12.58	9.66	7 26 3 264
9.1	1110	11.0	6	7.48	.00	7 27 3 265
14.2	650	13.8	11	10.15	.00	7 27 3 266
9.1	1297	11.0	5	8.45	.00	7 31 2 267
13.7	875	17.4	9	12.90	.00	7 31 2 268
19.3	462	21.0	13	13.50	16.02	7 31 2 269
8.9	1297	11.6	5	8.22	.00	7 32 2 270
13.2	788	16.5	9	1.63	.00	7 32 2 271
18.3	484	20.7	13	12.60	12.25	7 32 2 272
24.6	343	25.3	28	16.46	79.28	8 1 2 273
31.2	138	27.1	33	10.56	83.83	8 1 2 274
34.3	138	28.3	39	12.70	114.89	8 1 2 275
30.5	175	26.8	33	12.83	96.21	8 2 2 276
34.3	148	28.0	39	13.61	123.92	8 2 2 277
24.6	292	23.5	28	14.03	62.49	8 3 3 278
29.2	161	25.3	33	10.79	70.53	8 3 3 279
24.4	336	26.5	29	15.84	71.37	8 5 2 280
28.4	198	28.3	34	12.53	81.17	8 5 2 281
34.0	148	29.9	40	13.34	119.30	8 5 2 282
24.1	331	25.0	30	15.15	57.87	8 6 2 283
28.2	188	27.1	35	11.71	73.34	8 6 2 284
33.0	126	28.0	41	10.93	98.52	8 6 2 285
32.8	163	28.0	33	13.77	112.24	8 7 2 286
34.8	143	29.6	39	13.68	128.54	8 7 2 287
29.2	195	28.7	33	13.13	93.37	8 8 2 288
25.4	351	27.7	33	17.58	76.62	8 9 2 289
29.2	193	29.3	38	12.95	92.85	8 9 2 290
33.0	158	29.6	44	13.61	129.73	8 9 2 291
31.0	183	27.7	39	13.89	107.55	8 10 2 292
35.1	138	28.7	45	13.38	111.89	8 10 2 293
21.8	366	24.4	33	13.59	39.60	8 11 2 294
27.7	200	26.5	38	12.10	72.98	8 11 2 295
32.8	161	28.3	44	13.57	122.03	8 11 2 296

APPENDIX I (contd.)
BURMA PLANTATION TEAK SAMPLE PLOT DATA

Average diameter	Number per ha	Top height	Age	Basal area per ha	Volume per ha	Plot Id.			
cm	no	m	yr	sq m	cu m				
25.7	237	26.5	31	12.33	60.04	8	12	2	297
28.7	173	27.7	37	11.04	71.58	8	12	2	298
22.1	314	23.5	25	12.08	40.09	8	13	2	299
23.6	282	24.1	31	12.30	52.06	8	13	2	300
23.6	272	25.6	25	11.96	47.16	8	14	2	301
8.9	1270	10.4	6	7.78	.00	8	15	4	302
11.9	848	13.4	11	9.64	.00	8	15	4	303
13.7	684	14.9	16	10.26	1.47	8	15	4	304
7.9	1250	10.4	6	6.24	.00	8	16	3	305
12.4	618	15.5	11	7.37	.00	8	16	3	306
15.5	509	17.7	16	9.69	4.27	8	16	3	307
16.3	378	17.4	12	7.83	.84	8	18	2	308
22.9	257	21.6	19	10.65	30.44	8	18	2	309
6.9	1391	9.4	4	4.98	.00	8	19	3	310
13.2	783	14.9	9	10.65	.00	8	19	3	311
8.1	1495	11.3	5	7.78	.00	8	20	2	312
14.0	806	16.5	10	12.37	.00	8	20	2	313
17.3	603	19.2	15	14.19	8.05	8	20	2	314
5.3	1661	8.2	3	3.83	.00	8	22	3	315
10.4	1018	14.0	8	8.82	.00	8	22	3	316
5.3	1898	6.7	3	4.06	.00	8	23	3	317
10.7	1097	14.0	8	9.83	.00	8	23	3	318
5.8	1567	7.6	4	4.38	.00	8	24	3	319
10.4	1122	12.8	9	9.44	.00	8	24	3	320
6.9	1470	8.5	4	5.62	.00	8	25	3	321
11.9	949	13.4	9	10.35	.00	8	25	3	322
13.7	776	15.5	14	11.43	1.05	8	25	3	323
7.9	1243	10.1	5	6.18	.00	8	26	3	324
12.7	811	15.5	12	10.19	.00	8	26	3	325
7.4	1411	11.0	5	5.92	.00	8	27	3	326
12.2	835	15.8	12	9.64	.00	8	27	3	327
9.7	1312	11.9	11	9.37	.00	8	56	4	328
10.2	1505	14.3	8	12.17	.00	8	57	3	329
8.9	1502	11.9	7	9.30	.00	8	58	3	330
25.9	225	25.9	28	11.89	68.08	9	1	2	331
29.7	185	26.8	33	12.88	96.77	9	1	2	332
32.0	175	28.3	38	14.07	116.57	9	1	2	333
28.2	178	28.0	28	11.27	87.19	9	2	2	334
31.7	166	27.7	33	13.02	103.84	9	2	2	335
34.0	146	29.0	38	13.25	116.01	9	2	2	336
23.4	235	24.7	25	10.17	43.52	9	3	2	337
26.9	195	25.9	30	11.04	70.74	9	3	2	338
29.2	178	26.8	35	11.96	88.93	9	3	2	339
8.4	1122	10.1	6	6.20	.00	9	4	3	340
13.5	610	15.5	11	8.79	.00	9	4	3	341
17.0	482	18.0	16	10.84	6.44	9	4	3	342
28.2	171	26.8	31	10.74	76.97	9	5	2	343
31.5	151	28.0	36	11.80	101.18	9	5	2	344
34.5	141	27.4	41	13.13	129.10	9	5	2	345
26.7	198	25.0	31	11.07	61.65	9	6	3	346
30.2	168	25.9	36	12.01	85.02	9	6	3	347
33.5	148	26.8	41	13.15	105.87	9	6	3	348
29.0	190	26.5	33	12.33	81.80	9	7	3	349
31.2	185	26.5	38	14.12	107.48	9	7	3	350
33.0	168	27.1	43	14.58	132.18	9	7	3	351
25.7	173	25.0	33	8.98	54.30	9	8	3	352
30.0	148	25.9	38	10.47	73.96	9	8	3	353
32.3	136	26.2	43	11.16	87.33	9	8	3	354
25.4	213	25.3	34	10.77	53.88	9	9	3	355
27.7	180	25.9	39	10.84	67.17	9	9	3	356
29.7	168	25.9	44	11.62	68.29	9	9	3	357
27.4	161	25.0	32	9.60	61.44	9	10	3	358
30.5	141	25.9	37	10.26	75.50	9	10	3	359
21.6	247	21.9	30	9.02	28.06	9	11	3	360
24.1	215	23.2	35	9.80	45.76	9	11	3	361
26.4	195	23.5	40	10.65	57.73	9	11	3	362
23.4	208	24.1	30	9.00	35.55	9	12	3	363
25.7	185	24.4	35	9.50	48.84	9	12	3	364
27.4	168	24.4	40	10.03	54.30	9	12	3	365
29.7	163	25.9	36	11.46	79.28	9	13	3	366
32.3	131	26.5	41	10.79	85.93	9	13	3	367
34.3	126	26.5	46	11.75	106.57	9	13	3	368
29.7	153	24.4	37	10.70	66.75	9	14	3	369
34.8	141	26.5	47	13.54	103.98	9	14	3	370
27.2	163	24.1	37	9.39	53.81	9	15	3	371

APPENDIX I (contd.)
BURMA PLANTATION TEAK SAMPLE PLOT DATA

Average diameter	Number per ha	Top height	Age	Basal area per ha	Volume per ha	Plot Id.			
cm	no	m	yr	sq m	cu m				
29.7	143	25.0	42	9.89	67.94	9	15	3	372
29.7	136	26.8	37	9.44	65.14	9	16	2	373
27.9	153	25.0	34	9.25	57.94	9	17	3	374
31.7	131	26.2	39	10.38	78.93	9	17	3	375
27.7	178	24.7	38	10.65	59.41	9	18	3	376
30.7	158	25.6	43	11.71	76.76	9	18	3	377
32.8	143	26.2	48	12.24	86.77	9	18	3	378
26.9	195	25.6	22	11.09	62.98	9	20	2	379
31.0	166	26.8	27	12.63	92.01	9	20	2	380
36.6	190	32.3	36	19.95	193.61	10	4	1	381
39.4	153	34.4	41	18.66	207.12	10	4	1	382
41.7	128	32.3	46	17.31	187.60	10	4	1	383
17.5	549	19.8	13	13.25	10.43	10	7	2	384
22.4	385	22.9	18	15.01	45.13	10	7	2	385
21.6	413	21.9	22	15.11	39.32	10	8	3	386
20.6	405	20.4	21	13.41	27.64	10	9	3	387
21.6	363	21.6	26	13.34	41.07	10	9	3	388
22.6	388	20.7	22	15.52	49.12	10	10	3	389
43.2	124	32.0	55	18.02	180.67	11	6	2	390
47.5	89	33.2	60	15.61	160.66	11	6	2	391
39.4	143	30.8	55	17.45	174.79	11	7	2	392
41.7	114	32.3	60	15.38	160.52	11	7	2	393
38.6	146	31.1	54	17.08	176.19	11	8	2	394
42.4	124	31.4	59	17.40	182.42	11	8	2	395
44.2	109	32.0	63	16.76	181.02	11	8	2	396
7.9	1394	11.6	4	6.75	.00	11	10	2	397
24.4	319	23.9	24	14.92	65.21	12	6	2	398
25.9	279	27.1	28	14.58	77.53	12	6	2	399
22.1	376	21.9	18	14.21	33.80	12	7	2	400
26.2	292	25.3	23	15.73	79.63	12	7	2	401
28.4	235	26.5	27	15.11	96.91	12	7	2	402
20.1	489	20.7	18	15.47	26.10	12	8	2	403
25.7	289	23.8	23	14.92	65.84	12	8	2	404
28.4	237	25.3	27	15.20	86.28	12	8	2	405
19.6	516	21.0	17	15.36	20.22	12	9	2	406
23.9	336	23.5	22	15.11	59.69	12	9	2	407
25.9	269	24.4	26	14.37	76.90	12	9	2	408
27.4	245	24.7	30	14.53	85.51	12	9	2	409
42.7	161	35.7	62	23.09	260.79	13	2	2	410
41.7	141	32.9	60	19.17	153.17	13	3	2	411
32.0	237	31.4	40	19.15	158.07	13	6	2	412
36.6	126	32.3	45	13.31	134.70	13	6	2	413
27.2	299	29.0	40	17.26	104.68	13	7	2	414
31.7	163	30.8	45	12.95	111.54	13	7	2	415
29.5	255	28.0	39	17.47	120.49	13	8	2	416
33.8	156	29.9	44	14.05	114.68	13	8	2	417
24.6	321	24.4	29	15.40	65.49	13	9	2	418
29.0	178	26.2	34	11.66	68.85	13	9	2	419
24.1	331	24.4	28	15.24	58.43	13	11	2	420
28.2	205	25.6	33	12.72	70.32	13	11	2	421
30.2	180	27.1	38	12.92	84.46	13	11	2	422
26.4	274	27.4	28	15.01	80.68	13	12	2	423
31.2	166	28.0	33	12.72	94.39	13	12	2	424
33.8	148	29.0	38	13.25	108.95	13	12	2	425
24.6	301	26.2	28	14.46	63.47	13	13	2	426
29.0	171	27.4	33	11.18	72.35	13	13	2	427
41.1	104	31.7	54	13.89	132.88	13	15	2	428
45.0	89	33.2	59	13.98	143.30	13	15	2	429
26.9	250	26.2	36	14.16	74.31	13	16	2	430
30.0	178	27.7	41	12.58	88.73	13	16	2	431
30.0	245	30.2	36	17.38	133.16	13	17	2	432
33.3	171	31.1	41	14.85	141.27	13	17	2	433
39.1	173	35.1	55	20.80	211.53	13	18	2	434
43.7	124	35.7	60	18.57	208.73	13	18	2	435
32.5	210	27.7	38	17.45	134.63	13	19	2	436
35.1	171	29.3	43	16.48	147.99	13	19	2	437
37.3	156	30.2	48	16.87	151.70	13	19	2	438
32.8	190	30.5	42	16.09	134.14	13	20	2	439
35.1	143	31.7	47	13.80	125.25	13	20	2	440
6.3	1426	8.8	5	4.52	.00	13	23	3	441
8.9	875	13.1	10	5.58	.00	13	23	3	442
7.1	1376	10.7	5	5.56	.00	13	24	3	443
9.1	1065	13.4	10	7.00	.00	13	24	3	444
9.4	998	11.9	10	6.89	.00	13	25	4	445
11.4	806	14.3	15	8.26	.00	13	25	4	446

APPENDIX I (concld.)
BURMA PLANTATION TEAK SAMPLE PLOT DATA

Average diameter cm	Number per ha no	Top height m	Age yr	Basal area per ha sq m	Volume per ha cu m	Plot Id.			
7.6	1527	10.7	5	7.12	.00	13	26	3	447
11.2	773	13.7	10	7.44	.00	13	26	3	448
12.4	645	15.5	15	7.90	.00	13	26	3	449
12.2	1043	16.2	15	12.28	.00	13	28	3	450
6.3	1362	8.5	4	4.18	.00	13	29	3	451
10.4	1080	13.7	9	9.02	.00	13	29	3	452
12.7	914	15.8	14	11.64	.00	13	29	3	453
6.9	1282	9.4	4	4.80	.00	13	30	3	454
14.2	640	14.6	9	10.33	.00	13	30	3	455
18.3	479	17.1	14	12.65	15.74	13	30	3	456
12.2	744	15.5	9	8.86	.00	13	31	2	457
6.6	1507	8.5	4	5.28	.00	13	32	3	458
9.7	956	14.3	9	7.05	.00	13	32	3	459
7.6	1280	10.1	5	5.74	.00	13	33	3	460
12.2	845	15.5	10	9.80	.00	13	33	3	461
15.2	516	18.0	16	9.46	2.87	13	33	3	462
6.9	1525	8.8	5	5.53	.00	13	34	3	463
11.4	927	13.7	10	9.55	.00	13	34	3	464
15.0	605	16.8	16	10.72	2.45	13	34	3	465
8.4	1250	11.6	6	6.77	.00	13	35	3	466
11.7	892	14.6	11	9.48	.00	13	35	3	467
15.0	563	18.3	16	10.08	4.62	13	35	3	468
7.4	1401	11.0	6	5.95	.00	13	36	4	469
9.7	1161	12.8	11	8.40	.00	13	36	4	470
11.4	929	15.8	16	9.39	.00	13	36	4	471
7.6	1379	9.8	7	6.43	.00	13	37	4	472
7.6	1184	9.1	7	5.53	.00	13	38	4	473
11.2	899	13.4	16	8.95	.00	13	38	4	474
11.7	811	13.1	13	8.63	.00	13	39	4	475
12.2	796	14.0	13	9.21	.00	13	40	4	476
11.4	932	10.7	13	9.66	.00	13	41	5	477
12.2	848	13.1	13	10.06	.00	13	42	4	478
11.9	914	13.1	13	10.01	.00	13	43	4	479
9.9	811	10.7	7	6.20	.00	13	44	4	480
13.0	625	14.0	12	8.24	.00	13	44	4	481
34.3	168	29.6	42	15.54	134.98	13	47	2	482
37.3	146	30.2	47	15.93	149.32	13	47	2	483
36.8	156	29.9	49	16.64	152.89	13	51	2	484
39.4	138	31.1	54	16.74	164.02	13	51	2	485
43.4	146	32.9	51	21.60	228.18	13	52	2	486
34.3	183	28.3	45	16.99	132.32	13	53	2	487
37.1	158	29.6	50	17.24	145.82	13	53	2	488
32.5	183	29.0	49	15.24	134.07	13	54	2	489
45.2	148	33.5	63	23.74	269.88	13	55	2	490
26.4	245	30.2	41	13.48	71.58	13	56	2	491
40.9	153	32.9	53	20.11	187.81	13	58	2	492
43.2	136	33.2	58	19.86	207.89	13	58	2	493
26.7	242	24.7	30	13.57	71.93	13	65	2	494
29.5	222	26.5	35	15.06	83.62	13	65	2	495
23.4	267	20.4	30	11.46	30.09	13	66	3	496
26.2	237	22.3	35	12.90	55.07	13	66	3	497

APPENDIX II

PARAMETERS ESTIMATED FOR TOP HEIGHT FUNCTIONS

A. Top height functions by Forest Divisions

(i) MODEL : H = n/p [1 - EXP(-p(1-m)A)]**(1/(1-m))

Forest Division	n	p	m	S.E. of regression
Ataran	5.814457	0.05038443	0.56932×10^{-6}	10.20274
	(10.2196)	(0.075609)	(0.643203)	
Insein	1.056612	0.2508538	0.6863101	4.63793
	(0.05114)	(0.317272)	(0.279697)	
Katha	9.580378	0.1258883	LT 0.1×10^{-6}	7.57769
	(16.6551)	(0.142724)	(0.654622)	
Magwe	1.958229	0.2280285	0.4805324	5.36365
	(0.67288)	(0.271805)	(0.355814)	
Myitkyina	5.15196	0.1637101	0.2328157	5.96400
	(5.91671)	(0.196382)	(0.506951)	
Prome	5.855394	0.0564250	LT 0.1×10^{-6}	11.16857
	(5.13371)	(0.036303)	(0.310954)	
Pyinmana	8.571329	0.09596226	LT 0.1×10^{-6}	5.68132
	(4.28784)	(0.033454)	(0.193215)	
Tharrawaddy	6.597725	0.0667681	LT 0.1×10^{-6}	5.32767
	(2.00347)	(0.020240)	(0.123733)	
Thaton	3.079587	0.1997844	0.3872508	4.83520
	(1.07244)	(0.101443)	(0.187234)	
Thaungyin	5.044180	0.0377362	LT 0.1×10^{-6}	10.33076
	(15.0344)	(0.108059)	(1.092410)	
Taungoo	11.764030	0.1124691	LT 0.1×10^{-6}	2.91757
	(92.0692)	(0.854180)	(3.307910)	
Yamethin	2.625459	1.3961740	0.8585434	3.32607
	(3.99459)	(4.123040)	(0.318978)	
Zigon	5.093795	0.0442016	LT 0.1×10^{-6}	6.86784
	(1.34631)	(0.012131)	(0.104319)	

Note : LT = Less Than.

A. Top height functions by Forest Divisions (contd.)

(ii) MODEL : $H = n/p\ [1 - EXP(-pA)]$

Forest Division	n	p	S.E. of regression
Ataran	0.831133 (0.25828)	0.0191585 (0.010915)	0.13512
Insein	0.340866 (0.19588)	0.0021987 (0.007327)	0.08573
Katha	0.944636 (0.04155)	0.0308207 (0.020163)	0.24050
Magwe	0.862077 (0.19184)	0.0601972 (0.012517)	0.14533
Myitkyina	1.404012 (0.50689)	0.0327663 (0.022998)	0.18942
Prome	0.213021 (0.15058)	LT 0.1×10^{-6} (0.005401)	0.08439
Pyinmana	1.835401 (0.21999)	0.0603047 (0.010588)	0.25413
Tharrawaddy	1.398785 (0.11119)	0.0425035 (0.005111)	0.20387
Thaton	1.437867 (0.18446)	0.0487390 (0.007361)	0.11970
Thaungyin	0.653684 (0.73612)	LT 0.009 (0.028445)	0.28286
Taungoo	0.473462 (4.16161)	LT 0.009 (0.130955)	0.03473
Yamethin	2.254224 (1.07290)	0.0772864 (0.044268)	0.17955
Zigon	1.034694 (0.07543)	0.0273807 (0.003293)	0.17566

Note : LT = Less Than.

B. Top height functions by Old Site Qualities

MODEL : H = n/p [1 - EXP(-p(1-m)A)]**(1/(1-m))

Forest Division	n	p	m	S.E. of regression
Site Quality I	8.420590 (7.40726)	0.0735609 (0.039819)	0.27939×10^{-6} (0.294226)	2.66414
Site Quality II	7.313680 (1.59862)	0.0719574 (0.011022)	LT 0.1×10^{-11} (0.078066)	5.40191
Site Quality III	6.530480 (1.20774)	0.0744982 (0.011789)	LT 0.1×10^{-11} (0.073558)	5.25126
Site Quality IV	5.270765 (2.92306)	0.0784982 (0.040844)	LT 0.1×10^{-11} (0.070008)	5.01245
Site Quality V	2.278185 (0.51612)	0.5296502 (2.863150)	0.6078029 (1.379810)	2.41915

Note : LT = Less Than.

APPENDIX III

ESTIMATED PARAMETERS FOR REGIONAL TOP HEIGHT FUNCTIONS

A. Top height functions for base age 20

MODEL : $H = S\,[(1 - EXP(-pA))/(1 - EXP(-p20))]$

Region	p	S.E. of regression
Heavy rainfall regions	0.0877 (0.0073)	0.1085
Medium rainfall regions	0.1072 (0.0056)	0.1650
Light rainfall regions	0.0985 (0.0049)	0.1902
All regions	0.0980 (0.0041)	0.1813

Analysis of variance to test the significance of the difference between functions for rainfall regions.

Source	RSS	DF	VAR	F
Heavy RF	0.106	34	0.0031	
Medium RF	0.490	65	0.0075	
Light RF	3.582	165	0.0217	
Total	4.178†	255		
All Reg.	4.210†	257	0.0164	
Differences	0.032††	2	0.016	0.97 ns (= not significant)

NOTE : As residual sum of squares† is reduced†† by combining regions, it is to say that there is no difference between functions.

B. Top height functions for base age 40

MODEL : H = S [(1 - EXP(-pA))/(1 - EXP(-p40))]

Region	p	S.E. of regression
Heavy rainfall regions	0.0713 (0.0052)	0.1177
Medium rainfall regions	0.0139 (0.0040)	0.3508
Light rainfall regions	0.0587 (0.0047)	0.2423
All regions	0.0338 (0.0029)	0.3173

Analysis of variance to test the significance of the difference between functions for rainfall regions.

Source	RSS	DF	VAR	F
Heavy RF	0.471	34	0.0139	
Medium RF	9.632	65	0.148	
Light RF	9.165	156	0.058	
Total	19.276	255		
All Reg.	25.888	257	0.100	
Differences	6.612†	2	3.306	32.8**

NOTE : † The difference between regional functions are highly significant** at a probability of 99 %.

APPENDIX IV

ESTIMATED PARAMETERS FOR STEM TIMBER FORM FACTOR FUNCTIONS

$$\text{MODEL : } F = a + bS + cA + dA^2 + eA^3 + fS^2 + gSA$$

Model	a	b	c	d	e	f	g	DF	ESS
24	-.2272	.0091	.0044					58	.1021
	(.031)	(.00099)	(.0002)						
25	-.372	.0098	.0121	-.000865				57	.0121
	(.012)	(.00034)	(.0003)	(.000004)					
26	-.382	.0099	.0131	-.000113	.000000206			56	.0119
	(.016)	(.00034)	(.001)	(.000027)	(.00000021)				
27	-.326	.0166	.0044			-.000135		57	.1013
	(.154)	(.01148)	(.0002)			(.000207)			
28	-.496	.0192	.0121	-.0000867		-.0001689		56	.0110
	(.052)	(.0038)	(.0003)	(.00000404)		(.000069)			
29	-.235	.0094	.0094				-.00000656	57	.1021
	(.067)	(.0023)	(.0013)				(.0000462)		
30	-.466	.013	.0143	-.0000897			-.000068	56	.0084
	(.021)	(.0006)	(.0005)	(.0000036)			(.0000136)		

where

F = form factor;

S = site index;

A = age;

a,b,c,d,e,f and g = constant and coefficients.

Individual F-tests for each model reveal that all the models, i.e. 24 to 30, are significant at a probability of 99 %. In terms of the error sum of squares (ESS) Model (30) is most desirable with Model (25) next to it. Model (30) involves one more coefficient than Model

(25), therefore the significance of including that extra variable is tested as follows :-

Source	Sum of Squares	DF	Variance	F
Model (25)	0.79331	3	0.26444	1236. **
ESS for (25)	0.01219	57	0.00021	
Model (30)	0.79705	4	0.19926	1321. **
Extra coefficient	0.00374	1	0.00374	24.9 **
ESS for (30)	0.00844	56	0.00015	
Total	0.8055	60		

NOTE : ** = Significant at 99 % probability.

APPENDIX V

```
C       THIS PROGRAM WILL TABULATE TOP HEIGHT TABLE
C            FOR PLANTATION TEAK IN BURMA.
C
C
C                                     -PA
C                  (1     -      E          )
C       H  =  S  ---------------------------
C                                     -P40
C                  (1     -      E         )
C                            P  =  0.03383224
C
C                                                                   AKM
C                                                                   4/4/81.
C
C
        REAL  H(16,15)
        REAL  P / 0.03383224 /
        DIV =  (1.0 - EXP(-P*40.0))
        DO    100   I = 1,16
C
C             AGE  =  5  TO  80
C
        A   =   I * 5.0
        DO    100   J = 1, 15
C
C             SITE  INDEX  =  7.5  TO  42.5
C
        S  =  5.0  +  J*2.5
        H(I, J)  =  S*(1.0  -  EXP(-P*A))/DIV
   100   CONTINUE
C
C             PRINT  THE  GENERATED  TABLE
C
        WRITE(6,  60)(I-3,I,  I  =  10,40,5),  I-3
     60 FORMAT(1H1,  30X,
       +'TOP HEIGHT BY SITE INDEX OF PLANTATION TEAK'//
       +  48X,  'IN  BURMA'//
       +  10X,  84(1H-)  /
       +  25X,  'TOP  HEIGHT  (METRES)'  /
       +  12X,  'AGE',  2X,  77(1H-)  /
       +  45X,  'SITE  INDEX'  /
       +  17X,  77(1H-)  /
       +  17X,  7(I3,  '.5',  I3,  '.0')  ,  I3,  '.5'  /
       +  10X,  84(1H-)   /)
        WRITE(6,61)  (I*5,  (H(I,J),  J=1,15),  I=1,16)
     61 FORMAT(10X,  I5,  2X,  15F5.1  /  )
        WRITE(6,62)
     62 FORMAT(/ 10X,  84(1H-)//////////////////)
        STOP
        END
```

APPENDIX VI

```
(TEAKA(1).SIM
C   THIS IS A SIMULATION PROGRAM TO SIMULATE
C    VARIOUS THINNING REGIMES
C
C
C            GENERAL STRUCTURE OF THE PROGRAM
C    # 1  INTITIALIZATION;
C    # 2 READ  AGE AND THINNING INDEX;  IF END FINISH AFTER PRINTING
C    # 3 INCREMENT AGE BY ONE YEAR
C    # 4 COMPUTE B' ANNUAL BASAL INCREMENT
C    # 5 THINNING AGE ARRIVED ?   THEN THIN, AND GO TO #2
C    # 6 IF THINNING AGE NOT ARRIVED AT, THEN GO TO #3
C
C          VARIABLES USED :
C          AGE = AGE                     HT = TOP HEIGHT  S = SITE INDEX
C          BB, VV = B.A. AND VOL. OF FINAL CROP
C          B1, V1 =      - DO -     OF MAIN CROP
C          B2, V2 =      - DO -     OF THINNINGS
C          B3, V3 =      - DO -     OF CUMULATIVE THINNINGS
C          B4, V4 =      - DO -     OF TOTAL YIELD
C
C                                  AKM.
C                                  5/4/81.
C
      REAL B1(30),B2(30),B3(30),B4(30), V1(30), V2(30), V3(30), V4(30)
     +  , BB(30), VV(30)
      INTEGER AGE(30), HT(30)
      COMMON // A, H, S, T, B, II
     + , B1, B2, B3, B4, V1, V2, V3, V4, AGE, HT, BB, VV
C*****     READ INITIALIZATION RECORD
      READ(5, 50,END=900) A, T, B, H, S
   50 FORMAT( 5F4.0 )
       WRITE(6, 60)
   60 FORMAT(1H1,10X,' GROWTH AND YIELD OF PLANTATION TEAK IN BURMA'/)
       WRITE(6, 61)
   61 FORMAT(10X,  '                     SIMULATION CONTROLS '/10X,
     +' AGE THINNING INDEX  BASAL AREA       TOP HEIGHT   SITE INDEX'/)
       WRITE(6, 62) A,T,B,H,S
   62 FORMAT(10X, F5.0,   F10.2, 5X, F8.1, F14.1, F14.1)
       II = 1
C*****     CHECK INITIALIZATION RECORD
       IF(A .LE. 0.0) GO TO 901
       IF(T .GE. 1.0) T=1.0
       IF(T .LE. 0.0) GO TO 902
       IF(B .LE. 0.0) B = GROSS()
```

APPENDIX VI (CONTD)

```
      IF(S .LE. 0.0  .AND.  H .LE. 0.0) GO TO 903
      IF(S .LE. 0.0) S = SITE()
      IF(H .LE. 0.0) H = HEIGHT()
      CALL STORE
C******    THINNING AT INITIAL AGE
      IF(T .LT. 1.0) CALL THIN (T)
C******    READ NEXT THINNING
  100 READ(5, 50, END=800) A2, T2
C******    CHECK THINNING PROVISIONS
      WRITE(6, 62) A2, T2
      IF(T2 .GT. 1.0) T2 = 1.0
      IF(A2 .GT. A) GO TO 110
      WRITE(6, 63)
   63 FORMAT(// '  ERROR IN THINNING AGE < INITIAL AGE')
      GO TO 100
  110 IF(T2 .GT. 0.0) GO TO 120
      WRITE(6, 64)
   64 FORMAT(// '   ERROR IN THINNING INDEX, < 0.0 ')
      GO TO 100
  120 INTV = 5
C******    GROW AGE, TOP HEIGHT, AND B.A.
  130  A = A + 1
      H = HEIGHT ()
     IF(INTV .LE. 0) T = (1.0 + T)/2.0
      B = B + BASAL()
      INTV = INTV - 1
      IF(A .LT. A2) GO TO 130
C******    NEXT THINNING AGE ARRIVED
      II = II + 1
      CALL STORE
C******    THIN THE CROP IF REUIRED
      IF(T2 .LT. 1.0) CALL THIN (T2)
      T = T2
      GO TO 100
C******    PRINT SIMULATED RESULTS
  800 CALL PRINT
      STOP
  900 WRITE(6, 65)
   65 FORMAT(// '  NO INITIALIZATION CARD ?????' /)
      STOP
  901 WRITE(6, 66)
   66 FORMAT(// '   STARTING AGE < 0.0 ?????????' /)
      STOP
  902 WRITE(6, 67)
   67 FORMAT(// '  INVALID THINNING INDEX ??????' /)
```

APPENDIX VI (CONTD)

```
      STOP
  903 WRITE(6, 68)
   68 FORMAT(// '   PROVIDE TOP HEIGHT (OR) SITE INDEX '/)
      STOP
     END
C*********************** END OF MAIN SEGMENT ****************
      REAL FUNCTION GROSS
C
C           IF INITIAL BASAL AREA IS NOT GIVEN, THIS
C           FUNCTION WILL ESTIMATE THE GROSS BASAL AREA
C
     COMMON    A
     REAL N
      DATA N, P /0.06583731, 0.0370428 /
      GROSS =  N/P *(1.0 - EXP(-P*A*1.0 -P*2.0))
      RETURN
     END
      REAL FUNCTION SITE
C
C           FUNCTION TO COMPUTE SITE INDEX
C
      COMMON A, H
      REAL P / 0.03383224 /
      SITE = H*(1.0 - EXP(-P*40.))/(1.0 - EXP(-P*A))
      RETURN
     END
      REAL FUNCTION HEIGHT
C
C           FUNCTION TO ESTIMATE TOP HEIGHT
C
      COMMON // A, H, S
      REAL P / 0.0383224 /
      HEIGHT = S*(1.0 - EXP(-P*A))/(1.0 - EXP(-P*40.))
      RETURN
     END
      REAL FUNCTION BASAL
C
C           FUNCTION FOR ANNUAL BASAL AREA GROWTH
C
      COMMON // A, H, S, T
     REAL N
      DATA N, P / 0.06113601, 0.0370428 /
      BASAL = N*S* EXP(-P*A*T)
      RETURN
     END
```

APPENDIX VI (CONTD)

```
      REAL FUNCTION FORM
C
C         FUNCTION FOR ESTIMATING FORM FACTOR
C         BASED ON AGE, AND SITE INDEX
C
      COMMON // A, H, S
      DATA P1,P2,P3,P4,P5/-.4668,.013,-.00006803,.01434,-.00008975/
      FORM = P1 + P2*S + P3*S*A + P4*A + P5*A*A
      RETURN
      END
C
      SUBROUTINE THIN (T)
C
C         ROUTINE FOR THINNINGS
C         COMPUTE MAIN CROP AND THINNINGS
C         ALSO FINAL CROP, CUMULATIVE THINNINGS
C         AND TOTAL YIELDS
C
      COMMON // A, H, S, XX, B, II
     + , B1, B2, B3, B4, V1, V2, V3, V4
     + , AGE, HT, BB, VV
      REAL B1(30),B2(30),B3(30),B4(30), V1(30), V2(30), V3(30), V4(30)
     +  , BB(30), VV(30)
      INTEGER AGE(30), HT(30)
      B = B1(II)*T
      B2(II) = B1(II) - B
      F = FORM()
      IF(F .LT. 0.0) F = 0.0
      V2(II) = 0.80*B2(II)*F*H
      B1(II) = B
      F = FORM()
      IF(F .LT. 0.0) F = 0.0
      V1(II) = B*F*H
      B3(II) = B2(II)
      V3(II) = V2(II)
      IF(II .EQ. 1) GO TO 10
      B3(II) = B3(II) + B3(II-1)
      V3(II) = V3(II) + V3(II-1)
 10   B4(II) = B1(II) + B3(II)
      V4(II) = V1(II) + V3(II)
      BB(II) = B1(II) + B2(II)
      VV(II) = V1(II) + V2(II)
      RETURN
      END
C
```

APPENDIX VI (CONTD)

```
      SUBROUTINE STORE
C
C          ROUTINE FOR INITIALIZATION
C          ALSO STORE VALUES IF NO THINNINGS
C
      REAL B1(30),B2(30),B3(30),B4(30), V1(30), V2(30), V3(30), V4(30)
     +  , BB(30), VV(30)
      INTEGER AGE(30), HT(30)
      COMMON // A, H, S, T, B, II
     + , B1, B2, B3, B4, V1, V2, V3, V4, AGE, HT, BB, VV
      B1(II) = B
      F = FORM()
      IF(F .LT. 0.0) F = 0.0
      V1(II) = B1(II)*F*H
      B2(II) = 0.0
      V2(II) = 0.0
      B3(II) = 0.0
      V3(II) = 0.0
      IF(II .EQ. 1) GO TO 10
      B3(II) = B3(II-1)
      V3(II) = V3(II-1)
   10 B4(II) = B1(II) + B3(II)
      V4(II) = V1(II) + V3(II)
      BB(II) = B1(II) + B2(II)
      VV(II) = V1(II) + V2(II)
      HT(II) = H + 0.5
      AGE(II) = A
      RETURN
      END
      SUBROUTINE PRINT
C
C          ROUTINE TO PRINT SIMULATED RESULTS
C
      REAL B1(30),B2(30),B3(30),B4(30), V1(30), V2(30), V3(30), V4(30)
     +  ,  BB(30), VV(30)
      INTEGER AGE(30), HT(30)
      COMMON // A, H, S, T, B, II
     + , B1, B2, B3, B4, V1, V2, V3, V4, AGE, HT, BB, VV
      WRITE(6, 600) S
  600 FORMAT(1H1, 20X, 'GROWTH AND YIELD OF PLANTATION TEAK IN BURMA'
     + //                ' SITE INDEX = ', F6.1,
     +       ' (METRES)'/
     + 10X,91(1H-)/
     + 10X,   59X,    '  CUMULATIVE       GRAND' /
     + 10X, 11X, '   FINAL CROP     MAIN  CROP        THINNINGS',
```

APPENDIX VI (CONTD)

```
     +                      '          THINNING          TOTAL' /
     + 10X,    59X,    '                YIELD             YIELD' /
     + 10X, 'AGE    TOP   ', 80(1H-) /
     + 10X, 3X, ' HEIGHT ', 5('   B.A.   VOL.    ')//
     + 10X, ' YR', 4X, 'M', 3X, 5('SQ M/HA CU M/HA ')/
     + 10X, 91(1H-)//)
       WRITE(6, 601) (AGE(I), HT(I), BB(I),VV(I),B1(I),V1(I),B2(I),V2(I)
     + ,         B3(I), V3(I), B4(I), V4(I), I=1, II)
 601   FORMAT( 10X, I3, I5, 2X, 10F8.1 /)
       WRITE(6, 602)
 602   FORMAT(/ 10X, 91(1H-), /////////////)
       RETURN
       END

E,P LIFLP
```

APPENDIX VI (CONTD)

GROWTH AND YIELD OF PLANTATION TEAK IN BURMA

SIMULATION CONTROLS

AGE	THINNING INDEX	BASAL AREA	TOP HEIGHT	SITE INDEX
10.	.65	14.2	.0	26.0
15.	.78			
20.	.83			
25.	.86			
30.	.89			
35.	.91			
40.	.93			
45.	.93			
50.	.94			
55.	.94			
60.	.93			
65.	.94			
70.	.93			
75.	.93			
80.	1.00			

APPENDIX VI (CONTD)

GROWTH AND YIELD OF PLANTATION TEAK IN BURMA

SIMULATION CONTROLS

AGE	THINNING INDEX	BASAL AREA	TOP HEIGHT	SITE INDEX
10.	.66	20.6	.0	35.0
15.	.74			
20.	.80			
25.	.86			
30.	.90			
35.	.91			
40.	.92			
45.	.93			
50.	.93			
55.	.93			
60.	.93			
65.	.93			
70.	.93			
75.	.92			
80.	1.00			

APPENDIX VI (CONCLD)

GROWTH AND YIELD OF PLANTATION TEAK IN BURMA

SIMULATION CONTROLS

AGE	THINNING INDEX	BASAL AREA	TOP HEIGHT	SITE INDEX
10.	.85	20.6	.0	35.0
20.	.85			
30.	.85			
40.	.85			
60.	.85			
80.	1.00			