THE ECOLOGICAL BASIS OF RAINFOREST MANAGEMENT

by

George N. Baur

André Mayer Fellow, 1961-62 (U.N. Food and Agriculture Organisation)

and

Research Forester, Forestry Commission of New South Wales

"The principle should be: Follow Nature; perhaps guide her, but do not dictate to her".
–*Pitt (1960)*

"All planned forestry is applied ecology".
– *Hewetson (1956)*

PREFACE.

This volume is the outcome of about 18 months spent investigating rainforest management in various parts of the world under an Andre Mayer Fellowship awarded by the United Nations Food and Agriculture Organization (F.A.O.), and supplemented by generous allowances from my employers, the Forestry Commission of New South Wales and the N.S.W. Public Service Board. The Fellowship tenure extended from March 1961 to July 1962, and was spent in the following main areas:

March-April, 1961: England, the time being spent primarily in library research at the Commonwealth Forestry Institute, Oxford.

May-June, 1961: Puerto Rico, attached to the institute of Tropical Forestry (formerly Tropical Forest Research Center) at Rio Piedras, a unit of the United States Forest Service.

July-mid August, 1961: Brazil, attached to the F.A.O. Mission to the Amazon at Belem, Para.

October, 1961: Puerto Rico, attached to the Institute of Tropical Forestry.

November-mid December, 1961: a tour of forestry activities in the south-eastern United States of America, arranged by the U.S. Forest Service.

Mid-December, 1961-March, 1962: Nigeria (Western Region), attached to the Federal Department of Forest Research, Ibadan.

April-July, 1962: Malaya, attached to the Forest Research Institute, Kepong.

The six weeks to the end of September, 1961, were to have been spent in visiting several countries bordering the southern Caribbean Sea (Surinam, British Guiana, Trinidad, Venezuela), but illness contacted in Amazonia forced the cancellation of this trip. The tour of the southeastern U.S.A. was carried out separately from the Fellowship on behalf of the Forestry Commission of N.S.W. and was concerned chiefly with current research and management in the pine forests of that area. However the tour included stops in the mixed hardwood forests of the so-called Mississipi Delta (the area between Vicksburg, Miss. and Memphis, Tenn.) and the southern Appalachian Mountains, and these provided valuable additional information on the ecology and silviculture of mixed stands.

During the seven years prior to departing on the Fellowship, I had been partly engaged in silvicultural and ecological studies of rainforest communities in northeastern New South Wales (Australia), and in connection with these studies had visited northern Queensland to observe similar work being carried out by the Queensland Department of Forestry in the more extensive rainforests of the northern State of Australia. This earlier work supplied the foundations for undertaking the Fellowship.

The theme of this report is that rainforest, in a broad sense, varies considerably in physiognomy and floristic composition with the varying environmental factors that shape all plant communities, and that any techniques to bring rainforest under scientific management must ultimately rest upon a sound understanding of the ecology of the community. As stated, this is a gross oversimplification. Economic factors in particular frequently outweigh the ecological factors in significance and it has been found necessary to consider these economic factors in this report. The basic premise, however, remains: economic conditions, in this technological age, can change with alarming rapidity, but the ecological behaviour of rainforest communities and of the species making up those communities is relatively immutable and can be disregarded only at great risk to the final success of management operations.

Professor P.W. Richards' monumental work The Tropical Rain Forest has proved invaluable in performing this study and it is not coincidence that the first part of this report follows closely the layout used by Richards. However in dealing with ecological considerations the intention has not been to duplicate the data already presented by Richards, but rather to stress those aspects that appear to be of greatest importance in forest management and to add supplementary information where this has been desirable and possible. Similarly H.C. Dawkins' The Management of Natural Tropical High-Forest and the F.A.O. publication Tropical Silviculture (3 volumes) have been of the greatest value in preparing the later, management parts of the report.

In outline this report deals first with the ecological factors determining the nature and occurrence of rainforest around the world. It then considers the utilization of rainforest sites and proceeds to the question of rainforest silviculture, paying particular attention to techniques involving the use of natural regeneration. These techniques are then examined to determine any underlying principles involved, and other aspects of forest management are dealt with, leading to a review of factors to be considered when implementing a programme of forest management.

Inevitably in a report of this type much of the data must come from published reports. In the selection of this material a certain inbalance will be noted and this is due in no small way to my lack of familiarity with languages other than English. Fortunately the main developments in the silviculture of natural rainforest stands have occurred in English-speaking territories, particularly Malaya, Nigeria, Trinidad, Puerto Rico and Queensland, so that the defects due to my linguistic incompetence are somewhat minimized. In the French-speaking rainforest territories of Africa silvicultural emphasis has been upon artificial regeneration which is considered only briefly in this report. Much other material has come from private sources and from departmental files and records in various countries: wherever possible these sources are acknowledged in the text. A small proportion of the data presented is original.

For consistency plants are referred to by their botanical names throughout the report, but well established common names are given when the species are first mentioned. Every effort has been made to ensure that currently correct botainical names are used, but owing to the vagaries of systematic botanists and to other reasons it is expected that a number of errors will have occurred. Also for consistency measurements are quoted as far as possible in British units. This is not due to any imagined superiority of the British system of measurement, but to the facts that in the literature cited it is the more common system used, and more importantly that it is the system which I have become accustomed to using in practice and in thought. A table of British:Metric conversion factors is included as appendix 5.

For the most part terms used in the report are as defined in the British Commonwealth Forest Terminology, but on occasions I have preferred to use the Australian synonym rather than the suggested term.

During the course of the Fellowship I have received very great assistance from many sources in many places, and I wish to acknowledge this help with sincere gratitude. Particular reference must be made to the following:

To the United Nations Food and Agriculture Organization for making the study possible through its Andre Mayer Fellowship programme and to the Forestry Commission of New South Wales and the N.S.W. Public Service Board for their continued and generous support.

To Mr Jean de Martini and Miss Clara Hemsted of the Training and Fellowships Branch and to Dr M.A. Huberman (now in Mexico) and Mr M. Anderson of the Forestry and Forest Products Division of F.A.O., Rome.

To the Director and staff of both the Commonwealth Forestry Institute and the Commonwealth Forestry Bureau in Oxford, and especially to Dr E.W. Jones and Mr John Pitt of C.F.I.

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To members of the F.A.O. Mission to the Amazon, especially the former Chief of Mission, Mr G.G. Gray, and the former Silviculturist, Dr C.H. Holmes.

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To the Director and staff of the Federal Department of Forest Research, Ibadan, Nigeria, and to the Chief Conservator of Forests and his staff in the Western Region Forestry Division, with special thanks to Messrs R.W.J. Keay, J.R. Charter and L. Okigbo of the F.D.F.H. and to Messrs P.T.W. Henry, J.F. Redhead and L. Skilling of the W.R.F.D.; and also to Mr Benjamin Daramola, botanical collector at the F.D.F.R., for his extremely competent knowledge of the Nigerian forest flora and for help in many ways.

To Dr and Mrs B.W. Taylor, of the F.A.O. Land Survey Team in Western Nigeria (now in Nicaragua).

To the Chief Conservator of Forests in Malaya and his staff in many parts of the Federation, and particularly at the Forest Research Institute, Kepong. Special thanks are due to Messrs G.G.K. Setten, J. Wyatt-Smith, Wong Yew Kwan and A.J. Vincent, and particularly to my guide, travelling companion, interpreter, plant namer and good friend, 'Che Abdul Hamid bin Din.

Mention must also be made of the very appreciable help given by Mr David Moore, Conservator of Forests, Trinidad, and by Mr E. Volck, Silvicultural Research Officer, Atherton, Queensland, and of the willing typing services rendered by the typists attached to the Division of Forest Management, Forestry Commission of N.S.W. Finally I must express my most sincere thanks to my wife, Ruth, and my daughters, Louise and Angela, for their continued support, help and encouragement over a period that was not without its difficult and anxious moments.

This report was originally prepared for limited distribution only, but at the suggestion of the former Commissioner for Forests in New South Wales, Mr E.L.S. Hudson, and his successor, Mr W.D. Muir, it has been revised for a wider audience. Although the contents of the report break little ground that is truly nes, it is hoped that this review of activities and information from a wide range of sources will be of some value to foresters and land-use planners throughout the rainforest regions.

The finished report is longer than had first been anticipated, partly due to repetition of various data in different sections of the report, and partly due to the desire to cover, as far as possible, all aspects of the Fellowship topic. As a result the report contains much detailed background information to support the main theses advanced. A summary of these theses will be found in Chapter 14, and the main development of these as they relate to the study topic will be found in Chapters 1, 6 and 11. These four chapters form the crux of the report.

George N. Baur.

Sydney.

June, 1964.

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CHAPTER 1

INTRODUCTION - THE PLACE OF RAINFOREST

> "Few writers on the rain forest seem able to resist the temptation of the 'purple passage', and in the rush of superlatives they are apt to describe things they never saw or to misinterpret what was really there." Richards (1952, p. 2.)

Defining Rainforest

The term "rainforest" * means different things to different people. At one extreme is that strict definition introduced by Beard (1944a, 1955) for use in tropical America, a definition which undeniably includes rainforest in its highest state of development but which, if widely applied, would probably eliminate rainforest entirely from the African continent and restrict its occurrence to a relatively insignificant proportion of tropical America and a somewhat larger, though still much reduced, proportion of southeast Asia and the southwest Pacific. Under these circumstances the problems of rainforest management become of much less moment purely because of the much smaller area affected. At the other extreme is a literal definition derived from the term itself: a closed plant community dominated by trees ("forest"), occuring under conditions of abundant moisture ("rain"). In this context such diverse communities as the Abies-Tsuga stands of Mt Olympus in the state of Washington, U.S.A., the simple structured Nothofagus forests of Chile, New Zealand and southern Australia, and a much wider spectrum of forests throughout the tropics and subtropics are all commonly known as rainforest. Australia, where the endemic sclerophyllous genus Eucalyptus dominates so completely the great bulk of forest communities occurring in the island continent, has taken this process even further, and tends to consider any closed forest of Indo-Malaysian or Antarctic floristic affinities as rainforest (colloquially "brush" or "scrub"), regardless of the implied need for favourable moisture conditions. (Baur, 1957; Webb, 1959.)

Schimper (1903), who recognized four types of rainforest, considered that "the most essential characteristic of a rainforest" was its being composed of evergreen hygrophilous trees. Schimper's general concept of rainforest is that which is being adopted in this report, and this stands between the two extremes mentioned above. He did not regard the coniferous forests of the North American Pacific North Coast as rainforest, but as a form of temperate coniferous forest, and these communities are not considered here though coniferous species (but rarely needle-leaf species) enter into the composition of some of the stands recognized here as rainforest. Similarly, communities containing some deciduous species are not automatically excluded from rainforest as is done by Beard, provided evergreen species dominate the stand. This is similar to the usage adopted by Richards for tropical rainforest and is still in agreement with Schimper, who noted that in the temperate rainforest "periodically foliaged trees occur as subordinate components".

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* The spelling of "rainforest" as a single word, rather than the commonly used two words ("rain forest") is preferred as indicating the community's status as a fully independent plant formation and to avoid undue emphasis on rain as the sole determining environment factor.

Rainforest, as interpreted in this report, can therefore be defined as a closed community of essentially, but not exclusively, broadleaved, evergreen, hygrophilous trees, usually with two or more layers of trees and shrubs and with dependent synusiae of other life-forms such as vines and epiphytes. It thus includes the characteristic vegetation of the humid tropics, even where this has a somewhat seasonal climatic regime, as well as that of moist, elevated areas in the tropics and subtropics and of the somewhat oceanic climates typical of parts of the southern temperate zone.

Within this broad definition of rainforest numerous structural and physiognomic combinations are possible, dependent upon such features as the height of the community, the number of tree layers, the presence of a deciduous element, the most common leaf size and the nature of the epiphytes. Schimper, as the pioneer worker in this field, recognized only four such combinations, tropical, subtropical, temperate and "temperate rainforest in the tropics", i.e. montane rainforest. Tropical rainforest was defined as "evergreen, hygrophilous in character, at least 100 feet high, but usually much taller, rich in thick-stemmed lianes and in woody as well as herbaceous epiphytes". Other usual features were the presence of stem buttressing, cauliflory and large, frequently compound leaves often showing marked drip tips. Temperate rainforest he described as being composed of evergreen, hygrophilous trees, with some winter-deciduous species often present as subordinates, with smaller more leathery leaves lacking drip tips, and with buttressing and cauliflory unknown. Subtropical rainforest was regarded as an extension of tropical rainforest beyond the tropics, characterized by a gradual reduction in the wealth of forms found in the tropics and by the addition of certain temperate forms. Montane rainforest Schimper noted as having a tropical character when occurring near the equator at relatively low elevations, but as having a temperate character from the first when occurring near the geographic tropics.

Subsequent workers have tended to proliferate these types. Beard (1944a, 1955), from the tropical lowlands and mountains of America, recognized at least five structurally distinct communities ("formations") that fit within the definition of rainforest used here: rainforest, evergreen seasonal forest, dry rainforest, lower montane rainforest and montane rainforest. Webb (1959), working along a latitudinal transect in eastern Australia from tropical north Queensland to temperate Tasmania, has classified five main vegetation types ("sub-formations") from within the defined limits of this report: tropical rainforest (mesophyll vine forest of Webb's new nomenclatural system), subtropical rainforest (notophyll vine forest), submontane rainforest (simple mesophyll vine forest), warm temperate rainforest (simple notophyll vine forest) and cool temperate rainforest (microphyll mossy forest). In both cases additional communities could be included within the definition without stretching its admittedly rather elastic limits too far, for example by adding Beard's semi-evergreen seasonal forest and swamp forest or Webb's semi-evergreen vine forest. Other workers have not subdivided rainforest to quite the same extent, but have introduced a somewhat bewildering array of names for similar communities. Thus Schimper's tropical rainforest is largely synonymous with rainforest (Chipp, 1926), wet evergreen forest (Champion, 1936a), and lowland evergreen rainforest (Burtt-Davy, 1938), not to mention Webb's mesophyll vine forest. Similarly Beard's semi-evergreen seasonal forest corresponds closely to semi-evergreen forest (Champion), semi-evergreen rainforest (Burtt-Davy), tropical wet forest (Holdridge, 1947), and mixed deciduous forest (MacGregor, 1934); and Beard's montane rainforest to temperate rainforest in the tropics (Schimper), mountain forest (Chipp), wet temperate forest (Champion), and upper montaine rainforest (Burtt-Davy).

The Floristic Elements in Rainforest

The floristic composition of rainforest tends to be complex. A plot of 5 acres in relatively undisturbed rainforest examined near Belem, on the Amazon, contained 36 families with representatives attaining a diameter breast height of at least 4 inches; slightly under 10 acres in northern New South Wales had 31 families reaching the same size. In both areas the inclusion of vines, herbs and epiphytes would have added appreciably to these numbers of families.

The floristic affinities of the great bulk of present day rainforest species appear to lie in groups which have arisen and evolved under conditions very similar to those at present prevailing in the world's rainforests, and which at the same time have contributed largely to the vegetation of the more adverse climatic conditions existing at the periphery of the rainforest zones. As Richards (p. 405) says of the tropical rainforest, it has been a centre of evolutionary activity from which the rest of the world's flora has been recruited. Two main areas of such evolutionary activity can be recognized, one occurring in the humid lowland tropics, and the other in the southern temperate zone. These have given rise to what can be regarded as a tropical and an Antarctic floristic element respectively. The first is typified by such pan-tropic families as the Lauraceae, Asclepiadaceae, Melastomaceae, Sapotaceae, Burseraceae and the succulent-fruited Myrtaceae, as well as by more geographically restricted, and possibly less ancient, families such as the Vochysiaceae (centred in America) and Dipterocarpaceae (centred in southeast Asia). The Antarctic element, which is of much less importance, is typified by the genus _Nothofagus_, and by the families Cunoniaceae, Eucryphiaceae, Winteraceae and possibly also by the Podocarpaceae, Monimiaceae and Proteaceae. To these two groups might be added a third, of north temperate affinities, and including such genera as _Quercus_ and its close relatives, and _Rhododendron_, which enter significantly into some of the tropical montane rainforests and which are also important constituents of some of the temperate rainforests recorded by Schimper for the northern hemisphere (e.g. in southern Japan). These northern temperate rainforests are not dealt with in this report.

Schimper's tropical and temperate rainforests are fairly distinct structurally, and show a marked predominence of the tropical and Antarctic floristic elements respectively. They can well be regarded as separate formations of equal status, united by their common characteristics under the general definition of "rainforest". In the subtropics both floristic elements come into direct contact, but although some mixing of the elements occurs, there is a tendency for one or other clearly to predominate and for the structure of the rainforests of the subtropics to show a strong similarity to either tropical or temperate rainforest, depending whether the tropical or Antarctic element is dominant. Thus in subtropical New South Wales, Webb's notophyll and simple notophyll vine forests occupy adjacent sites, the former with a strong tropical floristic representation and a very close structural similarity to tropical rainforest, and the latter with a predominance of of the Antarctic element and a structure akin to that of temperate rainforest. There is indeed greater structural similarity between the notophyll vine forests of New South Wales and, for example, Richards' Mixed Forest association of British Guiana, than there is between either notophyll and simple notophyll vine forest in New South Wales, where the ecological separation is closely related to soil fertility (Baur, 1957 *), or the Mixed Forest and Wallaba associations in British Guiana. Thus it appears desirable to regard Schimper's subtropical rainforest as a term of essentially environmental connotation applying to several communities of very distant kinship to each other, but closely related structurally and floristically to either tropical or temperate rainforest. Under these circumstances, subtropical rainforest cannot be given formation status.

The "temperate rainforest in the tropics" of Schimper is less easily dealt with. In all areas where this occurs, there appears to be some tropical floristic influence, sometimes quite strong (e.g. in Africa, Burtt-Davy, 1935; King, 1953). In Australia, the Antarctic element is dominant, extending to New Guinea but diminishing towards Malaya, while in India there is a strong north temperate floristic influence which continues through Malaysia to New Guinea, but is barely felt in northern Australia. Tropical America shows a similar occurrence of the three floristic elements. Structurally the rainforests of the tropic montane regions are very similar to each other in all areas and show much greater similarity to temperate rainforest than to tropical rainforest. Although the structural characteristics of montane rainforest are less closely allied to the dominant floristic element than is the case with rainforest in the subtropics, it appears desirable, as Schimper's original name suggests, to regard these montane rainforests as belonging to the temperate rainforest formation.

Subdivisions of Rainforest

As indicated above, rainforest, as understood in this report, consists of two formations of distinct structural characteristics. These in turn can be further subdivided into more precise structural units, or subformations, along lines similar to those used by Beard (1944a, 1955) and Webb (1959). Much further work in various parts of the world's rainforests is needed before it will be possible to define and classify all these subdivisions with any degree of precision; indeed, because of the general tendency for vegetation types at any level to grade into each other except where some steep environmental gradient occurs (e.g. sudden change in soil parent material), it may never be possible to classify all the possible subformations with accuracy and yet avoid an overabundance of divisions that are meaningless from most practical viewpoints. However, some subdivision is necessary, and the work of Beard and Webb provides a useful foundation. On this basis, the following subformations are recognized:

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* Notophyll vine forest of Webb is synonymous with the "tropical rainforest" of Baur, and simple notophyll vine forest with "subtropical rainforest".

Tropical Rainforest Formation:

Subformation	Beard Equivalent	Webb Equivalent
Equatorial Rainforest	Tropical Rainforest	-
Evergreen Seasonal Rainforest	Evergreen Seasonal Forest	Mesophyll Vine Forest
Semi-evergreen Rainforest	Semi-evergreen Forest	Semi-evergreen Mesophyll Vine Forest
Xeromorphic Rainforest	Dry Rainforest	-
Submontane Rainforest	Lower Montane Rainforest	Simple Mesophyll Vine Forest
Swampy Rainforest	Swamp Forest	Mesophyll Palm Forest
Subtropical Rainforest	-	Notophyll Vine Forest
Temperate Rainforest Formation:		
Cool Temperate Rainforest	-	Microphyll Mossy Forest
Warm Temperate Rainforest	-	Simple Notophyll Vine Forest
Montane Rainforest	Montane Rainforest	Microphyll Mossy Forest

This is not an exhaustive list. For example, in the temperate rainforest formation, it is considered doubtful whether the communities in the norther hemisphere, such as those of southern Japan, will be found to match those of the southern hemisphere sufficiently closely to be placed in the same subformations. Similarly it will probably prove necessary in cool temperate rainforest to separate those communities with winter-deciduous species (e.g. some forests in southern Chile) from those lacking deciduous species (e.g. the Nothofagus forests of southern Australia and New Zealand). Some of the main structural characteristics of the subformations listed above are shown in table 1. A few of the subformations do not fit exactly to the synonyms which are listed for Beard and Webb, but match part of these authors' definitions: this occurs when the communities defined by Beard or Webb include in their range of structural characteristics extremes that do not fall within the definition of rainforest being used here; Beard's semi-evergreen forest and swamp forest are examples. Communities which are immature, or which include relics of an earlier community being replaced by rainforest, are excluded from the classification.

Distribution of Rainforest

Rainforest forms the dominant vegetation in those areas of the world that receive a high and generally well distributed rainfall, coupled with an avoidance of extreme winter cold. Tropical rainforest is

TABLE 1

STRUCTURAL CHARACTERISTICS OF RAINFOREST SUBFORMATIONS

Formation	Subformation	No. Tree Layers	Upper Canopy Height	Emergents	Canopy Level	Dominant Leaf Size	Deciduousness	Buttressing	Heavy Vines	Epiphytes		Cauliflory
										Vascular	Non Vascular	
Tropical Rainforest	Equatorial	3, 4	120'+	r	cont. even	Meso-	a	+	p	+	p	+
	Evergreen Seasonal	3	100'+	p	cont. uneven	Meso-	p(<1/3)	+	+	p	r	p
	Semi-evergreen	2, 3	80'+	p	cont. uneven	Meso-	p(1/3 - 2/3)	p	p	vr	vr	vr
	Xeromorphic	2	60'+	a	cont. even	Meso-, Noto-	r	r	r	p	r	r
	Submontane	2, 3	80'+	r	cont. uneven	Meso-, Noto-	r	p	p	+	+	r
	Swampy	2, 3	80'+	r	discont. uneven	Meso	r	+	p	+	r	p
	Subtropical	3, 2	100'+	r	cont. uneven	Noto-	r	+	p	+	p	vr
Temperate Rainforest	Cool Temperate	1, 2	60'+	a	cont. even	Micro-	a or p	a	r	vr	+	a
	Warm Temperate	2	80'+	r cont.,	even	Noto-	a	r	r	r	p	a
	Montane	2, 1	50'-120'	a cont.,	even	Micro- Noto-	a	vr	r	r	+	a

NOTES ON TABLE 1

1. Number of Tree Layers: Where two values are given, the first is the more common
2. Emergents: Trees with crowns standing largely above the general canopy level
3. Canopy Level: Cont. = continuous, discont. = discontinuous; an uneven canopy indicates appreciable variation in the height of the upper canopy level.
4. Dominant Leaf Size: meso-, noto- and microphyll as defined by Webb (1959).
5. Deciduousness: the values indicate the proportion of upper canopy individuals which are deciduous.
6. Symbols: + = common or very common; p = present; r = rare; vr = very rare; a = absent.

distributed more or less evenly astride the equator in America, Africa and southeast Asia. In America the main zone is in the valley of the Amazon River and the adjacent Guianas, with extensions northwards through Central America and the islands of the Caribbean Sea, and southwards along the east coast of Brazil to beyond the tropics. The African occurrence is found along the coast of West Africa and in the Congo River Basin, as well as in parts of Madagascar and in the Mascarene Islands (Mauritius and Reunion). In southeast Asia, tropical rainforest is centred in the archipelego stretching from Malaya to New Guinea, extending south to beyond the tropics in eastern Australia, north and west through Burma and Thailand to southern China, India and Ceylon, and east to the islands of the Pacific Ocean. Within this general region of tropical rainforest, montane rainforest is to be found on the high perhumid mountains.

Temperate rainforest is much more limited in occurrence. Probably because of the severe winters of the land-dominant northern hemisphere it is very restricted north of the equator other than as montane rainforest, southeast China and parts of Formosa and southern Japan having the only appreciable area. Elsewhere in the northern temperate zone, it is replaced by summer-green forests or coniferous forests. South of the equator it is more widespread, being found in southeastern Australia, much of New Zealand, parts of southern South America and in a few small areas of South Africa.

World maps showing the distribution of tropical rainforest are given by Richards (1952) and Haig and al. (1958), while more detailed maps of particular regions have been given by Hueck (1957, South America), Keay (1959b, Africa), Champion (1936a, India and Burma), van Steenis (1959, Malaysia), Anon. (1950, Thailand), Webb (1959) and Williams (1955, both for Australia). Based largely on these sources a synthesis of the distribution of rainforest has been attempted, and is shown in figure 1.

It is impossible to make more than a rough estimate of the area occupied by rainforest at the present time. Hueck gives the area of the Amazonian Hylaea, which is the largest belt of rainforest in the world and also the area least disturbed by man, as 4.5 million square kilometres (1.7 million square miles), while other areas of tropical rainforest in the western hemisphere may amount to another 0.6 million square miles. In Africa, the total area is probably a little over 1.0 million square miles, and in the Asian-Pacific region slightly more, about 1.2 million square miles. This gives a total area for tropical rainforest in the order of 4.5 to 5.0 million square miles. By contrast, the total area of temperate rainforest in the world is probably less than 300,000 square miles. Rainforest of both formations thus occupies about 9% of the earth's land surface of 55 million square miles.

In past geological time, rainforest has occupied very much larger areas. The evidence for this lies both in the discontinuity of rainforest occurrence within individual land masses and in the fossil record. The discontinuous distribution of rainforest in eastern Australia (Baur, 1957; Webb, 1959) and in Africa (Moreau, 1933; Boughey, 1956) points strongly to the wider spread of rainforest in the Pleistocene, while fossils of undoubted rainforest affinities suggest an even greater distribution during parts of the Tertiary. There seems little doubt that these changes in rainforest distribution since the Cretaceous are related to changing climatic patterns during the same period.

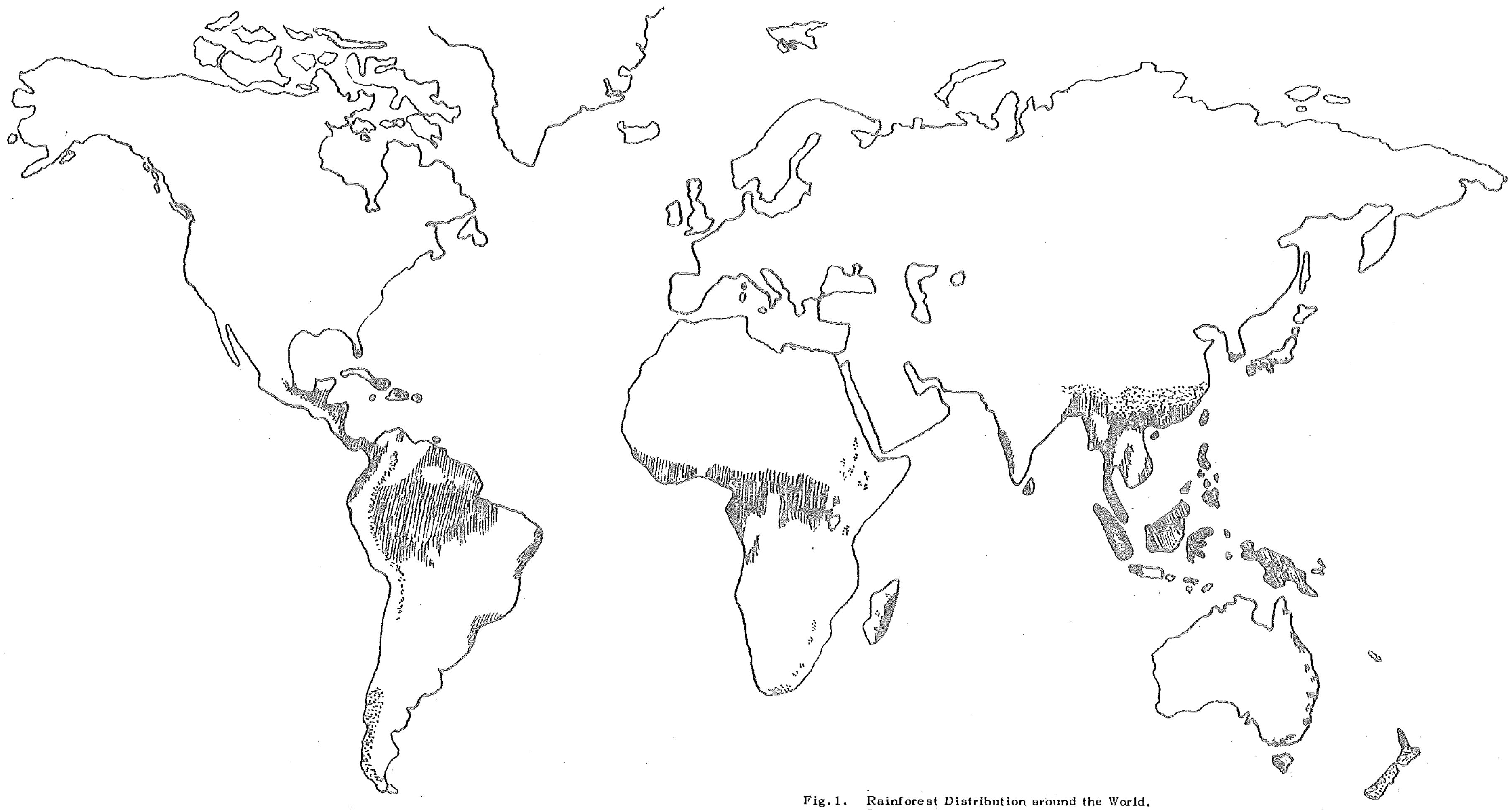

Fig. 1. Rainforest Distribution around the World.
Stippled: Tropical rainforest formation.
Dotted: Temperate rainforest formation.

The present boundaries of rainforest are far from static. Given freedom from fire and other disturbance there appears to be an almost worldwide tendency for rainforest to encroach into adjoining plant formations, as has been reported by Taylor (1962) from Central America, Charter and Keay (1960) from West Africa, and Baur (1962a) from eastern Australia. Although this tendency has been interpreted as a response to recent climatic change (Cromer and Pryor, 1942), the weight of evidence points to its being mainly a reaction to a temporary removal of strong biotic pressure. However the overall picture of rainforest distribution is certainly not one of expansion, but rather of contraction under the combined onslaught of shifting cultivation, settled forms of agriculture, grazing and fire. In New South Wales alone it is estimated that two-thirds of the area of rainforest present at the time of European settlement have been destroyed, mostly during the past century, and reductions of a similar order have occurred in the more extensive rainforests of Queensland and New Zealand. Destruction in the tropics has been slower, though the broad belt of Forest-Savanna Mosiac shown surrounding the rainforest belt of Africa by Keay (1959b) is indicative of the reduction that has occurred in the past in that continent. With modern public health measures permitting a more rapid increase in population, and with improved agricultural knowledge allowing the development of settled farming practices in the humid tropics, the rate of rainforest destruction must be expected to speed up immensely during the coming century and, indeed, the process is already well established in parts of West Africa and southeast Asia.

Importance of Rainforest

A type of vegetation covering nearly a tenth of the world's land surface is clearly of more than academic interest. When this vegetation happens to coincide with some of the finest growing conditions known in the world, and to occur in areas where the current rates of population growth are among the world's highest, it becomes obvious that sound understanding and proper management of the vegetation occupy high priority in the list of problems facing the world. This is the case with rainforest, particularly the tropical formation. For millions of years rainforest has existed, probably in forms little different from those extant now, its distribution varying with changes in the world's climate, until at the close of the Pleistocene its geographic occurrence approximated closely to that which it now occupies. In relatively recent times man entered the rainforest, in the first place often as a fugitive from more aggressive and powerful tribes*. Here he found shelter and lived by hunting the animal life of the rainforest and by collecting the edible fruits and roots of various rainforest plants. In such a primitive economy man's effect on the rainforest was little greater than that of the native fauna, and indeed must have been less than that of large animals like the elephant, which play a not insignificant role in determining rainforest structure in parts of Africa to this day. Such nomadic, food-gathering people still exist in parts of the rainforest zones in all three major areas of tropical occurrence, and had their temperate counterparts in the original inhabitants of Tierra del Fuego and Tasmania.

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* As an example, the early negrito inhabitants of north eastern Australia only survived the later migration of the Aborigines as a racially distinct group in the protection offered by the mountainous rainforests of North Queensland (Tindale, 1959).

To this stage, the importance of rainforest to the world at large was relatively slight. It was the home of a comparatively small number of people. Throughout the Cainozoic Era it had served as a focus of plant evolution and had appreciably enriched the floras of the more adverse climatic zones beyond its boundaries. It clothed steep mountain slopes, protecting their soil from excessive erosion in torrential downpours. It may have exerted some ameliorative effect on the climate. In some of its more swampy phases it had produced deep peat deposits which, in the course of geological time, were converted to lignite (brown coal). On its debit side, from an anthropocentric viewpoint, it served as a vast reservoir of some of the most malign diseases to which man is heir - a state of affairs which unfortunately persists in some regions.

With the coming of more civilized conditions, the importance of rainforests increased immensely. Plants, particularly those with edible roots or tubers which had previously been gathered from the natural forest, were found amenable to cultivation. Such plants as the pan-tropical yams (Dioscorea spp.) and plantains (Musa spp.), the American cassava (Manihot utilissima) and the southeast Asian cocoyam or taro (Colocasia esculentum) were brought into cultivation, were exchanged on a worldwide scale, and made possible permanent settlement within the rainforest. This settlement was usually accompanied by the development of a shifting or bushfallow system of agriculture, which in some cases led to the degradation of the rainforest, under excessive farming and burning, to grassland or savanna. Other plants of the rainforest, generally used by the native inhabitants but of less local significance than the staple food plants, proved to have considerable economic value in world trade.

Some, such as the American rubber tree (Hevea basiliensis), cacao (Theobroma cacao), the African oil palm (Elaeis guineensis), and coffee (Caffea sp.), have been extensively planted in the tropical rainforest regions of the world, and contribute a major proportion of the export earnings of the main producing countries. Others are less widely cultivated but, from natural sources and smaller artificial plantations, yield a wide range of products for international commerce, including such items as fruits (Brazil nut or Castanheiro, Bertholletia excelsa; Custard-apple, Annona spp.), latex (other rubber plants such as Castilla elastica and Sapium spp.; chicle producers such as Achras sapota, Dyera costulata and Manilkara huberi), resins (various Burseraceae and and Dipterocarpaceae; Agathis spp.), essential oils (rosewood oil, Aniba sp.), medicinal products (quinine, Cinchona officinalis; curare, Strychnos toxifera; hyoscine Duboisia myoporoides), insecticides (Lonchocarpus spp.; Derris spp.), spices (cloves, Eugenia caryophyllata; peppers, Piper spp. and Capsicum spp.; ginger Zingiber officinale), rattans (Calamus spp.), kapok (various Bombacaceae) and other products. Apart from their importance to the economy of individual producing countries some of these plants have had a major bearing on the development of world history, climaxed by the discovery of the Americas in the search for an easy sea route to the spice-rich lands of southeast Asia. In a less commercial sense, rainforests have contributed greatly to the enjoyment of garden-lovers throughout the world with plants ranging from flowering trees (African tulip tree, Spathodea campanulata; Australian silky oak, Grevillea robusta and flame tree, Brachychiton acerifolius) to a host of ferns and "fern-allies", orchids, aroids, bromeliads and other ornamental herbs, shrubs and vines.

So far the importance of rainforests as timber producing areas has not been mentioned. To the forester, the significance of rainforest, and particularly tropical rainforest, lies in the fact that it constitutes a high forest zone equalled in extent only by the northern hemisphere coniferous forest belt or taiga, but botanically vastly more varied. Whereas the total tree flora of the taiga can be measured only in hundreds of species, that of the rainforest must be measured in thousands. Richards (p. 229) quotes some figures showing the wealth of tree species in tropical rainforest: 3,000 species from the Outer Provinces of the former Netherlands East Indies, 2,500 from the Amazonian Hylea as a whole, 600 from the Ivory Coast. Haley (1957) records more than 100 species over 20 feet in height from a single one acre plot in north Queensland. Such arboreal diversity cannot be matched in any other vegetation zone in the world.

Timber does not appear to have been widely used by the original inhabitants of the rainforests. Logs of certain species were utilized to make canoes, small timber provided the main source of fuel for the villages, and some poles were used in the construction of buildings, but the mud- or thatched-walled, thatch-roofed houses still so common in the less developed tropical rainforest regions typify the general style of building used throughout the humid tropics. The original dwellers in the temperate rainforests of Tasmania and Tierra del Fuego, despite the rigorous climate, apparently never built themselves more than temporary shelters of branches: well might Charles Darwin call the Fuegians "the most abject and miserable creatures I anywhere beheld" *. The reasons for this little use of timber by the local inhabitants are not hard to find. Timber borers and wood destroying fungi abound in the tropical rainforest environment and cause the rapid rot of all but a few highly resistant species of timber, and these resistant species are difficult to handle in the absence of fairly well developed technological skills. The relatively permanent mud and the cheaply replaced thatch were an obvious choice under the circumstances.

Per capita consumption of timber products other than fuel remains low in most tropical rainforest countries. Typical figures for annual consumption of sawn timber per head of population over the period 1957-59 (derived from F.A.O., 1960a) are:

Temperate Countries		Tropical Countries	
** Australia	13.4 cubic feet	Belgian Congo	0.53 cubic feet
Germany (West)	6.4	Brazil	1.6
+ New Zealand	23.1	Ghana	0.71
United Kingdom	5.8	Reunion	1.9
United States of America	16.2	Trinidad	3.9
U.S.S.R.	15.2		

World average, 4.9 cubic feet per head of population.

*Journal of Researches, entry of December 25th, 1832.

** Although Australia possesses tropical rainforest, the percentage area of such forests is low and timber production comes largely from the eucalypt forests.

+ In New Zealand timber consumption is now based essentially on the produce from its extensive plantations of exotic conifers.

Although chiefly due to the generally lower standard of living in tropical countries compared with that of most temperate countries, the low consumption of timber in the tropics also reflects to some extent the long standing prejudice against wood products in the rainforest zone. However with rising living standards, the application of the results of forest products research, and education in the use of timber, the local consumption of timber must be expected to increase appreciably in coming decades. Thus the general use of timber for buildings in British Guiana (Groves, 1945) is reflected in an unusually high consumption figure for that country.

Exploitation of rainforests to provide timber for export commenced very shortly after the first European contact with the rainforest regions took place. As early as 1501, less than 10 years after Columbus first set foot in the New World, quantities of the live-coal ("braza") coloured pau brasil (Caesalpinia echinata) were being carried to Portugal from the east coast rainforests of South America, the wood itself giving its common name to the largest country in South America (Souza, 1945). From these beginnings nearly 500 years ago was established the international trade in tropical rainforest hardwoods which continues to the present. Throughout most of this time the emphasis has been on the export of a limited number of specialty timbers for which direct substitutes were not locally available in the importing areas. Much of the early trade was concerned with cabinet timbers such as the American mahogany (Swietenia macrophylla) and cedar (Cedrela spp.). The diminution in supplies of Swietenia in the mid 19th century led to the development of an export trade in the mahoganies (Khaya spp. and Entandrophragma spp.) from West Africa (Pollard, 1955). The species involved were those which would command a high price on the world market; while most were richly coloured and figured cabinet species, others with unusual qualities were also exported once their qualities were recognized and a reliable demand established; greenheart (Ocotea rodiaei) from British Guiana and basra locus (Dicorynia paraensis) from Surinam as sources of borer-resistant marine timber, balsawood (Ochroma lagopus) from the Caribbean for its extremely soft, low-density timber, and lignum-vitae (Guaiacum spp.) for its conversely hard, high density timber are examples. Changing fashions have occasionally caused a formerly important species to lose its demand: thus the ebonies (Diospyros spp.) which were exported in considerable quantity from West Africa early in this century now rarely figure in the bills of lading from the Gulf of Guinea; their fall from favour as cabinet woods and the substitution of plastics for their more specialized uses have relegated them to among the least valuable species of the African rainforests (Pollard, 1955).

While the premium quality specialty timbers continue to be most sought after, there has been a steady increase in the number of other species exported. Some of these have entered the trade as substitutes for established, but decreasingly available, species, but more important has been the development of export trade in the lighter, general purpose timbers such as the Malayan merantis (various Shorea spp.) and the Nigerian obeche (Triplochiton scleroxylon). This trend was becoming evident in the 1930's, received a considerable boost (at least so far as West Africa was concerned) during the 1939-45 war, when softwood supplies to Britain from northern Europe were cut off, and has been maintained since. The log export figures for Nigeria are of interest in this regard:

Log Exports of:

Year	Mahogany Volume cubic ft	%	Obeche Volume cubic ft.	%	All Species Volume cubic ft.	Source
1911	1,709,000	99.8	-	-	1,712,000	Pollard (1955)
1938	603,000	39.7	767,000	50.5	1,519,000	Pollard (1955)
1958-59	1,360,000	8.8	10,290,000	66.7	15,430,000	Western Nigeria Forestry Division (1959)

Along with the rapidly developing home demand, the export trade in tropical timbers is increasing at a fast tempo. Gallant (1960) reports a 320% increase in tropical hardwood log exports and a 260% increase in exports of sawn tropical hardwoods between 1950 and 1957, at a time when world exports of coniferous logs and sawn timber increased only 35% and 39% respectively: although timber from other plant formations is included in Gallant's figures, the great bulk of the tropical hardwoods would originate from the rainforests. However in spite of the growing importance of rainforest timbers, both in the producing countries and in world trade, their total contribution of wood products remains relatively small. Gallant notes that the areas of tropical (including forest other than rainforest) and temperate forest in the world are approximately the same and that their yields of fuelwood are of the same order of magnitude, but that in 1957 the volume of industrial wood removed from tropical forests was only 7% of the volume from temperate forests and that the removals per acre from tropical forests in use were only 16% of the removals from temperate forests in use (2.4 cubic feet per acre as against 15.0 cubic feet per acre). Yet the volume of cellulose per acre and its gross rate of increment are generally much higher in tropical rainforest than in temperate forests.

The general picture of the utilization of tropical rainforest timbers is thus one of a low home demand and of a long history of highly selective exploitation for a few valuable export species. In the last 30 years the tendency has been for many more species to enter the export trade and for home demand to increase. These factors have led to a somewhat more thorough exploitation of the forests in the main producing countries and to a higher yield, both financial and in volume, per acre, though the average yields remain very low by temperate forest standards. In turn, the rising yields and more complete logging have made possible increasingly intensive silvicultural treatment of the tropical rainforests.

It is not coincidence that improvement and regeneration treatments of extensive areas of tropical rainforest have occurred only since the upswing in demand for rainforest timbers has been evident, nor that such treatments have been most successful and most widely applied in the countries where demand is greatest. Using the past as a pointer to the future, it can be expected that the tropical rainforests will be called upon to play an increasingly important role as timber producing areas in the years ahead. Here, rather than in the temperate zones, is where the world must ultimately look for the reservoir of its most versatile renewable natural resource. With this end in view, the development of sound silvicultural practices in the tropical rainforests becomes a problem of very great urgency.

The role of temperate rainforest as a timber producer has been and can be expected to remain much less than that of tropical rainforest. The area involved is considerably smaller and a large proportion of the more accessible land formerly under temperate rainforest has been successfully converted to permanent agriculture. Much of the remaining stands are in areas of steep topography where their protective functions far outweight their value for timber production. Its influence on the world's timber trade has been relatively slight, and has been local rather than in the field of exports, though in the past some of the Podocarpaceae have been sought after in world markets. There is little reason to expect this position to alter appreciably in the future. If anything, its significance will decline by conversion of the rainforest communities to artificial stands of species of faster growth and of easier working qualities, such as Eucalyptus spp., Pinus spp. and Pseudotsuga menziesi. Nonetheless some such communities yielding locally important timbers will continue to be managed as rainforest, for example the coachwood (Ceratopetalum apetalum) rainforests of New South Wales, so that the silviculture of temperate rainforest is not without some importance. This applies particularly where forests, essential for protective purposes, can also be managed to supplement timber supplies.

CHAPTER 2

THE RAINFOREST ENVIRONMENT

"A wealth of plant geographical observation has demonstrated that vegetation is distributed in accordance with regional climatic patterns, changes as soil parent material changes, differs on opposing slopes, varies with the geographical differences between floras, and develops with time." Major (1951).

Introduction - Some Ecological Principles

Plant ecology is often described as the study of the relationships between plants and their environment. This is a very incomplete definition, though more charitable and explicit than some*. However, it does serve to stress that an important section of ecology deals with the effects of environment upon the occurrence and development of vegetation, and in this context, environment can be interpreted as including all those external factors that influence the nature of vegetation in any way.

Before considering these factors and their effects on the development of rainforest in any detail, it is perhaps necessary to examine briefly a few rather fundamental precepts. Vegetation is composed of living organisms, and consequently it is constantly changing as the individual plants pass through the various stages of their life cycle to ultimate death, and to replacement by new plants of the same or different species. When this continual process of change reaches a state of relative equilibrium, so that the general composition and character of the vegetation remains broadly the same over a given area for a period longer than the life-span of the longest living individual (the climax period), then can the vegetation be regarded as climax.

To attain this state of internal dynamic equilibrium climax vegetation must be also in a state of equilibrium with its environment. Again, by virtue of the nature of certain environmental factors, the equilibrium is relative only. However, provided that within this climax period the conditions necessary for the individual species to complete their life cycle recur, the vegetation is able to persist with its average composition unaltered. If the conditions for certain species to complete their life cycle do not recur, then the community will gradually change in composition until it at last reaches a different state of equilibrium and produces some other form of climax vegetation. The most obvious examples of such change are associated with primary or secondary succession, as when vegetation commences to develop on recently exposed land surfaces, or to redevelop in areas where the original vegetation has by some means been destroyed. Similar changes can also occur under the direct influence of changing external environmental conditions as, for example, with a long term alteration in regional climate, or with changing biotic pressures: in such cases the environment must reach stability before a climax vegetation can be restored. Where such changes take place in a number of readily recognized stages, the process can be called imposed succession.

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* A leading British geneticist has reputedly defined ecology as "the study of the incomprehensible by the incompetent", while Richards' "the subject matter of the Journal of Ecology" is scarcely more revealing, albeit less unkind.

The factors of the environment that lead to the development of climax vegetation are very numerous, but can, for convenience, be divided into five groups: climatic, edaphic, topographic, biotic and historic. This approach is a development from the well-known soil forming factors discussed by Jenny (1951), and it has been expounded by Major in the paper from which the quotation at the head of this chapter is taken. It recognizes that vegetation is a function of these five independent groups of factors acting together, and so does away with the somewhat unreal attempts to identify different types of climaxes - climatic climax, edaphic climax, and so on. Any climax is a relatively stable plant community maintaining itself in equilibrium with all five groups of factors. As any or all of these factors alter in space, so will the climax vegetation alter: conditions will become less favourable for some species that go to make up the vegetation, and these as a result will become scarcer and ultimately disappear, possibly to be replaced by others that find the changed conditions more to their liking.

By the same token, this approach greatly reduces the conditions under which the terms post-climax and pre-climax can be applied to vegetation. A post-climax community is a remnant of an earlier climax vegetation community, left behind after changed environmental conditions have caused a migration of vegetation, and incapable of maintaining itself in its present condition: if this latter point does not apply, the community is by definition climax, not post-climax. Example of post-climax vegetation are certain isolated rainforest patches left in the "derived savanna" zone of West Africa when the bulk of the original rainforest was destroyed by increased biotic pressure in the form of frequent cultivation and burning: in such patches the regular fires can trickle through the undergrowth, destroying any regeneration and thus preventing the community from surviving any longer than the life span of its longest lived constituent. Other examples of post-climax vegetation are the Australian communities, where old, overmature eucalypts occur above well developed rainforest: the invasion of rainforest into the sclerophyll forest that formed the earlier climax vegetation is again the result of a change in environmental factors, usually a greatly reduced incidence of fire. On the other hand, the so-called "gallery forests" that are frequently found fringing watercourses in the savanna zones of Africa are usually not post-climax communities: these are mostly quite stable communities in equilibrium with their localized, riverbank environment and they appear capable of existing in their present state indefinitely.

Pre-climaxes are merely late stages in a succession towards the ultimate climax, and typically possess the structure and physiognomy of the climax without having its floristic composition. Examples of pre-climaxes are the mixed rainforest communities which are ultimately replaced by the Cynometra alexandri - dominated rainforest in the imposed succession from grassland to rainforest in Uganda (Eggeling, 1947); the Araucaria - dominated rainforests of eastern Australia in a similar imposed succession (Cromer and Pryor, 1942); and the Octomeles sumatranus - dominated communities found in primary succession on areas of volcanic blast or recent alluvium in New Guinea (B.W. Taylor, pers. comm; Lane-Poole, quoted by Richards, p. 255). Since the early stages in any succession appear to pass much more rapidly than the later stages (Richards, pp. 276, 377), pre-climaxes may occupy considerable areas in any locality. Thus Eggeling states that in the Budongo forest, the mixed pre-climax community covers 60% of the area, whereas the climax Cynometra community occupies only 32%.

One other interpretation of ecological principles should be stressed here, as it follows from what has already been written, even though it applies more to the following two chapters than to this one. Any plant community consists of the individual plants of various species growing within it. Each species has only a circumscribed range of tolerances within which it can grow and complete its life cycle; as the environmental factors change over a distance, these tolerance limits are exceeded for some species and these are lost to the community, while at the same time the altered conditions enable other species to enter the community. Since it must be extremely rare for any two species in a regional flora to have identical tolerance limits, this sifting process occurs virtually by a species at a time (though in a complex community such as equatorial rainforest the chances of finding different species with similar ranges of tolerance are increased). The result is a continuum of species, and over an extensive tract of land in which the environmental conditions are only gradually varying, the plant communities found at either end of the tract may differ appreciably in both composition and physiognomy, without there being any clear limits of demarcation present within the tract. This effect appears to be well shown within the rainforest belt of the Amazon (see for example Heinsdijk, 1960). Where, however, there is a rapid change in environment, such as occurs at the geological junction of two radically different soil parent materials, the extreme contrast may cause many species to reach their tolerance limits at the same point, resulting in a very sharply defined boundary between two quite distinct communities. A "striking instance" of such a boundary has been reported by Wood (quoted by Richards, p. 222) for the junction between the Eperua falcatos and Ocotea rodiaei - dominated rainforest communities in British Guiana; equally striking and more commonly encountered are the almost sharp line boundaries produced by fire on the margin of rainforest communities in many parts of the world.

Taken to its extreme, this viewing of the vegetation of any region as a continuum of species would deny the existence of distinct plant associations, or indeed of distinct formations or subformations, as the entire vegetation could be expected to be varying constantly. To a point this indeed is the case, but in practice it is possible to select sections within the continuum over which the physiognomy and the dominant species alter but little, certainly compared the internal variations produced by the chance occurrence of individual species at different stages in their life cycle. As an example, associations can be selected, as Heinsdijk has done, within the Amazonian rainforest continuum. These for the most part are rather arbitrarily selected units of vegetation, but the writer seriously doubts whether any better method is likely to prove practicable or even possible under the circumstances: only in such a floristically impoverished and abnormal region as northern Europe could the detailed statistical examination of numerous plots (e.g. Braun - Blanquet, 1932) be seriously considered as the initial basis for vegetation classification. Within any one of Heinsdijk's associations, selected plots at the extreme geographic limits are likely to prove much more similar in composition and physiognomy than are two closely adjacent plots within the association, one dominated by large mature trees and the other occupying a gap formed by a recently wind-blown veteran.

The preceding brief review of ecological principles offers nothing that is new or original, though the approach adopted does not appear to have been widely used in rainforest studies. It appears at least to have the advantage of providing a realistic framework in which to consider and understand the occurrence and behaviour or rainforest.

In the remainder of this chapter it is proposed to review briefly the five groups of environmental factors mentioned above, paying particular attention to those factors of importance in their effects on rainforest management.

CLIMATE

The Climatic Factors

Climate is composed of a number of meteorological factors which are of the utmost importance to the development of any vegetation. Fundamentally, it is a measure of the ability of the atmosphere to provide moisture, heat, air movement and light to the environment. These features have been considered in some detail by Richards (chapters 6, 7, 8) in relation to the tropical rainforest, and only the salient points will be mentioned here, dealing first with the independent factors (i.e., those which are largely unaffected by the vegetation itself), and then proceeding to the dependent factors of the microclimate.

However, before considering these separately, the climagrams (figure 2) for a number of selected rainforest sites serve to provide an introductory view of the regional climates under which rainforest develops. In each climagram, mean monthly rainfall has been plotted against the mean monthly temperature at a standard scale. Locality details of the eleven sites illustrated are given in table 2.

These eleven sites cover between them all the rainforest subformations recognized in this report. Several points should be noted in connection with these localities. Firstly, the annual rainfall tends to be high, as the formation name infers: the lowest annual rainfall in table 2 is 54 inches at Atherton, a station occurring right on the boundary between submontane rainforest and eucalypt woodland. Secondly, all stations show some degree of seasonal character in their climates. For sites near the equator, the seasons are marked by less or more rain (e.g. Belem and Benin), but as one draws away from the equatorial zone, temperature differences also become apparent (Atherton, Cairns), and beyond the tropics the seasons are much more an effect of temperature than of rainfall (Coffs Harbour, Hokitika). In a few areas the seasons are more statistically apparent than real: Landon (1957) notes that over much of Malaya (including the Kepong and Cameron Highlands stations) "almost any month may happen to be the wettest or driest in any particular year". Thirdly, rainforest can develop in areas with a pronounced dry season. Taking the often used, though somewhat arbitrary, value of less than four inches as indicating a dry month, it can be seen that Atherton has no less than 7 consecutive dry months, Cairns 6, Ondo and Benin 5, Coffs Harbour 4, and Belem 2. Finally, it can be seen that rainforest in some form or other can occur as climax vegetation over a wide range of temperature conditions, with mean temperatures from over 80° F (e.g. the Malayan lowlands) down to 50° F and even less: temperatures in Tierra del Fuego can be expected to be considerably lower than those recorded for Hokitika, some 10 degrees closer to the equator.

Rainfall

Rainfall is important ecologically by providing a crude, though nonetheless most convenient, measure of the capacity of the site to supply moisture for the growth of plants. The quantity, distribution and reliability of precipitation itself is significant only insofar as it contributes

Fig. 2. Climagrams for Rainforest Sites.
For site details see table 2.

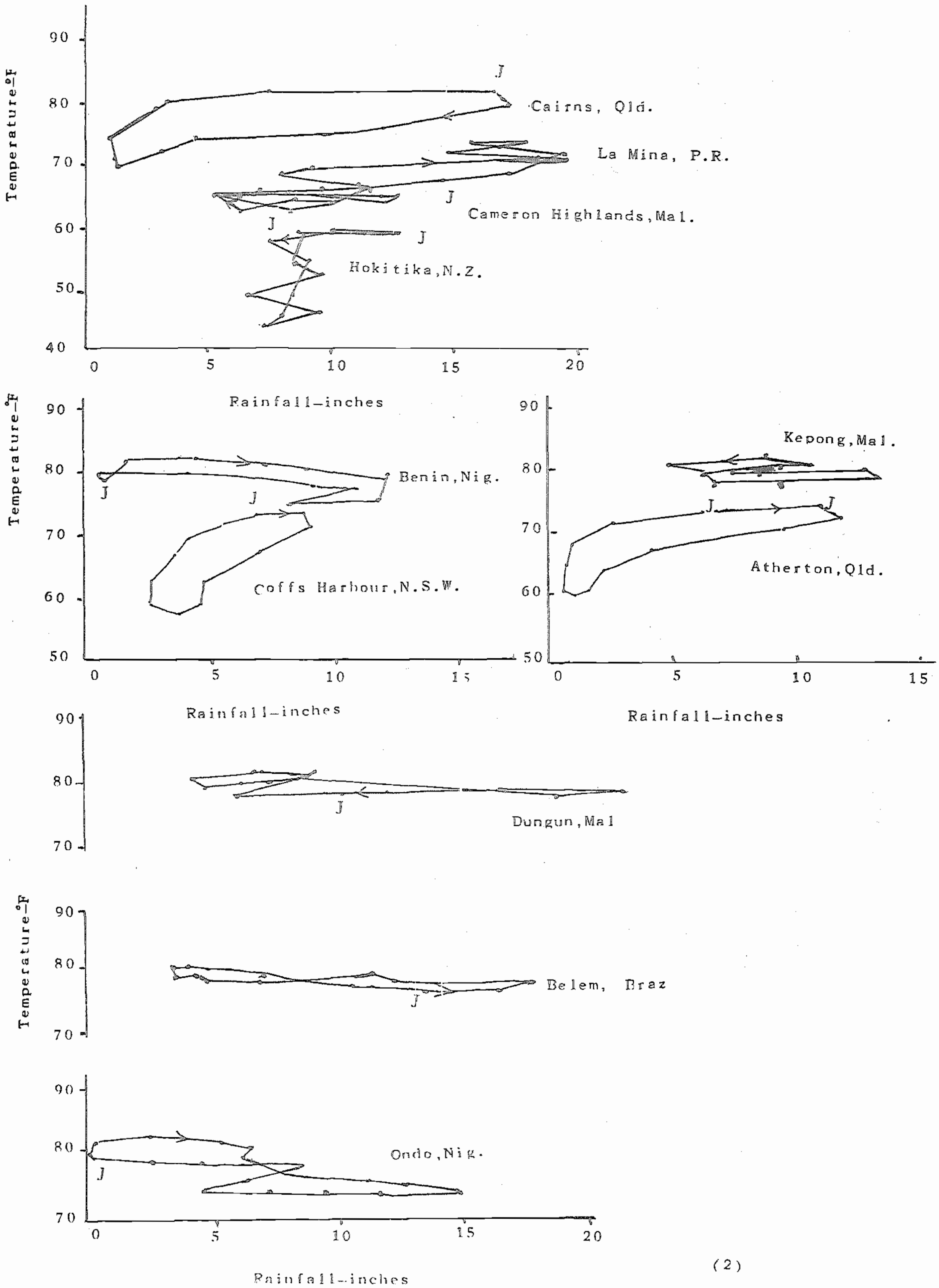

TABLE 2

Locality Details for Sites in Figure 2

Station	Altitude	Latitude	Longitude	Mean Annual Rainfall	Mean Annual Temperature	
Atherton, Queensland	2470 ft	17.3° S	145.6° E	54 in	68.1° F	Submontane
Belem, Brazil	40	1.5 S	48.5 W	106	78.1	Equatorial and swampy
Benin, Nigeria	100	6.4 N	5.5 E	78	79.2	Evergreen seasonal
Cairns, Queensland	20	16.9 S	145.8 E	86	76.3	Evergreen seasonal
Cameron Highlands, Malaya	4750	4.5 N	101.4 E	104	64.5	Montane
Coffs Harbour, New South Wales	20	30.3 S	153.1 E	65	66.3	Subtropical and warm temperate
Dungun, Malaya	10	4.8 N	103.4 E	109	80.5	Equatorial and Xeromorphic
Hokitika, New Zealand	30	43.7 S	171.0 E	108	52.6	Cool Temperate
Kepong, Malaya	320	3.2 N	101.6 E	106	80.5	Equatorial
La Mina, Puerto Rico	2350	18.3 N	66.8 W	183	70.3	Submontane
Ondo, Nigeria	150	7.1 N	4.8 E	63	76.6	Semi-evergreen

to this capacity. For this reason, it is not possible to determine absolute rainfall values, marking the limits of the distribution of rainforest and its various subformations, unless discussion is limited to areas of similar soils, free from extreme biotic disturbance, and where the moisture for plant growth comes entirely from atmospheric precipitation.

Under these conditions, the rainfall limits for evergreen seasonal rainforest in tropical America are stated to be an annual total of 70 inches, with three months each under 4 but over 2 inches, and for Beard's semi-evergreen seasonal forest (corresponding fairly closely to the semi-evergreen rainforest of this report) to be between 50 and 70 inches, with five months each under 4 inches but over 1 inch (Richards, p. 317). In Nigeria, Keay (1959a) gives an annual rainfall of 48 inches as marking the boundary of the rainforest zone, though this value is modified by humidity.

The limitations in the meaning of such values as these must, however, be recognized. Within the tropics, rainforest extends well beyond these minima along stream banks, and in other areas with favourable moisture conditions provided by the topography or soil, and may be absent from wetter areas where the soil has little capacity to retain moisture. Thus the excessively drained limestone soils in parts of the West Indies carry semi-deciduous forest formations though the annual rainfall exceeds 60 inches, and the seasonal drought is not lengthy (Beard, 1946a; Gleason and Cook, 1926). On the other hand, well developed evergreen seasonal rainforest occurs on the deep, well structured, heavy textured soils of the "planalto" (low plateau) around the C.B.A. station near Santarem, on the Amazon River, though apparently reliable records from C.B.A. stretching over eleven years indicate a mean annual rainfall of only 34 inches, with seven months under 4 inches.

Despite these exceptions - and they are extremely numerous - it remains generally true that rainforest "can exist only where the annual total of rainfall exceeds a certain minimum and there is no prolonged drought" (Richards p. 135). The 50 inch isohyet appears to provide a rough estimate of the normal limit of rainforest development in the tropics and subtropics, while in the temperate zones, where evapotranspiration is reduced, even lower rainfall will produce rainforest on well drained sites. In less humid sites, the rainforest is replaced by more xeromorphic, deciduous or sclerophyllous communities. Within the tropics the merging boundaries between the equatorial, evergreen seasonal and semi-evergreen subformations are also broadly marked by differences in the annual rainfall and in its seasonal distribution, the length of the dry season being of greater significance.

Besides its influence on the occurrence of rainforest, the rainfall pattern has certain other important effects on rainforest behaviour. Where the rainfall is distinctly seasonal, the flowering and fruiting of many species are closely correlated with the seasonal change, there being a general tendency for the fruit to ripen towards the end of the dry season and for the seeds to germinate early in the wet season. In establishing natural regeneration in such a seasonal climate the succeeding dry season is usually critical. Thus in the semi-evergreen rainforests of Nigeria, seedlings of Mansonia altissima are normally very plentiful during the wet part of the year, but very few survive the lengthy dry season. Similarly in the F.A.O. silvicultural area on the Curua River (a tributary of the Amazon River near Santarem) prolific regeneration of the valuable Cedrela odorata was obtained around selected seed trees following a good seedfall in early 1961, but by July of the same year (during the dry season) most of the seedlings had died. In attempting to establish such regeneration in the course of silvicultural treatment, it is obviously essential to maintain conditions as conducive to survival as possible during this critical first dry season.

Deciduousness might be expected to coincide closely with the dry season in tropical areas, but this is not necessarily so. In Nigeria, many of the deciduous rainforest species appear to produce new leaves early in the dry season, having been leafless during the latter part of the wet season. For deciduous species in Amazonia, Pitt (1961) notes that most have their leaffall during the dry season, but Dinizia excelsa, a true emergent in the evergreen seasonal rainforest at Curua, loses its leaves in the middle of the rainy season. Taylor (1960, appendix 1) shows that in Ghana, some rainforest species are deciduous in every month except June, though most have their leafless period during the dry season.

The reliability of the rainfall has several side effects. For at least a few species that are irregular in their flowering, an abnormally dry season appears to provide the stimulus needed to produce flower primordia. This is indicated for Triplochiton scleroxylon in Nigeria (Mackenzie, 1961) and for Nothofagus fusca and N. truncata in New Zealand (Kirkland, 1961), and probably applies to many other species. Another effect of abnormally dry seasons is to make the rainforest more vulnerable to fire damage, and where the rainforest boundary abuts land that is regularly burnt, a retreat of the rainforest is most likely to occur during years of below average rainfall, and an invasion by the rainforest in exceptionally wet sequences of years. Much of the boundary between rainforest and sclerophyll forest in Australia appears to be determined by this uneasy balance of advance and retreat, and the same can probably be said for the African rainforest - savanna boundary.

Other Atmospheric Moisture

Rainfall is not the only source of atmospheric moisture to the site, nor is the supply of moisture to the site the only ecological effect of atmospheric moisture. Moisture is also provided in small amounts by condensation in the form of dew and mist, and as one moves away from the tropics, it can also come from falls of snow and hail, while the amount of moisture vapour in the air can profoundly influence the evapotranspiration rate. Except possibly for some of the very high latitude temperate rainforests in South America, snow cannot be regarded as an important source of moisture for rainforests, though it is by no means uncommon in the temperate climatic zone where rainforest occurs. Thus in northern New South Wales (lat. 28-32°S) snowfalls periodically occur at altitudes above 2,500 feet and are of almost annual occurrence above 3,500 to 4,000 feet, where even subtropical rainforest still persists in restricted sites. It seems not unlikely that some of the crown damage to rainforest trees at these altitudes is produced by unusually heavy falls of snow.

Hail appears to be most common and severe in the subtropics, being rare though not unknown in the equatorial zone, and less rare but not of great severity in the temperate zones. Again in northern New South Wales, hail storms of considerable force occur quite regularly, though the area of damage is usually restricted, and they have been known to defoliate completely areas of eucalypt forest, killing cattle grazing beneath the trees. Similar damage in rainforest is not known to the writer, but has undoubtedly occurred * and must exert quite a distinct pressure on the course of the life cycle in such areas.

Atmospheric water vapour is, in most cases, of relatively little improtance as a direct supplier of moisture for plant growth, though there can be little doubt that the extremely profuse epiphyte flora of montaine rainforests should be attributed largely to the frequent mists that swathe most tropical mountains, and similar effects can be observed in the temperate rainforest zones. Atmospheric water vapour can, however, play an extremely important ecological role by reducing evapotranspiration rates, particularly during periods of low rainfall.

Relative humidity tends to be high in rainforest localities, approaching saturation point most evenings. However, quite low humidities can be experienced during daylight hours, especially in the dry seasons. Thus the extremely dry "harmattan" wind that blows southwards over West Africa from the Sahara during the dry season can appreciably reduce the relative humidity well within the rainforest belt for several days at a time, and Keay (1959a) considers that the low humidities associated with this phenomenon are as important as rainfall in determining the limits of rainforest occurrence in Nigeria. On the other hand, the dry season in some rainforest localities is marked by high humidities and frequent morning mists, which, by reducing transpiration rates at least over part of the day, must compensate for and counterbalance the reduced rainfall at this time of the year. Such mists appear to be common in parts of the Amazon rainforest belt during the dry season and may help explain the quite mesic vegetation at C.B.A. near Santarem in an area of very low total rainfall and of a long dry season. Similar heavy morning mists are experienced in the Nigerian rainforest belt during the dry season, and are a feature of the climate in the Mayumbe district of the former Belgian Congo where there are produced as a result of a cold ocean current off the nearby coast (Dawkins, 1955a; Wilten, 1957).

On a very restricted scale, high atmospheric moisture contents in littoral sites, brought about by constant breezes blowing off the sea, may produce a distinctive type of vegetation. In New South Wales, slopes immediately behind the beaches frequently carry a very characteristic wind-shorn scrub composed of certain species from the local rainforests (Tristania conferta, Eugenia spp., Elaeodendron australe, etc.; see Baur, 1957). These species have a high tolerance to salt and they serve a valuable protective function in sheltering the commercially important forest stands beyond the scrub. When this scrub is destroyed, widespread mortality from the unimpeded salt-laden winds off the ocean normally occurs.

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* The "Big Scrub" area in northern New South Wales, a one-time extensive rainforest area now largely converted to agricultural holdings, is subject to particularly frequent and severe hailstorms.

Temperature

With its wide latitudinal and altitudinal distribution, it is to be expected that rainforest in its various forms can tolerate a considerable range of temperature conditions, and some indication of these conditions is given by the data in figure 2 and table 2. However, certain features of the temperature regimes under which rainforest occurs deserve mention.

Mean annual temperature is a function of both latitude and altiitude. For low altitude stations, there is relatively little difference in the mean temperatures up to about 15° latitude, beyond which they decrease gradually to the vicinity of the geographic tropics, and then at a fairly steady rate with further increase in latitude. Similarly in mountains, there is a relatively steady decrease in temperature with increase in altitude. The actual rates of temperature decrease vary greatly with the local configuration of land and sea: average values appear to be in the order of a 1° F fall in mean temperature for each one degree rise in altitude or for each 250 to 300 feet increase in elevation.

Near the equator, low altitude stations have mean annual temperatures of about 80° F, and show extremely small seasonal variation, the slightly cooler months usually being associated with the periods of highest rainfall. Greater seasonal variation in temperature occurs as one moves away from the equator, and usually also with distance from the sea, though in such inland stations as Manaus, nearly 1,000 miles up the Amazon basin, the difference between the mean temperatures of the hottest and coldest months is only 3° F. It is, however, not unlikely that the immense waters of the Amazon River and its tributaries have an appreciable modifying effect on temperature in this instance. Diurnal variations in temperatures also tend to increase with distance from the sea, but for most areas of rainforest within about 10° of the equator the mean diurnal temperature range is in the order of 10 to 20° F, and temperatures above 100° F or below 60° F are rarely experienced. Tropical mountains show a similar pattern of temperature variation, but with the mean temperatures reduced. Plants under these conditions have extremely equable temperature regimes in which to grow.

Toward and beyond the tropics seasonal variations in temperature become appreciable and again are greatest away from coastal influences, with differences of up to 20° F between the hottest and coldest months being common in rainforest localities. The average diurnal range does not appear to be very different from that nearer the equator, but the extremes are much greater. Even at low altitude stations near the tropics, frost may be occasionally recorded, and it becomes increasingly severe with increases both in altitude and latitude. At the same time, the absolute maximum temperatures tend to rise slightly: even at Hobart, Tasmania (latitude 43° S) centuries are not unknown, whereas in Rabaul, New Britain (latitude 4° S) the maximum temperature has never exceeded 100° F. Thus rainforest near and beyond the tropics has to tolerate a temperature range nearly double that found near the equator. It is, however, possibly significant that in the southern hemisphere, with its large areas of water and relatively small land tongues extending into the oceans, the extreme range of temperatures encountered in the humid areas is rarely greater than 80° F. In the northern hemisphere, with its large continental land masses, the extremes tend to be much greater, and the minimum temperatures, in particular, much lower: rainforest vegetation is not found to any extent here, being replaced by winter-deciduous forests.

The minimum temperatures experienced are probably the main cause of the gradual impoverishment of the rainforest flora as one moves away from the lowland tropics, the species of tropical affinities not being replaced in nearly the same profusion by species from the temperate (e.g. Antarctic) floristic elements. The minimum temperatures can also produce profound effects on the course of secondary succession in rainforest outside the tropics by their influence on the microclimate, and this is of considerable significance in the management of rainforest areas in such sites: the development of frost hollows where clearing for plantations is carried out is an example that has been experienced in subtropical and warm temperate rainforest areas of New South Wales and is by no means unknown elsewhere.

The temperature regime of rainforest sites is essentially that which would be expected in such areas by virtue of altitude and latitude. Temperature itself does not exert a particularly significant role in limiting the distribution of rainforest in its widest sense, except where winters are severe, as in most of the northern temperate zone, or where mean temperatures are consistently low, as in tropical high mountains or southern hemisphere high latitudes, and in both these latter cases the disappearance of rainforest is often less an effect of temperature than of exposure. On the other hand, temperature plays a most significant role in determining the distribution of various species within the rainforest (see e.g. de Beuzeville, 1943), and is the dominant factor affecting the relative distribution of the tropical and temperate rainforest formations, as well as certain of the individual subformations such as submontane, montane, subtropical and warm and cool temperate rainforest.

Light

Light is one of the more important dependent, micro-climatic factors in its effects on rainforest, but is relatively unimportant as an independent factor in broad regional climatic patterns. It is, of course, an essential factor in the development of any vegetation as the source of the photosynthetic energy needed for plant growth, but with few exceptions it is rarely a limiting factor as far as the distribution of rainforest is concerned. The main exception to this is possibly on certain mountainous areas where it has been suggested that the reduction in sunlight, due to frequent cloudiness or mist, is important in producing the dwarfing of the vegetation in montane rainforest and even more spectacularly in the montane thickets (Brown, quoted by Richards, p. 153). A similar effect may account in part for presence of scrubby, thicket vegetation (e.g. the "Horizontal Scrub" of south-western Tasmania) in certain low altitude temperate areas subject to almost constant mist. Reduced light alone is probably not the sole cause of this dwarfing, but interacts with the low temperatures and constant wind. Richards (p. 154) suggests that the presence of a well-defined mist belt may often account for the transition from submontane to montane rainforest, though decreased light is only one of a number of factors producing the change.

Rainforest areas generally are not notable for long hours of sunshine. The typically high rainfall experienced in rainforest zones makes for considerable cloudiness, which may be common even during dry seasons, and figures quoted by Richards (p. 148) suggest that the average daily sunshine in rainforest is normally only about 50% of the possible, and appreciably less in montaine mist belt areas *. Richards' data also indicate that, in tropical rainforest areas, the total solar radiation available for photosynthesis is probably no greater than in many temperate regions.

The hours of possible sunshine show relatively little seasonal variation in the tropics, but with increase in latitude the length of day varies considerably during the year. Temperate rainforest in Tasmania and southern New Zealand may experience over 16 hours of sunshine during mid-summer, while in tropical latitudes the maximum is 14 hours right at the tropics with very short twilight periods, a difference that may explain why certain temperate species are unsuccessful in their development in tropical mountains with otherwise similar climates. Despite the slight seasonal variation, there is some evidence that day length even within the tropics provides the "trigger" to set off deciduousness in those species that lose their leaves each year: this certainly would partly explain the rather unexpected patterns of deciduousness in many tropical species mentioned previously.

Wind

Wind behaviour varies considerably in the areas where rainforest occurs and, on a limited scale, may even prevent the development of rainforest entirely in sites that appear otherwise suitable. Two main ecological effects result from wind action. Firstly, the air movement has an important effect upon evapotranspiration, so that sites exposed to constant strong winds experience relatively xeric conditions. This is reflected in the rather sclerophyllous vegetation found in many littoral and exposed montane sites in rainforest regions. Similarly, areas subject to very dry seasonal winds, such as the "harmattan" in West Africa, receive a more severe dry season than the rainfall figures alone would suggest. Under the influence of these strong, desiccating winds, humidity is reduced to an extremely low value, and conditions are ripe for uncontrolled fire to sweep into the rainforest margins.

The second effect of wind is mechanical, ranging from the shearing and dwarfing of the vegetation found in exposed sites where wind blows almost constantly, to the extreme destructive effects of periodic winds of hurricane force such as the tropical cyclones of the Caribbean, eastern Australia and the Indian Ocean and, on a more localized scale, the line squalls (locally termed "tornadoes") of West Africa and elsewhere.

Both effects of wind play significant roles in determining the physiognomy of rainforest. In areas that experience strong winds almost throughout the year, the vegetation tends to become dwarfed and sclerophyllous as is commonly found in littoral scrub and montane thicket: both types of vegetation can be derived from rainforest but,

* Against this, rainforest found fringing watercourses in some savanna regions (e.g. parts of Africa), where the moisture comes primarily from teluric sources, receives considerably greater hours of sunshine.

by the reduction in height of the community, can not justifiably be termed "forest". Few plants have the ability to withstand these winds and grow to tree size despite them, though in littoral sites Araucaria excelsa and Casuarina equisetifolia appear to possess this ability. In most cases, however, such areas of dwarfed vegetation appear permanently unsuitable for production forestry. In less extreme cases, commercial timber may be produced, though tree height and log lengths are restricted. On the Atherton Plateau in north Queensland, subject to fairly constant south-easterly winds, much better forest development is found on protected west-facing slopes than on the more exposed easterly aspects.

Hurricane-force winds are more spectacular in their results. The more restricted types, such as line squalls, are encountered in probably most rainforest sites, and are usually associated with thunder-storm activity. They may uproot large living trees, blow down already dead trees, and cause severe damage to the crowns of smaller stems growing in the open. Jones (1956) suggests that, in Nigeria, line squalls tend to recur in the same places, and he considers them to be an important factor in creating the climber tangles that are such a feature of Nigerian rainforests. In most tropical rainforests, winds similar to these are of importance in perpetuating the gap structure of the natural forest, and thus exert a major influence on the course of the life cycle of rainforest communities.

Truly tropical cyclones ("typhoons" of the China Sea, "hurricanes" of the Caribbean Sea) have rather more restricted areas of occurrence, of which the China, Caribbean and Coral Seas and the Indian Ocean in the vicinity of the Mascarene Islands are probably the worst affected. These great storms are associated with drenching rain and winds that commonly exceed 100 miles per hour. They range widely from their tropical breeding grounds: Caribbean cyclones may be experienced in the northeastern U.S.A. and Coral Sea cyclones in Victoria. However, they usually dissipate their force if they travel for any distance over land, so that their full destructive effects are normally experienced on islands and along the seaboard of continental areas in their path. Individual cyclones follow erratic courses, but places adjacent to their usual paths may receive a high frequency of cyclonic "strikes". Wadsworth (1957) observes that since the time of European Settlement, Puerto Rico has averaged one severe cyclone every 10 years, Webb (1958) records ten very severe cyclones in north Queensland over a period of 72 years, and, from recent history, one might suspect that the incidence in the island of Mauritius is even higher *. The effects of these storms on rainforest vegetation have recently been studied by Webb (1958) and by Wadsworth and Englerth (1959).

Webb, working in north Queensland, points out that, in areas particularly prone to cyclone damage, the vegetation has developed a typical structure. In relatively sheltered valleys windthrows are uncommon, but defoliation during the storms lets in increased light near ground level, permitting the subsequent development of Calamus

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* G.N. Sale (Comm. For. Rev. 42(4), 1963, pp. 358-9) in a review of "A History ofWoods and Forests in Mauritius" by N.R. Brouard, mentions four cyclones in the period 1644 to 1702 and a further four from 1931 to 1960: eight cyclones in a recorded period of eightynine years.

australis and other climbers. As a result, the vegetation consists of a fairly even rainforest canopy about 100 feet high over a dense understory of Calamus about 10 feet high. In more exposed sites, where local intensification of the winds occurs, the rainforest has an uneven canopy, with scattered emergents and areas of smaller trees laced together by masses of vines. Webb observes that trees of 8 to 16 inches D.B.H. were most frequently shattered by the cyclones, and he notes that if hot, dry, windy weather follows the cyclone, the fire risk in the forest can become great.

In Puerto Rico, Wadsworth and Englerth distinguished four direct types of damage following a cyclone: defoliation, both directly from the wind and occurring shortly afterwards as the damaged leaves die; bark shredding and loosening, caused by the stems whipping about, especially where defoliation was not severe; breakage, ranging from small branches to large trunks; and uprooting either as complete windthrows or to produce leaning stems. The indirect effects of the cyclone were less spectacular but still serious, and included sunscald after defoliation reduced stem quality following bark damage, insect and fungal attack where breakage had occurred, the development of reaction wood in leaning trees, and dense vine growth in openings interfering with the establishment of regeneration. The authors found that trees on exposed hills and ridges withstood the wind at least as well as those in the valleys, and that the financial value of the damage tended to be greater in the valleys, where the stands were usually of higher initial quality. Damage showed little relation to soil depth, but was fairly closely correlated with the average soil moisture content, uprooting being most common on deep, moist soils, particularly where the trees were normally protected from the prevailing tradewinds.

Regarding the condition of the forest as it was affected by the cyclone, Wadsworth and Englerth reported their findings as:

1. In mixed, irregular stands variations in damage were due to differences in the degree of exposure of individual trees, and probably also to species' characteristics. Dominant, exposed trees were usually more severely damaged than subordinate trees in the stand.

2. Damage was less selective in pure, even-aged stands. Such stands, if damaged at all, were damaged severely, and in all cases these stands suffered more than mixed, irregular stands.

3. Thinning shortly before the hurricane greatly increased the damage in even-aged stands.

4. Real differences existed in the susceptibility to damage of individual species; some species were more susceptible to windthrow, others to breakage, and some apparently were fairly resistent to all damage. Native species were generally more resistant than exotics.

Results such as these provide most important pointers to management techniques in areas subject to frequent cyclone damage and, from similar data, Webb (1958) has expressed doubts whether the production of mill log timber is feasible in the cyclone belt of coastal north Queensland. Certainly plantation forestry passes from the realms of normal silvicultural and economic problems to the state where sheer statistical probability on the likelihood of cyclone damage becomes of overriding importance.

Damage of the type discussed has very real ecological effects, extending from the maintenance of the gap structure in rainforest, through the distinctive types of vegetation noted in Queensland by Webb, to the communities completely deficient in large trees recorded by Beard from St Vincent (quoted by Richards, p. 147), and to even more apparently anomalous rainforest phenomena. In northern New South Wales, small grassland areas (up to about 200 acres in extent) occur surrounded by rainforest in certain upland sites, and it has been suggested that these have resulted from the destruction of the original forest by cyclones in areas where winter frosts greatly retard the redevelopment of rainforest in the clearings so created. That such destruction can occur was shown by a severe cyclone in 1954, when one area of over 100 acres of virgin subtropical rainforest was almost completely flattened in Yabbra State Forest. Where rainforest is able to become re-established after such damage (i.e. in the absence of subsequent fires and heavy frosts), the new crop may differ greatly from the one it replaces: in certain areas of eastern Australia rainforests dominated by huge stems of Laportea gigas, normally a secondary species, probably owe their origin to such storms. Even more spectacular effects can be found in the "storm forests" of the Malayan State of Kelantan, where a great storm, possibly associated with the Krakatau explosion of 1883, devastated vast areas of the state. The area now contains even-aged stands of Shorea and Dipterocarpus spp. approaching silvicultural maturity, mixed with virtually non-productive areas dominated by palms. As Browne (1949) says of this region, "disaster tantamount to clear falling has resulted either in complete victory or utter failure (in about equal proportions) of a new dipterocarp stand". Similar damage from a freak storm may account for the curious, almost impenetrable vine scrubs reported from parts of the Amazon basin by Heinsdijk (1957): these are apparently self-perpetuating, or at least very long lived phases, and if indeed they are the result of storm damage, they bear out the contention of Watt (1947) that "there are exceptional factors of rare or sporadic occurrences... which create a gap phase of exceptional dimensions... This will persist like a tidal wave ..., it may even influence the structure of the next generation. In other words... (the forest may) be explicable in terms of some past event which happened it may be 200 or 300 years ago".

Microclimate

Previous sections have dealt with the independent climatic factors that affect the development and distribution of rainforest. These factors have, however, another aspect which is dependent upon the vegetation itself, forming the microclimate. Microclimates play a most significant role in the development of rainforest, and it is safe to say that in no other type of vegetation are microclimatic effects so marked as in the multistoreyed, complex rainforest communities. To the silviculturist the microclimate is of particular interest, as it represents the only aspect of the climate that is normally amenable to some degree of control by the forester.

The variations of microclimate due to tropical rainforest and, conversely, their effects on the rainforest, are dealt with in some detail by Richards (chapter 7), and the conclusions reached by Richards form the basis of the following notes.

The microclimate within any area of rainforest varies from the top of the uppermost tree canopy, where conditions are broadly similar to those in an area of open ground, to ground level, where virtually all the external climatic effects are damped down by the lateral and vertical spread of vegetation on all sides, producing a remarkable equable climate. Between the treetops and ground level a gradient of microclimates exists, varying from place to place within the rainforest area with changes in the local physiognomy. In particularly dense, luxuriant rainforest (e.g. equatorial rainforest), the differences between the two extremes of the gradient are most marked, while in less complex communities (e.g. xeromorphic rainforest, montane rainforest or semi-evergreen rainforest at the peak of deciduousness) the gradient is less pronounced, though still quite considerable, giving most rainforest stands an air-conditioned, if not dehumidified, atmosphere.

Air movement is normally slight within dense rainforest even though stiff breezes may be blowing above the canopy and in open areas beyond the forest. Richards (p. 160) quotes one storm in eastern Brazil where a mean wind speed of 65 miles per hour outside the rainforest was reduced to only 4 mph at a station $7\frac{1}{2}$ miles within the forest, while other results indicate a similar ratio of wind velocities between the tree tops and the ground level. Although this stillness of the air is characteristic of the climate within the rainforest, sites on steep or exposed slopes may experience much greater wind movement near the ground during heavy winds. One effect of this reduction in wind speed is to reduce evapotranspiration in the understory plants, and to permit the development of very delicately leaved plants which could barely withstand severe mechanical damage from a greater degree of air movement.

Precipitation is effectively retarded by the rainforest canopy, and any worker will appreciate how quite heavy showers of relatively short duration are hardly even a nuisance near ground level, though once the undergrowth becomes wet, the position alters radically so far as pleasant working conditions are concerned. From the same Brazilian site, Richards (p. 162) gives figures indicating that only one third of the average rainfall actually falls to the ground, with about another quarter running down the tree trunks; the remainder is either absorbed by bark or epiphytes, or is evaporated from the leaves and trunks.

Temperature shows marked differences in values at various levels in the rainforest, the undergrowth commonly experiencing a daily range of temperatures only one third as great (and often even much less tree tops). Most of this difference in the range is due to the much greatermaxima at the tree tops, minimum temperatures often being similar at both levels (Richards, p. 164). However, in extra-tropical localities at least, the minima can also have the effect of reducing the range of temperatures in the undergrowth. Figure 3 shows diagrammatically the minimum temperatures experienced across one of the anomalous grassland areas found surrounded by rainforest at high altitudes in northern New South Wales. Recorded 2 feet above the ground during a winter period, a distinct temperature gradient can be seen extending from the centre of the opening to within the adjacent rainforest. On the coldest

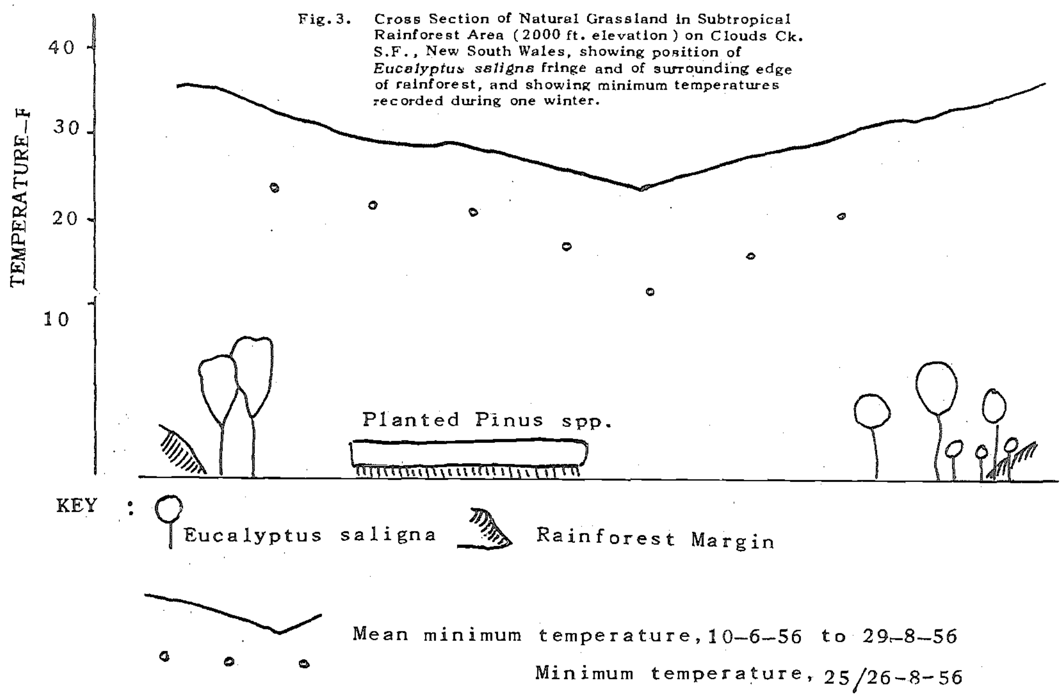

Fig. 3. Cross Section of Natural Grassland in Subtropical Rainforest Area (2000 ft. elevation) on Clouds Ck. S.F., New South Wales, showing position of *Eucalyptus saligna* fringe and of surrounding edge of rainforest, and showing minimum temperatures recorded during one winter.

night recorded the temperature fell to 33° F in the rainforest undergrowth, but was only 12° F in the centre of the opening; sufficiently cold to destroy seedlings of any local rainforest species or eucalypt exposed to it. An imposed succession is operating in this case, with the grassland slowly being invaded first by the moderately frost tolerant Eucalyptus saligna, and then by the rainforest species under the modifying influence of the eucalypts. While fire probably plays some part in delaying the invasion, there seems little doubt that the major factor preventing the rapid recolonization of the grassland by trees is the severe winter temperature in the opening. A similar effect of much lower minima in clearings compared with in the rainforest has had important silvicultural consequences in other parts of northern New South Wales; warm temperate rainforest rich in Araucaria cunninghamii has been cleared after logging to make way for open plantations of this valuable conifer, only to find that the low temperatures in the newly created openings have been sufficient to kill large areas of the planted trees. Some type of cover crop is clearly needed before Araucaria can be re-established on such sites after thorough cleaning.

While virtually all regional climatic patterns in the rainforest region are considerably altered when considered in the interior of the forest, few are of greater ecological importance than the atmospheric humidity. Humidity as a microclimatic factor in the rainforest is discussed in some detail by both Richards and Schultz (1960), and the former's conclusions (pp. 173-4) summarize the situation well: "... in the tropical rainforest there is no humidity gradient at night, the atmosphere at all levels being near saturation. The rise of temperature in the morning causes a ... fall of relative humidity, beginning at the top storey of the forest. During the morning, the warming of the lower layers of the atmosphere and the mixing of upper and lower layers by wind and convection currents cause the saturation deficit to increase even at low levels, but the evaporation from the soil and transpiration from the leaves, combined with the lower temperature in the shade and the smaller amount of air movement, prevents the saturation deficit from ever rising as high in the undergrowth as in the upper storeys. The range of humidity therefore diminishes sharply from above downwards, and a gradient of humidity is set up which changes in steepness, and probably in form, as the day goes on". Because of this gradient, the daily range of humidity in the undergrowth is always much smaller than in the upper storeys of the rainforest, though for relatively brief periods, even the undergrowth may experience quite low humidities: Evans (quoted by Richards, p. 167) from evergreen seasonal rainforest in southern Nigeria, records a mean minimum humidity of 69% in the undergrowth during the dry season, compared with 62% in the upper canopy. Nonetheless the gradient is sufficiently steep that, even in areas with a decidedly seasonal climate, the understorey retains its essentially mesomorphic characters, while the upper storey becomes distinctly xeromorphic, as evidenced by deciduousness or sclerophylly. Seedlings in the more seasonal types of rainforest become established in an environment of fairly constantly high himidities, and become exposed to the more extreme conditions only gradually. One of the great difficulties faced in the silvicultural treatment of such forests (e.g. semi-evergreen rainforest) is that the opening of the canopy in logging and treatment reduces the entire microclimate gradient and may result in understorey humidities lower than the young seedlings are able to tolerate during the period of dry season water stress.

The microclimatic factor that probably shows the greatest range of conditions from the upper canopy to the ground level within rainforest is light. The difficulties in attempting to measure light are numerous and have been discussed by both Richards and Schultz in some detail; notwithstanding these difficulties, numerous attempts have been made, one of the most promising approaches for both ease and usefulness being that of Evans (1956). This approach has recently been used by Whitmore and Wong (1959) in an area of little disturbed equatorial rainforest in Singapore. These authors divide the light reaching the forest floor into three components: shade light transmitted through the leaves and reflected from the foliage and trunks of the trees; sky light passing through holes in the canopy; and sunflecks. Sunflecks, which have attracted much attention in studies on light in rainforest, were found at Singapore (lattitude $1^{\circ} 20'$ N) to be present from two hours after sunrise until two hours before sunset. Of the total light reaching the herb layer, Whitmore and Wong found that 50% was contributed by the sunflecks (in the less luxuriant evergreen seasonal rainforest of Nigeria, Evans found that the sunfleck proportion was increased to 70%). Of the remaining sources of ground light, 13% was found to be skylight, and 87% transmitted light; comparable proportions from Nigeria were 17% and 83%. Expressed as a rough balance sheet, the total light energy reaching the forest floor is as follows:

	Singapore (Equatorial Rainforest)	Nigeria (Evergreen Seasonal Rainforest)
Light from sunflecks	50%	70%
Sky light	6%	5%
Transmitted light	44%	25%
Total light energy at floor (compared with outside forest)	2%	3%

The final figures in this balance sheet indicate too well the general gloominess of the rainforest interior. Workers from many rainforest areas have produced results indicating a light intensity away from sunflecks of only about 1% of full daylight and, when allowance is made for the sunfleck contribution, both the Singapore and Nigerian figures quoted above are of this order. This value, of course, varies considerably within any area of rainforest. It will vary from the very low value at ground level to 100% above the upper canopy, and wherever a distinct tree strata exists, it will be greater above than below. It will increase seasonally in forests with deciduous species common in the upper canopy. It will vary in a horizontal plane with differences in the density of the overhead canopy; in recent gaps the light intensity at the ground may approach 100% for much of the day. It will also vary in different types of rainforest: Richards (p. 182) shows that in British Guiana, the light intensity at ground level in xeromorphic rainforest dominated by Eperua falcata (Wallaba) is more than twice as great as in some of the more complex equatorial rainforest types.

Logging and silvicultural treatment, in which the rainforest canopy is opened up in some way or other, obviously have a profound influence on the amount of light reaching the forest floor. Poisoning operations in the tropical shelterwood system of Nigeria and in the Malayan uniform system are deliberately designed to exert some control over the light at ground level. In Nigeria, the attempt in the earlier versions of T.S.S. was to strike a balance between optimum growth for the economic tree seedlings and the retarding of weed and climber growth; in Malaya differing degrees of opening are used, dependent upon the apparent light requirements of the main tree species present: the meranti-type Shorea spp. can tolerate and respond to much greater light than Dryobalanops aromatica, which therefore requires more shade to be retained during poisoning operations. Nicholson (1960) in North Borneo has studied the response of several local dipterocarp seedlings to varying degrees of light in shade houses. The shade houses were constructed to provide 100, 87.5, 75 and 50% of full daylight, and Nicholson found that survival was closely related to the amount of shade provided and that in all five species used, growth was initially depressed by exposure to the 87.5 and 100% light intensities. After 16 months the growth made by Shorea leprosula to the different intensities was:

% full daylight	100%	87.5%	75%	50%
Mean height	23.0 in	35.6 in	64.7 in	75.0 in
Mean weight	0lb 15 oz	2lb 5 oz	5lb 5 oz	6lb 0 oz

However, once the seedlings were established (about 12 months), Nicholson found a tendency for those in the better light conditions to catch up to those that were more shaded. The greatest benefit from shading was shown by Dryobalanops lanceolata, which thus appears to show similar behaviour to its Malayan relative. Nicholson considered that the results had only slight practical value, since, under field conditions, a 50% shade cover would indicate fair root competition which would have a depressing effect on growth, that humidity effects would also influence the results, and that since the light intensities vary so greatly in treated forest, close control of light is almost impossible. Nicholson's results differ from those of Schultz (p. 40) in Surinam, where a wide range of woody species were found to reach their maximum growth when exposed to full sunlight. Schultz concluded that, for most tree species, "an approximately linear relation exists between growth rate and light intensity". Clearly this aspect requires more study.

The gradient of light intensity in rainforest, ranging from perhaps 2% near the ground to 100% above the canopy, is very steep. Workers in various regions have found that the lower tree storeys exert considerably greater shading effect than does the upper storey, and use is made of this in the Nigerian tropical shelterwood system, for example, where the most important "clearance poisoning" operation (see Chapter 10) is virtually confined to the middle storey. In most Nigerian rainforests this middle storey is fairly clearly defined and its removal produces a very marked increase in the light at ground level.

Climate as a Factor in Rainforest Environment

Preceding sections have indicated some of the effects of climate on rainforest behaviour. The external climatic factors must be recognized if the reasons for different types of rainforest development are to be understood, but to the forester responsible for managing the stands, the microclimate is probably of greater interest. Between the external climate and the ground level climate within the rainforest exist a host of conditions which are to a greater or lesser extent amenable to some control by the forester. In particular, temperature, humidity and light can be varied by manipulation of the forest cover and, as has been pointed out above, such manipulation forms the basis for silvicultural treatment in a number of rainforest areas. To the present, such treatment is largely empirical, and the possibilities for different combinations of treatment in the multistoried rainforests, with their great range of lifeforms, size classes and species, are almost infinite. One of the rainforest silviculturists' main needs from experimental ecology at the present time is quantitative data on the effects of the various components of the rainforest on the microclimate. Until this is provided, many regeneration treatments must remain "hit or miss" affairs.

SOIL

The Significance of Soil

Soil type, like vegetation, is not itself an independent factor of the environment, but rather results from the interaction of other factors on the soil parent material, and it is this parent material that constitutes one of the independent factors determining vegetation. The parent materials that produce rainforest-supporting soils are extremely varied, and in table 3 some of these parent materials are listed, along with the rainforest subformations which they carry. The weathering of these parent materials, under the influence of climate, topography, various organisms and past history, produces the mantle of soil in which the trees and most other plants in the rainforest community are established and grow.

Soil is important to plant growth in several ways. It provides the physical support and anchorage needed before any tree growth is possible, and it directly or indirectly supplies the nutrients and moisture that are required by plants. Both functions of the soil are equally important for rainforest development, and this section will be mainly concerned with considering a few examples of soil characters that have affected in some way the course and nature of rainforest development. However, since it has been shown that rainforest can occur on a wide variety of parent materials, and since the soil-forming factors even within the rainforest regions vary greatly, it is only to be expected that rainforest soils will exhibit a great range of characters. Consequently before considering examples of the effects of soil on rainforest, it is worth examining briefly the manner in which these soils are produced from the parent material and the type of soils which result.

Soil Formation in Rainforest Regions

Two soil-forming factors are common to all rainforest regions, namely abundant moisture, usually from precipitation, throughout most of the year, and luxuriant vegetation. Where the moisture does not readily drain away, so that the soil is inundated for all or much of the year, the swampy conditions dominate all other factors and produce fairly characteristic swamp soils. These swamp soils are of two basic types, depending upon the presence or absence of an appreciable surface layer of peat.

Swamp soils lacking peat are by far the more widespread, often occupying extensive areas along the flood plains of major streams, fringing lakes, and occurring in other sites subject to prolonged waterlogging. Examples of considerable extent are to be found in the Niger River delta of West Africa and along the annually inundated banks (the "varzea") of the Amazon River. Frequently, though not invariably, the parent material is alluvium and the resultant soils are of fine texture, poorly aerated, typically showing mottling, and with little accumulation of organic matter. The yielding nature of the soil and its poor aeration are probably its outstanding features.

Peaty swamp soils are less common, though by no means unimportant in certain areas. Such soils provide over 90% of the 16 million cubic feet of timber exported annually from Sarawak (Forestry Department, Sarawak, 1959), and underlie more than one million acres of forest in Malaya (Wyatt-Smith, 1959d). In addition to these and other southeast Asian occurrences, peaty swamp soils are known also from the rainforest regions of Africa and South America. In contrast to the non-peaty soils, these peaty types develop in sites where the water source is extremely deficient in nutrients and in southeast Asia, at least, they most commonly occur just inland from the mangrove forests of the coast. The "soil" consists of masses of peat which is usually lens shaped across the swamp, being thickest at the centre where, in one Sarawak area, it has formed to a depth of 42 feet. Radiocarbon dating of peat from this Sarawak site has indicated an age of 4,300 years for peat

TABLE 3

Parent Materials Supporting Rainforest

Subformation	Parent Material	Country	Locality
Equatorial	Granite; Shales & Claystones	Malaya	Widespread
	Alluvial Silt and Clay	Brazil	Belem
	Basalt	North Borneo	Kalumpang
Evergreen Seasonal	Unconsolidated Sands	Nigeria	Benin district
	Sedimentary Clays	Brazil	Curua Una R. (planalto)
Semi-evergreen	Unconsolidated Alluvial Sand	Brazil	Curua Una R. (flanco)
	Limestone	Puerto Rico	Northern Hills
	Schist	Nigeria	Ondo district
Submontane	Andesite	Puerto Rico	Luquillo Mountains
	Granite	Malaya	Fraser's Hill
	Granite, Shales, Basalt	Queensland	Atherton Tablelands
Subtropical	Basalt	New South Wales	McPherson Ranges
Swampy	Peat	Malaya	West Coast
	Unconsolidated Sands	Nigeria	Benin district
Xeromorphic	Beach Sand	Malaya	Jambu Bongkok
	Alluvial Sand	Brazil	Isla das Flores
	Alluvial (?) Sand	British Guiana	Moraballi Creek
Montane	Andesite	Puerto Rico	Luquillo Mountains
	Granite	Malaya	Fraser's Hill
Warm Temperate	Shale	New South Wales	Eastern Dorrigo Plateau
	Basalt	New South Wales	Mount Wilson
	Rhyolite	New South Wales	Whian Whian S.F.
Cool Temperate	Basalt	New South Wales	Point Lookout

from the base of the lens, suggesting an accumulation rate of one foot every hundred years (Forestry Department, Sarawak, 1959 and 1960). Towards the edges of the swamps the peat thins out and the frequently noted concentric zonation of vegetation within the peat swamps is largely associated with these changes in depth, although the proximity of solid land (with some local mineral-rich inflow) and the nature of the material underlying the peat also influence the vegetation (Wyatt-Smight, 1959d). The soils are virtually pure peat, derived from the residues of past forest vegetation; they are highly acid (pH3-4), extremely deficient in nutrients, and almost permanently saturated with water. The low nutrient status and the anaerobic conditions caused by the waterlogging doubtlessly combine to produce conditions unfavourable to plant decay and thus permitting the accumulation of plant remains at a faster rate than their decay.

Dryland rainforest soils are subject to quite different formation processes which are of two types, both dependent upon high precipitation and consequent severe and continued leaching of the soil. The primary weathering of the parent material is typically chemical (by hydrolysis), in which the main products formed are silica and silicates (e.g. kaolin), sesquioxides of iron and aluminium, and various bases. The bases are largely either taken up by the plants' roots shortly after release, or else rapidly leached from the profile, while the subsequent behaviour of the silicates and sesquioxides determines which of the two main types of rainforest soils are produced. Silicates are relatively soluble in pure rain water, but tend to be precipitated and immobilized in the profile by solutions containing humic substances, whereas the sesquioxides are relatively insoluble in pure rain water, but are mobilized by humic solutions. Under tropical conditions, the temperatures at the soil surface are sufficiently high to prevent the accumulation of organic matter under normal circumstances: evidence given by Richards (p. 218) suggests that no humus accumulation occurs at temperatures above 77°F. Consequently the weathered parent material is subjected to penetration by fairly pure rainwater, which leaches down the silicates and leaves an eluvial horizon rich in sesquioxides. This is the process of <u>laterisation</u>, by which the very common red and yellow soils of the humid tropics have been produced, although it is probably extremely rare for the ultimate stage of laterisation (the production of true concretionary laterites) to take place under rainforest. Laterisation also occurs well beyond the lowland tropics on parent materials that are particularly rich in iron and aluminium, e.g. basalt and andesite, to produce krasnozem (red loam) soils.

Under cooler conditions the opposite process, <u>podsolisation</u>, occurs. Here humus tends to accumulate and, as a result, the sesquioxides are taken into solution and subsequently deposited in the lower illuvial horizons of the soil while the eluvial horizon is rich in silicates. This process is common in most rainforest soils beyond the tropics, except where the parent material is particularly rich in sesquioxides, and also in tropical montane areas (e.g. Pitt-Schenkel, 1938 in Tanganyika; Lamprecht, 1954 in Venezuela). Podsolisation also occurs in some lowland tropical soils that are initially poor in sesquioxides, and in which excessive drainage, due to coarse texture, and exceptionally low nutrient status retard the normally rapid decomposition of organic matter in the tropics. Under these conditions, humic colloids are apparently released and mobilise what sesquioxide is present. Such tropical podsols are formed on very sandy parent materials, e.g. the extensive beach sands of eastern Malaya and the probably ancient alluvial sands of the Guianas. According to Schultz (1960, p. 120), such bleached sands in Surinam invariably contain less than 5% of clay: with higher clay content the soils show a reddish colour to the surface, suggesting that laterisation is taking place, possibly due to the better moisture retention causing more rapid decomposition of the organic matter. This may explain why tropical podsols are not more common on other sandy parent materials, such as the widespread "Benin Sands" of southern Nigeria. Schultz also believes that podsol formation in the lowland tropics is often due to past shifting cultivation, which has impoverished and degraded what was initially an infertile soil: the consequent loss of nutrients would probably tend to retard humus breakdown and thus to promote podsolisation.

Fertility of Rainforest Soils

The two processes of laterisation and podsolisation together account for the formation of the majority of dryland rainforest soils. Both are associated with rapid leaching of bases from the soil so that particularly in the tropics, one finds the apparent paradox of extremely luxuriant vegetation growing on most infertile soils. Barnard (1957), for example, has described Malaya as "a desert covered by forest". The phenomenon is well known (see Richards, pp. 219-220), though disregard of it in the past has led to disastrous attempts at land settlement in many parts of the world. The explanation lies in the closed nutrient cycle which the vegetation itself sets up.

The roots of the rainforest plants are largely confined to the upper soil layers, but in well drained soils may ramify to a depth of six feet (Beveridge 1957), or even much more: Schultz (p. 111, profile C/O) records "fibrous roots frequent at least to 450 cm (15 ft)". These rapidly absorb any nutrients released through the decay of the organic litter, and, at the lower levels, are able to tap the somewhat richer nutrient sources of the less weathered parent material to replace such nutrient losses as do occur. At any time, therefore, much of the nutrients in the plant-soil ecosystem is held in the vegetation. On clearing and burning, this accumulated fertility is released temporarily but then, through wind and rain action, is rapidly dissipated. In the graphic description of Milne (quoted by Richards, p. 220), "The entire mobile stocks are put into liquidation and, as is usual at a forced sale, they go at give-away value". Studies in Trinidad on the effects of clearfalling and burning showed that, in addition to greatly increased evaporation, insolation and temperature extremes on the soil surface, there was an immediate loss in organic matter and nitrogen in the soil, a reduced carbon/nitrogen ratio, and an initial rise in pH which was soon lost as the bases were leached out (Brooks, 1941).

If, after clearing, forest vegetation is allowed to redevelop on these soils, the closed nutrient cycle can be gradually re-established through the release of nutrients from the continually weathering parent material. The speed of this re-establishment doubtlessly varies with the initial fertility of both the soil and the parent material. On tropical podsols the re-establishment is extremely slow, and in Malaya the clearing of xeromorphic rainforest from these coastal podsols results in the development of heath-like "padang" vegetation, which may, with protection, ultimately revert to rainforest, but which is more likely to suffer repeated burning and degradation to poor grassland and extensive sand-scalds. This, however, is an extreme case. More typically, secondary succession back to rainforest occurs and the slow increase in the ecosystem's nutrient cycle provides the basis for the widespread shifting cultivation and bush fallow agricultural systems of the humid tropics and also, by application of the "accelerated succession" hypothesis of Tansley (1944), for the success of taungya plantation schemes (see Chapter 9). These systems, however, rely on sufficient time to elapse between successive clearings for the nutrient content of the ecosystem to build up to a level akin to that in the virgin forest. If the population pressure is such that insufficient time elapses between successive clearings, then soil degradation of an almost permanent nature will occur. This appears to have happened in the Maya empire of pre-Columbian Central America and probably also accounts for many areas that have been changed from rainforest to savanna in the tropics.

As indicated above, rainforest soils tend generally, though not invariably, to be deficient in plant nutrients, and it is probable that, over considerable areas, fertility more than any other factor provides the main limit to production on rainforest sites. The flora is clearly well adapted to making the utmost use of what nutrients are available, but on the most infertile rainforest soils, e.g. tropical podsols and peat swamps, it is apparent that the species present are largely determined by their ability to tolerate low nutrient conditions.

Most nutrients are derived ultimately from the soil parent material, but nitrogen poses an interesting problem as to its origin in the soil. Richards (p. 221) points attention to the common abundance of leguminous trees in rainforest, particularly in what might be regarded as less favourable sites where there is a tendency to single species dominance, and suggests that the possession of root nodules containing nitrogen-fixing organisms confers considerable advantage to rainforest plants. Certainly in both America and Africa, tropical rainforest is often rich in legumes, but this is far from the case in southeast Asia and even less so in the eastern Australian rainforests where legumes may be completely lacking over large areas. Possibly other rainforest families in these regions also possess the ability, through symbiotic microorganisms, to fix nitrogen, but the question is one that would appear to repay some study. Certain independent microorganisms such as some blue-green algae, which may be common in rainforest areas, are known to fix nitrogen also and these, coupled with the frequent thunderstorm activity over many and perhaps most rainforest areas, may be sufficient to maintain the nitrogen economy of the soil.

Soil Influence on Rainforest Composition

Detailed studies in a number of areas have provided interesting examples of the effects of soil on the occurrence both of individual species and of rainforest subformations. To the present such studies have been very localized in a few sites, but as further work is carried out, it must be expected that similar results will be found with many more species and over much wider regions. Frequently a close correlation has been found between species occurrence and some pedological characteristic, without it being at all clear how the one actually influences the other. Thus Sombroek (in Glerum and Smit, 1960) has shown that south of Belem, the valuable Amazonian species

Euxylophora paraensis occurs chiefly in sites either where there are iron concretions in the soil, or where the low plateau surface ("planalto") has broken away along the edge of small gullies. On a total area of 54 acres classed as planalto-edge, 73 trees of Euxylophora paraensis occurred, whereas on other plots totalling 44 acres and classed as away from the planalto edge, only seven trees were recorded.

Schultz (1960), in his very comprehensive studies in northern Surinam, found several close correlations between the presence or absence of individual species and certain soil characteristics. Thus in the Mapane area, Ocotea sp. ("wana pisie") was shown to avoid any hydromorphic soils where mottling occurred within 2 feet of the surface, while Qualea rosea was most abundant on deep sandy soils derived from Zanderij Tertiary alluvial deposits: Qualea rosea has a very long taproot and Schultz believes that sandy soils are necessary for this taproot to develop. A similar reason has been advanced by Sykes (1930) for the restriction of Gossweilerodendron balsamiferum and Cyclicodiscus gabunensis to the deep Benin sands in southern Nigeria.

On very infertile soils and on soils with impeded drainage, the floristic composition is determined by what species can tolerate the low nutrient status and the anaerobic conditions respectively. Such soils have typically a very characteristic flora whose constituent species react in such a way that physiognomically distinct subformations are produced on these sites. Thus the infertile tropical podsols support xeromorphic rainforest, as typified by the Eperua falcata communities of British Guiana, and the Shorea materialis communities of eastern Malaya, while the waterlogged soils support swampy rainforest with a considerable range of highly typical species around the world. Although Eperua falcata is most characteristic of the podsols in the Guianas (e.g. Richards, p. 240), it is not restricted to such soils. Schultz (p. 128) notes that it has a tendency to single species dominance on both xeric and very moist sites in Surinam, though often rare in the intermediate areas with more favourable soils. Its relatives Eperua leucantha and Eperua purpurea are dominants in similar xeromorphic rainforest on the upper Amazon (Aubreville, 1961). Other species show a similar wide range of tolerances to soil conditions, with a tendency to greater abundance on the more adverse sites than on the more favourable soils. In Malaya, Koompassia malaccensis occurs widely and is common in both peat swamps and some of the poorer dryland forest soils (Wyatt-Smith, 1961b), while in Gabon the economically important Aucoumea klaineana occurs naturally in swampy sites, but also is one of the chief colonisers in secondary successions on a wide range of well drained soils (Becking, 1960). Species such as these would appear to combine their tolerance to a wide range of soil conditions with a low tolerance to competition: on the generally more favourable, well drained, moderately fertile soils many species can grow, and the increased competition is sufficient to restrict their frequency to a marked extent. Only on less favourable sites is the competition reduced to the level where these species can achieve a relatively dominant position in the community.

Somewhat similar behaviour is shown by Ceratopetalum apetalum in New South Wales. In the northern part of the State this species is restricted to the less fertile podsolic soils derived from shale or acid igneous parent material (e.g. trachyte) and it is virtually excluded from the krasnozems formed from basalt. However, in the more temperate southern parts of the state it occurs also on the more fertile krasnozems which, because of climatic reasons, lack many of the species which occupy the basalt soils further north. Both on the podsolics in the north and the krasnozems in the south Ceratopetalum tends strongly to dominate the community in which it occurs, and to contribute much to the structure of the warm temperate rainforest with which it is almost invariably associated. By contrast, the northern basalt soils, from which Ceratopetalum is absent, support subtropical rainforest. In parts of northern New South Wales warm temperate and subtropical rainforest adjoin each other under identical climatic conditions, but on markedly different soil parent materials. The resultant soils have similar physical properties, but different chemical properties, of which the most pronounced is the availability of phosphorus in the soil, and it is believed that phosphorus is the main factor responsible for the distribution of warm temperate and subtropical rainforest in northern New South Wales (Baur, 1957).

In the case of these extra-tropical Australian rainforests, soil fertility has a major influence on the distribution of the rainforest subformations, and it seems likely that the occurrence of xeromorphic rainforest is similarly determined by the chemistry of the soil rather than by its physical condition. However, there are many examples that show that the physical characteristics of rainforest soil can also strongly influence the nature and the composition of the vegetation. Thus at the F.A.O. experimental area on the Curua River in Brazilian Amazonia, the very clayey soils of the low plateau ("planalto") away from the river support fairly luxuriant evergreen seasonal rainforest, with trees frequently exceeding 150 feet in height, while the sandy soils of the "flanco", which occupies a narrow strip of country between the planalto and the river, supports semi-evergreen rainforest with few trees over 100 feet high and with a much higher incidence of deciduous species. The differences in structure here are probably a reflection of the better water retention in the planalto soils during the fairly severe dry season.

In Nigeria, the transition from evergreen seasonal to semi-evergreen rainforest occurs gradually with decrease in rainfall and increasing severity of seasonal drought, but the boundary between the two is distinct in some areas where the deep Benin sand deposits adjoin the shallow soils derived from ancient crystalline rocks (Rosevear, 1956; Keay, 1959a). Lamb (1941) has given examples of the different rainforest communities occurring on different parent materials in this area, recording from the Ohuso F.R. a Gossweilerodendron-Cylicodiscus community (evergreen seasonal) on the Benin sands, and a Cistanthera - Celtis prantli (semi-evergreen) on the crystalline rocks. From elsewhere in West Africa, Taylor (1960) in Ghana, and Emberger, Manganot and Miege (1950 and b), in the Ivory Coast, have given similar examples of the effect of soil parent material on the rainforest composition. In Malaya, Wyatt-Smith (1961b has shown a correlation between the occurrence of various rainforest types in the Federation and the underlying soil, while de Rosayro (1942) has done the same in Ceylon.

In Puerto Rico, Wadsworth and Bonnett (1951) have shown that submontane rainforest and montane rainforest (referred to as lower montane rainforest and montane thicket respectively) occur on quite different soils, though the original parent material is the same in both cases. Compared with the fairly deep, well drained soils of the submontane rainforest, the higher altitude soils (which occur above about the 73° F isotherm), show a heavy accumulation of organic matter and a relatively impervious subsoil, features possibly associated with the change from laterisation to podsolisation as the dominant soil-forming process. These authors conclude that it is impeded soil drainage, rather than any climatic factor, that determines the occurrence of thes two rainforest subformations, though the drainage itself can probably be related to the external temperature and rainfall.

Soil and Silviculture

The preceding sections have given a few examples of the influence of soil in determining the composition and, in some cases, even the structure of rainforest communities and it has been shown that these influences can be profound. Although data is so far lacking, it can reasonably be expected that differences in productivity of a similar order will also be found in rainforest soils. Such effects place a very real limit on what the silvicuturist can hope to achieve.

To date, the effects of soil in rainforest silviculture have been noted most in plantation schemes, where care has to be taken in selecting species suited to the soil. Unfavourable physical soil characteristics can in fact probably only be overcome by correct species choice, though in intensive working, artificial fertilizing may be justified to correct certain unfavourable chemical conditions. The importance of soil is not, however, confined to plantation management. The studies in Trinidad (Brooks 1941) have stressed some of the dangers inherent in any radical alteration of the community on certain rainforest soils, be it for agriculture, forest plantings, or even clear cutting as a form of silviculture involving natural regeneration. These dangers are greatest on the intrinsically less fertile soils. Other work in Trinidad (Beard, 1944b; Ayliffe, 1952) has shown other difficulties that soil can cause in silviculture, with heavy clay soils failing to produce regeneration under the tropical shelterwood system (Chapter 10), although it occurs copiously on adjacent sandy soils. Occasionally, silvicultural techniques may be able to improve soil conditions. This could be the case where fairly drastic canopy opening is carried out above soils with accumulated humus, enabling the soil temperatures to rise higher and so speed the decomposition of humus. Drainage schemes in swampy sites may also improve the soil for many species, though not necessarily for those naturally present in the area. Except on a small scale, drainage of swampy rainforest soils is probably only justified in connection with agricultural development, but such development may in turn affect nearby forests. Drainage in some peat swamp soils in western Malaya has appreciably lowered the watertable in adjacent forest reserves, and in the long run this can only lead to an alteration in the species composition of such reserves.

To sum up, soil is a most important factor in rainforest silviculture, and one that cannot be appreciably altered by management, except at considerably expense or, by misuse, in the wrong direction. It provides definite limitations to what can be achieved by forest management, and these limitations must be recognized in advance by the silviculturist.

TOPOGRAPHY

The Topographic Factor

The third independent factor of the environment is topography. In its effects on the vegetation this acts as a combination of climate and soil and, although of appreciable local significance, topography is of less general importance in determing rainforest composition and structure than are the previous two groups of factors. The effects of topography can, in fact, be broadly grouped into two classes on the basis of their modifying the climatic and edaphic factors respectively, and a few examples are probably sufficient to illustrate these effects.

Topography Modifying Climate

On a very broad scale, some of the effects of topography on climate have already been discussed, particularly in connection with decrease in temperature with increase in altitude and the fairly widespread increase in precipitation with increase in altitude, while the land configuration can also have an important bearing on rainfall patterns. At a more local level, however, topography can appreciably alter the climate of areas in close geographic proximity and in the same altitudinal range. This occurs in several ways, and involves different features of the climate.

Solar energy, particularly beyond the tropics, can be greatly modified by aspect. In the southern hemisphere, south-facing slopes receive less energy per unit area than do north-facing slopes, while the reverse position holds in the northern hemisphere. The more shaded slopes tend to be cooler, evapotranspiration is reduced, and the vegetation takes on a more mesic aspect than on slopes exposed to a greater intensity of sunlight. In southeastern Australia where, over extensive areas, the vegetation is a mosaic of rainforest and sclerophyll forest (see Chapter 5), these differences in sunlight intensity are reflected in a very frequent restriction of the rainforest to the south-facing slopes, while the relatively hotter and drier northern slopes carry the more xeric eucalypt communities. The effect is not only due to the differences in solar energy received, since the northern slopes are also exposed to more desiccating winds and are more prone to severe fire damage, but solar energy must nonetheless be regarded as a major contributing cause of the distribution. Similar effects of rainforest developing on the shaded southern slopes have been recorded by Phillips (1928) in South Africa.

Exposure to wind is very largely determined by topography and is one of the most important effects that topography has on the distribution of vegetation. Wind has been considered already in the section on climate, where its effects on vegetation were discussed. These effects are greatly dependent upon the local features of the topography, and examples of this have already been given, e.g. the relationship between topography and cyclone damage noted by Wadsworth and Englerth (1959) in Puerto Rico and by Webb (1958) in North Queensland; the restriction in height of rainforest stands in sites exposed to the prevailing southeasterly winds on the Atherton Plateau (Queensland) and the better development in sheltered west-facing slopes; and the diminution of rainforest to scrub and thicket on exposed montane ridges and littoral headlands. The effect of desiccating winds in determining the pattern of rainforest - eucalypt forest in southern Australia has also been mentioned above: over fairly extensive areas, a recurrent pattern of eucalypt forest on the northerly and westerly slopes and of rainforest on the southerly and easterly slopes can be recognized, the maintenance of the sclerophyllous vegetation on the exposed sites being compounded by the prevalence of fierce fires, which the hot winds and the topography favour.

Topography Modifying Soil

Topography is regarded as one of the independent factors of soil formation, and its effect in producing soil catenas, with the soil type varying in a recurrent pattern from gully bottom to ridge top, is now recognized in many regions. On the higher sites the soil is constantly being removed by natural erosion, leaving a generally shallow, skeletal soil, whilst in the valleys it accumulates in depth and tends to be enriched by the nutrients leached from the upper soils. In the valleys, therefore, the soil is deeper, more fertile, and more adequately supplied with moisture, and this is reflected in the more luxuriant development of the vegetation in the lower sites. This is clearly seen in parts of eastern New South Wales where the moist, fertile conditions in the valleys permit the development of rainforest, while the slopes and ridges carry eucalypt forest which is maintained by the less favourable soil and recurrent fires (Baur, 1957). Similarly the the extensive "gallery rainforests" found fringing streams through vast areas of the savanna and steppe country in tropical Africa and America are due to the more favourable soil conditions, particularly in respect of moisture, in these sites. Even where climatic conditions in the higher topographic positions adjoining these fringing belts of rainforest are suitable for the developing of rainforest, as in the "derived savanna" region of Nigeria (Keay, 1959a) or in many of the New South Wales eucalypt slopes, the rainforest that could occur in such sites is less resistent to the onslaught of fire and other biotic pressure than the rainforest in the more optimum valley bottom situations, where it is able to persist as a climax community long after the adjoining stands have been destroyed.

In addition to these conspicuous examples of a different plant formation occupying the favourable topographic sites, there are many examples where the lower sites carry a distinct assemblage of rainforest plants in areas where the higher positions support a different rainforest community. Thus Symington (1943) distinguished "riparian frainge" as one of the forest "formations" in Malaya; Wadsworth (1957) has pointed out that the Dacryodes-Sloanea submontane rainforest association in Puerto Rico, and elsewhere in the Lesser Antilles, is probably in fact two inseparable associations, with Sloanea and some associates restricted to the valley bottoms; while in New South Wales Baur (1957) has recognized an Elaeocarpus grandis association as occurring along streams in areas which elsewhere support the Tarrietia (syn. Argyrodendron) subtropical rainforest association. In the case of Elaeocarpus, the restriction of this species to the stream banks is probably not due to a preference for such sites, but rather to the method of dissemination of its large, heavy fruits. In New South Wales these are normally water distributed and consequently the species tends to be confined to creek bank situations, but by contrast, in north Queensland the seeds are distributed by the large, indigenous cassowary, and

Elaeocarpus grandis is found over a wide range of topographic conditions.

The constant erosion of soil from rainforest areas is to be expected under the high rainfall which these areas receive, and Richards (p. 207) gives data to show that the rate of erosion is in fact considerable. In steep topography this movement of the soil is manifest also by soil creep, which shows its presence by the downhill sweep in the butts of the trees growing on the slopes. This is very evident in some montane rainforests, for example in the Luquillo Mountains of Puerto Rico and at Frasers Hill in Malaya, though the phenomenon is by no means confined to montane rainforest.

In passing, it should not be forgotten that certain rainforest soils, notably swamp soils, owe their very existence to particular topographic conditions.

Complex Topographic Effects

While topography affects vegetation by modifying the soil and climate, there are some obvious relations between topography and vegetation which are difficult to explain purely in terms of one or other of these two factors, but which may result from an interaction of both. The Malayan ridges dominated by Shorea curtisii (seraya) are an example of this. These occur widely through the Federation (Wyatt-Smight, 1961b) and provide one of the rare examples in Mälayan equatorial rainforest of a community approaching single species dominance. Shorea curtisii is a distinctive species with a glaucous crown, and the ridges dominated by this tree are a conspicuous feature of the Malayan landscape. Wyatt-Smith (1948, 1960c) has shown that these ridges carry a better stocking of desirable species than do the lower topographic positions, and that regeneration is also better on the ridges, though more subject to suppression by the stemless palm (Eugeissona triste), which is also most frequent on these ridges (Wyatt-Smith, 1960a). The Shorea curtisii communities are normally found in the altitudinal range of 1,000 to 2,500 feet above sea level, but may extend higher in the more sheltered central ranges of Malaya, while on coastal ranges it may be found almost to sea level on exposed slopes.

Another Malayan dipterocarp, Shorea glauca, also has its occurrence closely related to topography, normally being found in gregarious stands on seaward slopes from sea level up to several hundred feet. Vincent (1962) has noted that where this species occurs inland it is a fair indication that in quite recent geological times the site has been coastal.

In Puerto Rico, Dacryodes excelsa behaves much like Shorea curtisii, forming more or less gregarious stands with a high stocking on the upper ridges in the submontane rainforest. Its dark, glossy crowns are as conspiciuous on such sites in Puerto Rico as are the cauliflower coloured crowns of the Shorea in Malaya. Another Puerto Rican species whose distribution is largely dependent on topography is the palm Euterpe globosa. At the lower altitudes in the Luquillo Mountains this is mainly found in areas of impeded drainage, but at higher altitudes (above 1,500 feet) it occupies extensive areas on steep slopes, where its occurrence is closely related with the erosion rate. Wadsworth (1951) states that the palm is slow growing, but dominates the early succession on landslips, and by its dense shade delays the invasion of more valuable species. On stabilized slides, the palms tend to disappear gradually from the community.

One very widespread topographic effect in rainforest is the telescoping of altitudinal vegetation zones on exposed slopes, the so-called Massenerhebung effect discussed by Richards (p. 347 et seq.). Beard (1942) has described a striking example of this from Trinidad, where montane rainforest occurs 1,000 feet lower on the windward side of the island than on the more sheltered central and leeward areas. It is found in many islands, where montane communities occur at much lower altitude than on neighbouring continental areas, as well as on exposed coastal ranges. The effect as it applies to Shorea curtisii on the coastal ranges of Malaya has already been mentioned. Another outstanding example from Malaya can be seen on the Bukit Bauk F.R. in eastern Trengganu, where on this isolated coastal hill, montane rainforest with Podocarpus, Tristania, and Rhodamnia occurs at an elevation of 1,000 feet. In central Malaya, similar communities are rarely found below 3,000 feet. The exact way in which exposure produces this effect is obscure, though constant wind apparently plays an important part.

Topography and Silviculture

As shown above, rainforest composition can be strongly influenced by topographic effects, and it is important that this should be recognized, since certain highly desirable communities, e.g. those dominated by Shorea curtisii and Dacryodes excelsa, appear to be limited in extent by virtually immutable topographic factors. Silviculture probably cannot extend these stands to any appreciable degree and, in attempting to manage these natural communities, foresters must be resigned to the ecological limitations which are present.

Topography also plays other roles in rainforest management. Compartment subdivision is very dependent on topography. In the even relief of the southern Nigerian rainforests, or of those of the Amazonian planalto, a rectangular subdivision can be superimposed almost at will, whereas in hilly or mountainous topography, such as occurs in Malaya, this is impracticable and compartments must be based on local features of relief (Barnard, 1955). Similarly, logging is greatly affected by relief, being generally much easier and cheaper where the topography is flat. The report on silvicultural systems for rainforest in the Asia-Pacific region (F.A.O., 1960b) notes that one of the factors favouring mechanized logging is the occurrence of flat topography, while in the mountainous rainforest terrain of Ceylon tractor logging is forbidden (ibid). The flat relief of much of Amazonia is regarded as favouring mechanized logging, coupled with river transport of the logs to mills (Gachot, Gallant and McGrath, 1953), just as is the case in the Benin forests of Nigeria. Conversely, very steep topography, too rough for the use of tractors, has led in the Philippines to high-lead logging which has significant repercussions in the method of managing these forests (Walton, 1954).

THE BIOTIC FACTOR

Organisms of the Rainforest

Like any forest community, rainforest is composed of plants, shelters various animals including man, and supports in the soil beneath it a rich flora and fauna of small and micro-organisms. These together constitute the biotic factor, partly independent (the regional flora and fauna) and partly dependent upon the rainforest itself, and like the other environmental factors, an appreciation of the importance of this factor is essential before any attempt can be made to manage the rainforest.

For ease of discussion, the biotic factor can be divided into a number of component parts, of which the following can be fairly clearly distinguished: flora, fauna, microorganisms, man and fire. The last is somewhat anomalous and in most cases can be related to the activities of man, but its influence is sufficiently great to warrant its separate consideration.

Flora

As indicated in Chapter 1, rainforest vegetation can be regarded as having several distinct and far distant floristic origins which have produced broad floristic elements. Of these the pan-tropical element, and to a lesser extent the Antarctic element, are of major importance. The northern element (Quercus and its close relatives, Hammamelidaceae, etc.) appears to have its origins in the pan-tropical element, but to have reached its greatest development in more temperate climates further north. These elements have evolved under the influence of past and present environmental conditions in the various rainforest regions of the world, and have been enriched by recruits from other local elements, such as the capsular-fruited Myrtaceae of Australasia, so that today the individual regional floras show considerable variation from each other.

In broad terms, the occurrence of rainforest depends as much on the presence of a suitable flora capable of producing a rainforest type of physiognomy as on suitable climatic and edaphic conditions. Thus, parts of southwestern Australia possess climate and soils which, in eastern Australia, would be quite suitable for supporting rainforest. The absence of rainforest from this region is due to the absence of a suitable flora, probably as a result of the complete elimination of a previously present rainforest flora during climatic cataclysms during the Pleistocene and early Recent eras, and to the existence of extensive barriers (ocean to west and south, desert to north and east) precluding subsequent migration of rainforest elements since then.

Sometimes the recognition of these elements and subelements can help explain complex silvicultural problems. Much of the temperate rainforest in New Zealand is composed of a mixture of podocarps (Podocarpus, Dacrydium) and broad-leaved dicotyledonous trees (Weinmannia, Beilschmiedia, Elaeocarpus, Knightia, Quintinia, etc.) of which the podocarps are by far the most valuable and desirable constituents. It has long been recognized that the podocarps are in slow decline in these forests, and the reasons for this phenomenon, which is of considerable interest to silviculturists who would wish to increase the podocarp stocking, have been the subject of much speculation.

Recently Robbins (1962) has hypothesised that these mixed forests are a fusion of two distinct sub-elements, a podocarp element which dominated much of the islands in pre-glacial times, and a broad-leaved element which has been favoured by more recent conditions, and which is gradually replacing the podocarps, although "so close are the environmental requirements of both these forests that the shift..... has been extremely prolonged and gradual". Somewhat similar is the constant struggle between the rainforest and the autochthonous elements (eucalypts, etc.) in eastern Australia (Baur, 1962a).

The specific tolerance to environmental conditions of individual species within a regional flora is, of course, the explanation of distinct rainforest communities in any area, and numerous examples of this have been given earlier in this chapter. Such differences extend beyond mere species composition of these communities to differences in the physiognomy of the stands. The prevalence of buttressed trees and "stranglers" on the basalt soils of northern New South Wales, and their rarity on the less fertile rainforest soils, provide the most striking visual distinction between subtropical and warm temperate rainforest in this region, and similar comparisons can be made in most extensive rainforest areas.

The distribution of individual species is not necessarily related only to their tolerance to the environment. Competition between species may also be important, as evidenced by the absence of Ceratopetalum from basalt soils in northern New South Wales (Baur, 1957), and by Robbins' interpretation of the New Zealand temperate rainforest mixture. Equally important on occasions may be seed dispersal mechanisms, as is indicated by certain riverain species whose distribution is limited by their water-dispersed seeds, e.g. Castanospermum australe in eastern Australia (Baur 1957), and Pterocarpus santalinoides in Nigeria (Keay, 1959a).

From a more anthropocentric viewpoint, inherent differences in the characteristics of certain species create many problems in rainforest management. Differences in timber qualities between species, differences in the susceptibility of unwanted species to girdling and poisoning, differences in their ease and prevalence of regeneration, and not least, the occurrence of certain distinctly unpleasant species in the rainforest (e.g. the stinging Laportea spp. of Australia and New Guinea, poisonous members of the Anacardiaceae, and various myrmecophilous trees), all provide examples of the manner in which the local flora can affect rainforest management.

Fauna

A widely read American magazine some years ago produced an interesting article on some of the more unusual animals of the rainforest, and illustrated it with a picture of rainforest in the Guianas showing some large animal to almost every square yard of the forest. This indeed is the popular conception of wildlife in the "jungle", but it is a most considerable exaggeration. When obtaining profile diagrams in rainforest, the writer felt inclined to include representations of any of the larger mammals or reptiles seen during the project, but only on two occasions was he able to do this (figure 11, barking deer in Malaya; figure 17, spider monkeys in Brazil). Danger from wildlife in the rainforests rarely lies with the jaguars, leopards or tigers, with the boas, mambas, cobras or taipans. Far more real is the danger from the disease-carrying insects and arachnids, and from the smaller rodents and similar animals which act as hosts for various human diseases. Such diseases to this day hamper man's attempts to manage rainforest in the tropics to his own advantage, and have severely retarded development of the humid tropics in the past.

Nonetheless animal life is a real feature, albeit not usually a conspicuous feature, of the world's rainforests, and although in many cases the wildlife is dependent upon the vegetation for shelter and food without appreciably affecting the vegetation itself, there are also many examples of animal life exerting a real influence on the course of rainforest development.

Possibly the most fundamental of these influences is the part played by various animals, mostly but not exclusively insects (especially termites and wood-boring beetles), along with microorganisms, in breaking down plant remains and thus perpetuating the cycle of nutrients (see section on soils, above). It is this rapid turnover of nutrients that in no small measure determines the luxuriant appearance of rainforest. As well as the insects which actively participate in the breakdown of debris, and the earthworms and other soil-inhabiting creatures which help distribute the resultant organic matter through the soil, all animals that feed upon the vegetation, or that in turn feed upon the herbivores, contribute to this continuous cycle.

Animals also contribute to the maintenance of a rather characteristic micro-relief in many rainforests. This is most evident in areas of flat topography and of rather heavy, clayey soils which are more resistant to weathering than loose sands, and it can be seen particularly well in the planalto areas of Amazonia. The micro-relief is only partly due to animal activity; windthrow of standing trees is of equal or greater importance. In the planalto soils termites and ants construct mounds above the general soil level; these in turn are destroyed or damaged by armadillos, ant-eaters, lizards and other similar animals, to produce a very uneven land surface of hollows and hummocks with a range of about 18 inches from the base of the first to the top of the second. Although it does not appear to have been studied, this micro-relief is probably of some significance in the occurrence of regeneration, with the more vigorous regrowth commonly being found on the hummocks.

Pollination and seed dispersal in rainforests depend very largely on the assistance of animals. The reduced air movement within rainforests results in wind pollination being most unreliable, and it seems likely that the majority of rainforest plants, even trees of the uppermost storeys, are insect or bird pollinated, with conifers where they occur (Agathis, Araucaria, Podocarpus etc.) providing the most notable exceptions. Some of the specialized mechanisms of pollination in rainforest plants are well known (Ficus, Orchidaceae, the part played by humming birds and moths, etc.). For similar reasons, a very high proportion of rainforest seeds tend to be distributed by animals. Examination of 123 species from the Nigerian rainforests by E.W. Jones (pers. comm.) showed that no less than 79 species (64%) had edible fruits, with even 46% of the upper storey trees having such fruit. Similar figures can probably be produced for most rainforest areas, though in the dipterocarp-dominated forests of southeast Asia the proportion may be reduced, since the dominant family is typically wind dispersed. Because of the widespread animal dispersal, regeneration may often show little correlation with the occurrence of seed trees nearby, as has been found in applying the Tropical

Shelterwood System in Trinidad (Moore, 1957). Fauna dispersing the seeds may be birds, bats or ground animals. Examples of these are numerous: Travers (1961) in New Zealand notes that dense clumps of germinating Dacrydium cupressinum seeds can be found in bird droppings under perching trees; Wadsworth (1957) observes that most of the Puerto Rican submontane rainforest trees are bird or bat dispersed; Wong (1959) records that in Malaya seeds of the palm Eugeissona triste are distributed by rats and squirrels; Eleaocarpus grandis in north Queensland, in contradistinction to its creek bank occurrence further south, is widely distributed through the rainforest by cassowaries; and any follower of an elephant's trail cannot fail to be impressed by the variety of plants that germinate in its wake.

Not all the effects of animals are so constructive to the rainforest communities as these: there are also many destructive effects caused by the fauna. The destruction can occur in many ways, the loss of immature fruit by birds and small arboreal mammals, the attacks by insects on damaged trees and even on healthy plants, the constant grazing of the herbivores, the wilful damage by larger animals such as carnivores sharpening their claws on the trunks of trees or elephants their tusks. In virgin forest such destruction is constantly occurring, but the balance is preserved with little or very gradual effect on the composition. However under the unnatural conditions often imposed by man's activities, these destructive effects can be magnified, as illustrated by the severe insect damage to extensive areas of regeneration of such species as Chlorophora excelsa and various Meliaceae, or by the browsing damage to enrichment plantings. Such destruction can pose great silvicultural problems. Probably even more serious in the long run is the type of destruction that is occurring in New Zealand, by introduced deer and possums, to rainforest that has evolved in the complete absence of such biotic pressure (see for example McKelvey, 1960) *. A rather interesting form of animal damage to natural rainforest occurs in Nigeria, where elephants apparently contribute appreciably to the maintenance of the gap structure which is such a feature of these forests (Jones, 1956, p. 109), though similar damage does not appear to have been recorded by the Asian elephant.

Elephants and other large grazing animals have also been blamed for the restriction of rainforest and the maintenance of savanna and steppe in other parts of Africa (e.g. Eggeling, 1947). Certainly the former large herds of ungulates in East Africa may well have had such an effect, but it was probably of minor importance compared with the damage caused by frequent man-caused fire.

Though of little importance to forest management, the common symbiotic association between plants and ants in the rainforest is worth recording. Myrmecophily, in which plants have a specialized structure which houses ants, is quite widespread in all three main regions of the tropical rainforest: some Cecropia spp. and certain leguminous trees

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* Similar destruction apparently also occurred at an earlier date in the forests of Mauritius: see N.R. Brouard, "A History of Woods and Forests in Mauritius", reviewed in Comm. For. Rev. 42(4), 358-359, 1963.

(e.g. Tachigalea sp.) in tropical America, Barteria in West Africa, and some Macaranga spp. in southeast Asia provide examples. In Nigeria, myrmecophily does actually provide a minor problem of silviculture: the ants associated with Barteria fistulosa are so vicious and poisonous that labourers will rarely poison the small trees during silvicultural treatment, and as a result this light-demanding species is tending to be favoured under the Tropical Shelterwood System. A converse association to myrmecophily is common in parts of tropical America, where ants that construct their mud nests in the branches of small trees sow in the nests the seeds of certain plants (bromeliads, etc.) which germinate and help hold the nests together with their roots.

The importance of insects and other animals in spreading disease in rainforest areas has already been mentioned, with the mosquito-borne malaria and yellow fever, tsetse fly-borne sleeping sickness, mite-borne scrub typhus and rat-borne leptospirosis being a few of the examples. To man these have been a source of worry for centuries, but there is little doubt that to these diseases we owe the fact that rainforest still covers as extensive an area as it does.

Finally, although not an ecological problem, it must be stressed that timber borers and similar insects which play so important a role in breaking down dead wood are a serious pest to people engaged in the utilization of rainforest, particularly in the tropics. The need to protect commercial timber from the depredations of such insects adds appreciably to the cost of handling this timber.

Microorganisms

The microorganisms present in rainforest have been little studied, but it cannot be doubted that these are an important facet of the biotic factor. While possibly of less significance than insects in causing mortality to living trees, they play a major role in the breakdown of plant debris, and similarly necessitate the taking of protective measures by the forest exploiter. Their entry into damaged trees causes decay and subsequent degrade in log quality. In the soil, various fungi and bacteria are of the utmost importance in the nutrient cycles, and the symbiotic association between members of the Leguminosae and certain bacteria is probably the prime source of nitrogen in many rainforest soils. Richards (p. 221) has drawn attention to the common abundance of leguminous trees in the rainforest, particularly on the generally less favourable forest soils. Free-living bacteria and algae may also contribute to the nitrogen economy of the rainforest.

Mycorrhizal associations between fungi and vascular plants are also very common in rianforest. J.F. Redhead (pers. comm.) in a study of about ninety Nigerian trees found that the large majority were associated with mycorrhizal fungi, though only in Afzelia bella * was the association with an ectotrophic mycorrhiza (i.e. with the fungus forming a hyphal mantle outside the roots). The significance of mycorrhiza is still obscure, though experience with Pinus spp. suggests that ectotrophic mycorrhizae at least are an advantage to the tree by aiding in the uptake of various nutrients, particularly phosphate. In Puerto Rico trial plantings of Pinus spp. over a lengthy period were

* No other species of Afzelia were studied.

unsuccessful until mycorrhizal soil from beneath healthy pines was introduced into the island, and similar experiences are common in other countries lacking indigenous pines.

Man

Man is merely a specialized type of animal, and the impact of truly primitive man on rainforest was, and in a few instances still is, no greater than that of other animals. He destroyed a few plants for food and to fill his simple needs, and he hunted some of the animals, but his influence was little greater than that of the larger apes and probably much less than that of large creatures such as the elephants. However, as his living standards rose, his influence became much greater. He used more plants for his daily living, and in the process wrought greater destruction on the forest, his use of fire (see next section) for hunting had important repercussions at the periphery of the rainforest areas, and when he learnt to introduce agriculture to the rainforests, his capacity for destruction and change became almost unlimited. As Keay (1959a) says: "The chief enemy of (rain) forest ... is native agriculture".

As pointed out in Chapter 1, in some areas the aboriginal inhabitants of rainforest areas never developed agriculture, and here the effects of man on the rainforest have been least (e.g. the Malayan aboriginal negritos, Wyatt-Smith, 1958). However, in most areas shifting cultivation was ultimately introduced. Forest patches were cleared by axe and fire, planted with food crops for one or more seasons, and then when the fertility of the soil was exhausted, they were allowed to revert to forest. At best a secondary succession was set up, and the effects of this may persist in the forest composition and structure for several centuries (see for example Keay, 1959a; Schultz, 1960). At worst, the rainforest was almost permanently destroyed, to be replaced by grassland or savanna. With more settled forms of agriculture, and an increasing population, the destruction or alteration of rainforest became generally more severe; Cameron (1960a) notes that in five centuries the New Zealand Maoris destroyed half the original forests of the country, and European settlers in the succeeding 120 years destroyed half the remainder. Facts such as these cannot be overlooked when attempting to understand the distribution and structure of rainforest.

Man has sometimes had more beneficial effects on the rainforest. The small, anomalous occurrence of Dryobalanops aromatica in western Malaya (Kanching Forest Reserve) is widely believed to be due to some long past introduction by the local aborigines. Small patches of rainforest, or individual rainforest trees, remaining within the "derived savanna" belt of Nigeria have often been deliberately preserved for reasons of utility or religion (Keay, 1959a).

Fire

Fire is an important factor in the distribution of rainforest. It perhaps warrants the status of a full environmental factor, though since it is most often associated with man's activities it is more conveniently regarded as one of the biotic factors. Man however, is not the only cause of fire: lightning and sometimes volcanic action may also produce fire.

Rainforest in its virgin state is fairly immune to fire. The heavy rainfall and high internal humidities do not favour the spread of fire, though under exceptional conditions of hot and continuing dry weather, some and possibly all, rainforest communities can carry fire. Thus under unusually severe conditions in 1957, with high temperatures and very strong desiccating winds, fire in eucalypt forests some miles distant "spotted" into the Nothogfagus moorei cool temperate rainforests at Mount Boss State Forest in northern New South Wales, and were able to spread through these stands aided by the thick leaf litter and the prolific moss and lichen growth on the trunks and branches of the trees. Although most of the trees recovered, many were fire scarred at their base, and some, hollowed by age, collapsed. Clarke (1956) has recorded the presence of fire in Ocotea rodiaei rainforest in British Guiana, and it is apparently not uncommon in the xeromorphic rainforests of Eperua falcata in the same area. Semi-evergreen rainforest in the Curua River area of Brazilian Amazonia shows the signs of repeated burning, while even the evergreen seasonal rainforests of the same area have yielded pieces of charcoal from the soil, although there are no indications of human interference in the district.

Disturbed rainforest is more prone to fire damage, a fact utilized by the farmers in shifting agriculture : the smaller trees and undergrowth are felled, the debris allowed to dry out and then the area is burnt. During the fire, the larger standing trees are usually killed by the heat, while the fire is often able to spread some distance into the surrounding rainforest. To prevent the spread of similar fires, belts of undisturbed forest are often left as fire breaks within plantations in rainforest areas (see Chapter 9), while in north Queensland, rainforest under silvicultural treatment is protected by a marginal strip of untreated forest along roads and at the boundary with eucalyptwoodlands (Chapter 10).

After fires of this type, a succession leading back to rainforest is usually established. If, however, the fire is repeated frequently enough, the development of more fire resistant species is favoured. These may be rhizomatous grasses (e.g. Imperata spp.), or, where a seed source is available, fire resistant trees from another type of community. Thus, on the climatic margin of rainforest repeated burning will convert rainforest to savanna, as has happened over much of Africa. Where fire resistant trees are absent, repeated fire will produce grassland. This has occurred over much of New Guinea (Robbins 1961), and also in the Sobo Plains of southern Nigeria, an area lying well within the rainforest belt and isolated from any existing areas of savanna (Keay, 1959a). In Australia, repeated burning favours the fire-resistant eucalypts, which extend their range or are maintained at the expense of rainforest, while in parts of Central America, Pinus spp. have apparently been similarly favoured by regular fires in what was originally rainforest, to produce pine savanna (Taylor, 1962). If such areas are protected from fire, re-establishment of rainforest will gradually occur, as can be seen in many areas of eastern Australia, and as is being illustrated by the controlled burning plots in the derived savanna of Western Nigeria at Olokemeji F.R. (Charter and Keay, 1960). The speed of such re-establishment depends, among other factors, on the degree of soil degradation that has resulted from past burning, and on the availability of seed in the area to re-introduce the rainforest species.

Fire is thus of major importance as an environmental factor not so much for its direct effects upon rainforest structure and composition (except in an historic sense in certain sites), but in determining over vast areas the margin between rainforest and some other types of plant formation, such as sclerophyll forest, savanna or grassland. On a world scale, there is probably a greater distance of rainforest margin limited primarily by fire than by any other factor, or group of factors. This fact has often been overlooked in the past, and it cannot be stressed enough. An understanding of rainforest distribution is frequently impossible unless the significance of fire is recognized.

HISTORY

The Historic Factor

The final independent environmental factor recognized by Major is time, and in this interpretation a seral community is thus a community limited primarily by the time which it has had to develop, just as other communities are limited by a nutrient deficiency, the length of the dry season, the amount of exposure, or the frequency of fire. However it is probably desirable to differentiate between those communities which have reached a degree of equilibrium, however unstable, with their environment (climax communities), and those which have yet to attain this equilibrium (successional communities). Rainforest succession is dealt with in detail by Richards (Chapters 12, 13, 14 and 17), and will be mentioned briefly later in this report.

Time, however, has another aspect which deserves brief consideration. This is the past history of any community, the environmental pressures to which the community has been subjected, possibly thousands of years previously, but which are still reflected in certain features of the forest. These environmental pressures may be "exceptional factors of rare or spasmodic occurrences" Watt, 1947), or they may be even more profound changes that have occurred, for example in the climate, millenia before. In either case, their significance must be appreciated if the distribution, structure, and composition of rainforest are to be properly understood.

Examples of rainforest communities possessing apparently anomalous features which can only be explained on the basis of past history are widespread, and reference has already been made to some of these. A few examples will suffice to illustrate some of the effects which the historic factor can have on the nature of rainforest.

Distribution of Rainforest

As demonstrated in Chapter 1, rainforest has a very discontinuous distribution which is shown by both of the great floristic elements that by and large make up the rainforest flora, and hence by both the tropical and temperate rainforest formations. The three separate occurrences of tropical rainforest in the earth's three main equatorial land masses, and, even more strikingly, the disjunct occurrence of temperate rainforest in South America, in New Zealand, in eastern Australia, in tropical montane regions, and to some extent in South Africa, are all reflections of far distant migrations of vegetation, and of connections between these areas. Many authors of plant geographies of specific regions have dealt with these historic floristic relations between areas, and Beard (1946a) for Trinidad, Asprey and Robbins (1953) for Jamaica, and Robbins (1962) for New Zealand can be quoted for examples.

At a more local level the discontinuity of rainforest in eastern Australia (Baur, 1957; Webb, 1959) and in Africa (Boughey, 1956) can be related to the more favourable conditions for rainforest development existing in these areas during the late Tertiary and Pleistocene, since when changing climate and biotic pressures have led to a great contraction of the rainforest areas. Negatively, the absence of rainforest from southwestern Australia is the result of a past period of climatic conditions sufficiently unfavourable to eliminate the previous rainforest flora, and of subsequent isolation from other areas of rainforest occurrence.

Within existing areas of rainforest, the presence of other plant formations is often explicable in terms of past historic events. Thus the grasslands of southern Nigeria's Sobo Plains result from past clearing and burning (Keay, 1959a); the grasslands of the Bunya Mountains in south Queensland are believed due to the regular gathering of aborigines to feast on the seeds of Araucaria bidwillii (Herbert, 1938), and somewhat similar grasslands at high altitude in northern New South Wales are believed due to the destruction of rainforest during a severe cyclone, followed by burning and subsequently maintained by winter frosts (Baur, 1957).

Other Historic Effects

The influence of history in determining the rainforest flora of any site has already been mentioned, but, in addition, the appearance of certain individual species within rainforest may reflect happenings long past. Beard (1946b) believes that the aggressive dominance of Mora excelsa in Trinidad is due to the relatively recent arrival of this species on the island, and to its invading and shading out the more long established trees of the Carapa - Eschweilera association. Robbins (1962) considers that the changing dominance of the conifer and broadleaved species components of the New Zealand rainforests is due to past climatic changes, which favour the development of the broadleaved species. In eastern Australia, the presence of veteran trees of Araucaria or Eucalyptus overtopping mature rainforest reflects the spread of rainforest into adjoining country, usually in response to a lengthy period of freedom from fire. Patches of rainforest locally dominated by Laportea gigas often indicate areas where the rainforest sometime in the past has been destroyed by cyclone, allowing the light-demanding Laportea to become established. Similar light-demanding species in other parts of the world are indicators of other historic disasters; Schultz (p. 220-221) comments on the distribution of Goupia glabra in Surinam, and suggests that this may be due to "the occurrence - at great and irregular intervals - of violent winds which are responsible for the formation of large gaps in the forest"; in New Guinea the dominance of Octomeles on the areas devastated by the cataclysmic volcanic blast of Mount Lamington in 1951 suggest that other areas where this species forms a single dominant forest may have been subject to similar blasts in the past (B.W. Taylor, pers. comm.); the occurrence of many of the more common West African rainforest species, including Triplochiton, Terminalia spp. and Chlorophora, are the result of the widespread destruction of these rainforests in the past, a result reflected also in the structure of these stands (Jones, 1950 and 1955-56; Keay, 1959a; Taylor, 1960).

Conclusion

As stated at the start of this chapter, rainforest results from the interaction of the five groups of factors which have been discussed above. Locally any one may prove to be limiting, but, in the end, the distribution and nature of rainforest depends upon all five. Some of these are amenable to certain change by the silviculturist, but others are immutable, and provide definite limitations on the silviculturist's activities. An appreciation of these distinctions is essential wherever rainforest areas are to be brought under scientific management of any type.

CHAPTER 3

STRUCTURE AND PHYSIOGNOMY

"In the rainforest region woody plants form not only the larger proportion of the mature forest vegetation, but play the chief part in its developmental stages .... "
Richards (p. 3).

Life Forms

By any standard, rainforest is a most complex form of vegetation and, although there are significant differences both between and within the two rainforest formations, the wealth of species and the richness and variety of the life-forms set rainforest apart from all other plant communities. The floristic composition will be considered in the next chapter. Here it is proposed to deal with the structure, and hence with the physiognomy, of rainforest, paying particular attention to those features which are of importance to silviculture.

The luxuriant appearance of rainforest is well known, though often exaggerated by those whose acquaintance with it is limited to roadside or riverfront glimpses. Even within the forest, where some order can be recognized from the chaos of the rainforest margin, the density and variety of the forest growth are impressive, even to those long familiar with this vegetation. This growth is primarily woody, and one of the outstanding features of rainforest is the dominance of tall, woody plants. This dominance is clearly brought out in Raunkiaer life form spectra, and in Table 4 some examples of such spectra are given, adapted from data given by Richards.

This data shows how phanerophytes dominate these rainforest communities even in the early stages of primary succession and this dominance must be ascribed to the generally favourable growing conditions where rainforest occurs. The phanerophyte element contains not only trees, which are considered in more detail below, but also shrubs, stranglers and woody vines while, in addition, epiphytes, herbs and other less conspicuous life forms contribute to the richness of rainforest.

Shrubs are probably the most obvious group of rainforest plants, since they are the plants with which anyone working in the rainforest is almost constantly in contact. Where the shrubs have irritant properties (e.g. certain Anacariaceae), stinging hairs (e.g. Laportea spp.), thorns or spines (e.g. Balanites) or are myrmecophilous (e.g. Barteria) this contact can not only be unpleasant, but can have an effect on silviculture. Thus in Nigeria the understandable reluctance of labourers to poison Barteria is resulting in an increase of this species in forest under T.S.S. In north Queensland, dense regeneration of Laportea moroides can literally prohibit entry into treated rainforest for about five years, and consequently it is necessary to eradicate seedlings of Laportea soon after treatment, or else to be prepared to forego further tending in the stands till the "stinger" phase has passed.

TABLE 4

Raunkiaer Life Form Spectra for Rainforest

-- Life Forms - % --

Subformation	Locality	Epi-	Phanero-	Chamae-	Hemicrypto-	Geo-	Therophytes-
Equatorial	British Guiana	22	66	12	-	-	-
Subtropical	New South Wales	18	68	4	8	1	1
Cool Temperate	New South Wales	3	63	21	7	-	6
Primary Succession (Xerosere)	Krakatau						
After 3 years		-	59	7	20	7	7
After 51 years		-	65	6	12	2	15
Temperate Summergreen Forest	Germany	-	27	6	39	23	5

One or two fairly distinct shrub layers can usually be recognized in rainforest. These have been excluded from the profile diagrams in this report except in two cases (figure 13, seasonal evergreen rainforest at Curua, in Brazil; and figure 15, similar rainforest at Sapoba F.R. in Nigeria), where the shrub layers have been drawn separately. These layers contain not only small individuals of the taller trees, but also numerous species which are restricted to shrub size. The small trees very characteristically have a single, unbranched stem, surmounted by a tuft of leaves, but this habit is shown also by many of the true shrubs. Richards (pp. 76-77) comments that this habit is "a constant feature of tropical rainforest and a striking difference from temperate forests". However, it is not confined to the rainforests of the tropics, being common among the shrubs of rainforest communities in New South Wales (e.g. Cordyline spp., Linospadix monostachya, Anopterus macleayanus). This habit is, of course, that found in palms, and small palms are frequent constituents of the shrub layers in the tropical rainforest formation (e.g. Linospadix in Australia, Eugeissona triste and the strange, entire-leaved Teysmannia altifrons in Malaya, Geonoma spp. in tropical America). Some of the more densely shade-casting palms (e.g. Eugeissona) can provide a serious problem in regeneration and may require specific treatment to destroy them (Wyatt-Smith 1959c). In montane and temperate sites, tree-ferns often take the place of these palms.

Besides the single-stemmed shrubs, rainforest usually also contains many heavily branched shrubs which cast dense shade. When present in any quantity these exert a strong effect on the microclimate near the ground and, like the more wide-spreading, low palms, can make difficult the establishment of regeneration. The Melastomaceae provide an excellent example of this type of shrub, though the habit is found in many families. Both in north Queensland and, when advance growth is deficient, in Nigeria, the removal of these shrubs is one of the essential operations in the present routine silvicultural treatment (see Chapter 10).

The shrub layer also often contains some plants which are really large herbs. These are mostly monocotyledonous plants (e.g. various Zingiberaceae and Marantaceae) and, on occasions, they may form thickets sufficiently dense to deter regeneration and to require special attention in silvicultural treatment. Plants such as these are a feature of the more open rainforest phases in southern Nigeria and probably provide elephants with some of their preferred foods, so that the dominance of the monocots and the existence of the open patches both tend to be long lasting (Jones, 1955-56). Bamboos also may be present in the shrub layers of rainforest, and these too may require special silvicultural treatment (Mohd. Alwy bin Haji Suleiman, 1961).

Ground herbs are usually present in rainforest, but as scattered plants rather than as a continuous ground layer. Only where the overhead canopy is sparse do the herbs tend to become abundant. Various botanical groups contribute to the rainforest herb flora, with ferns and some of the "fern-allies" being the most common. Other families commonly encountered include the Commelinaceae, Graminae, Cyperaceae, Gesneriaceae, Rubiaceae, Araceae and Melastomaceae. Germinating tree seedlings may seasonally contribute to the herb layer, while bryophytes are frequently found coating stones and upturned clods of earth on the soil surface. Richards (p. 97) believes that rainforest herbs can be classed as either shade-loving or shade-enduring, the former tending to be solitary in humid, shaded places, while the latter, which are the more common, are social in places with greater illumination. Except locally in forest openings where they may cover the ground surface, the true herbs have little silvicultural significance.

By contrast, the rainforest climbers have very great silvicultural significance and probably constitute the worst of all groups of rainforest weeds. These form a fairly distinct life form, though species suggesting a connecting stage with trees (e.g. Brassaia actinophylla), shrubs (e.g. Lantana), and epiphytes (e.g. certain Araceae and Orchidaceae) are not uncommon. They range from rather small, wiry vines restricted to the undergrowth (e.g. Rubus, Smilax, Rhipogonum), to very large vines which reach to the treetops and which may have stems as thick as a small tree, with a host of intermediate types. In temperate rainforest formation the small, wiry types are the most frequent, but in the tropical formation all types may be encountered, with the larger climbers generally more common. They often contribute appreciably to the floristic richness of rainforest. One plot established by the Nigerian Department of Forest Research in the Okomu F.R. (permanent sample plot 85) contained 65 species of climbers out of a total of 250 species, including herbs. Numerous plant families are represented by climbers, including Leguminosae, Asclepiadaceae, Apocynaceae, Bignoniaceae, Combretaceae and Vitaceae among the dictos; Palmaceae, Flagellariaceae and Pandanaceae among the moncots; Gnetum spp. in the gymnosperms; and various ferns and lycopods. The curious stem structures of many of these are much loved by plant anatomists, and indeed contribute greatly to the characteristic physiognomy of rainforest communities.

As a group, the climbers are strongly light demanding and for this reason tend to be most frequent in rainforest gaps or where the community has been opened up in the course of silvicultural treatment. The climber phase that results from such disturbance poses the rainforest silviculturist with one of his most difficult problems, for the vines can actually strangle small trees and saplings, be included into the weed of the growing trees with consequent degrade of timber quality, weigh down and deform the young trees, and severely depress the potential growth rate of the desirable stems by sheer weight of competition and by shading. The cutting of climbers is therefore an important silvicultural operation in most, if not all, tropical rainforest treatments and one that is not without difficulties since too early a cleaning after treatment often merely rejuvenates the climber phase. The Malayan practice of delaying climber cutting for about five years after the stand has been opened is now gaining popularity in many areas.

Although vines are most numerous in gaps and along rainforest margins (e.g. along river fronts and roads, where the virtually continuous curtain of climbers has done much to perpetuate the myth of the impenetrable rainforest), they are also found within well developed, mature rainforest stands. The climbers in such sites are usually large, with their crowns extending over and through the higher tree canopies and thus making a large contribution to the shadiness of the lower levels. Lancaster (1961a) has observed that the removal of these vines in one of the first stages in the Nigerian Tropical Shelterwood System causes a most appreciably lightening of the rainforest understoreys, and likens the operation to the seeding felling in the European Uniform System. It is probable that such vines have grown up with the trees in former gaps in the community (see Chapter 6); they ramify through the crowns of adjacent trees; they hang in great loops from the branches, sometimes reaching back to the ground (probably usually as a result of the death of a former support tree); and they bind the trees so firmly together that sometimes a large tree can be cut through at the base and still not fall, or else in falling may bring many other trees with it. Large climbers like these have probably a greater length of stem above the ground surface than any other group of land plants, lengths of up to 800 feet from ground to growing tip having been recorded with certain of the climbing palms. To avoid the dangers inherent in felling trees that are so bound together, as well as to improve the lighting and to facilitate access, climber cutting ahead of logging is a very common routine rainforest treatment.

Like many other light demanding rainforest plants, the seedlings of many climbers can germinate and survive for some years beneath dense shade, so that throughout the rainforest there is usually a reservoir of young vines waiting for the opportunity to assume active growth. At Sapoba F.R. in Nigeria, Redhead (1960a) found that in a compartment with good structure and few existing "climber tangles", 18.2% of milliacre quadrats contained seedlings of either Acacia ataxacantha or one of the climbing palms (Calamus spp. or Ancistrophyllum spp.), and that these were extremely evenly distributed over the whole area sampled.

As well as the mature rainforest with its large climbers, and obviously young rainforest with its dominance of vines, there are also found in various places areas of rainforest with apparently very long-lived phases marked by extremely dense vine growth. Webb (1958) has recorded such communities from north Queensland in areas subject to repeated cyclone damage, while areas lacking large trees and covered by often truly impenetrable tangles of vines (notably Acacia and climbing palms) are one of the outstanding features of much Nigerian rainforest (see for example Jones, 1955-56). These Nigerian tangles can be explained on grounds of past history and present biotic pressure, but from the Amazonian rainforest Heinsdijk (1957, 1960) has reported similar vine-dominated forests where biotic pressure at least appears to be absent.

Stranglers are an interesting and distinctive life form which is largely confined to rainforest and rather unevenly distributed through it. They are trees which start life as epiphytes, their seeds germinating in the crowns of existing trees, often in branch angles where moisture and plant debris accumulate to provide a suitable seed-bed. The young stranglers make slow early growth while sending their roots down from the host tree to the soil. Once contact with the soil is made, growth increases while the roots anastomise around the host, in extreme case completely enveloping it. Probably in all cases stranglers weaken the vigour of the host, and thus are to be regarded as weeds; further than this some stranglers in time kill the host by competition, strangulation of the stem, and shading of the crown. When the host dies, the strangler remains as a tree which is able to maintain an independent existence. The plants possessing this curious habit are rather limited. Ficus spp. are the most typical,*while other groups include the American Clusia spp. and the facultative strangler Meterosideros robusta of New Zealand. In New South Wales, Quintinia sieberi frequently behaves as a strangler, but its host is limited to the tree ferns and at maturity it is only a small tree. Some of the strangling Ficus spp., which are particularly common in certain eastern Australian subtropical rainforests, are by contrast extremely large trees at maturity: a tree of Ficus watkinsoniana in norther New South Wales has been measured with a breast height diameter of 18.5 feet, a crown spread of 108 feet, and a total height of 177 feet. Trees such as this tower above their associates and are among the largest trees in the rainforest. Since the tree mentioned has over 80 feet of its height made up of roots, the reason for this height dominance of stranglers in the community is not difficult to explain.

The other life forms that are found in rainforest - ephiphytes, parasites and semi-parasites, and saprophytes - are of little significance to rainforest management, though they contribute in no small measure to the distinctive appearance of rainforest and are of considerable interest ecologically. Epiphytes in particular have a certain diagnostic value in classifying rainforest subformations, while ephiphytic lichens on the stems of rainforest trees are one of the reasons for the apparent sameness of trees in these communities. These forms are discussed in some detail by Richards (pp. 110-131).

Trees in the Rainforest

The dominant life form of the rainforest is undoubtedly that of the trees, and to the forester concerned with managing and utilizing these communities, trees are clearly the life form of greatest interest. Although there are wide differences both between and within rainforest stands, most communities appear to support from 200 to 300 trees per acre larger than four inches diameter breast height (d.b.h.). Except in young, even-aged patches of rainforest, these trees are from a wide range of sizes, with the smaller size classes containing both trees which, at maturity, are of small stature, and immature individuals of potentially large trees. The largest trees encountered vary in size in different rainforest communities, but on favourable sites trees exceeding 200 feet in height and 6 feet in diameter are found in a number of rainforest regions: Richards (table 1) has recorded the statistics of some of the largest known trees from rainforest in the tropics, while subtropical and temperate rainforest may contain specimens that are no less impressive. Among the tallest rainforest trees are the Araucaria spp. of eastern Australia and New Guinea, and Koompassia malaccensis of Malaya, while Agathis spp. and certain of the strangling Ficus spp. are outstanding for their girth. Even taller are some of

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* It should however be stressed that not all Ficus spp. are stranglers; most are actually independent trees from the start and a few are climbers.

of the Eucalyptus spp. standing above rainforest in Australia. Trees of Eucalyptus grandis and Eucaplyptus microcorys exceeding 200 feet in height above subtropical and warm temperate rainforest are fairly common in New South Wales, while giant trees of Eucalyptus regnans more than 300 feet high are known in both Victoria and Tasmania above cool temperate rainforest, but these do not belong to the rainforest community proper (see Chapter 5).

These trees, from the smallest to the largest, stand above the shrubs, and tend to be arranged into a number of tiers or storeys. The extent to which these "storeys" is real is discussed further below, but it is indisputable that the mature rainforest trees do vary in height, some regularly overtopping others of their associates. The taller trees clearly experience a different microclimate to the smaller ones, and, as might be expected, trees from one storey differ in certain ways from those in other storeys.

The high stocking of trees in rainforest is made up very largely of those of smaller size, so that size/frequency curves typically have a J-shape: such a curve frequently indicates an all-aged forest (e.g. see Bruce and Schumacher, 1950), though as will be shown (Chapter 6), the reasoning behind this does not necessarily apply in mixed rainforest. This predominance of the smaller stems is illustrated in Table 5, where the number of stems (expressed as a percentage of the total number) in each size class is given for several different rainforest communities. The 4-8 inches d.b.h. class characteristically contains over 50% of all the stems present, though in the higher latitudes this value tends to be reduced with a complementary increase in the middle classes.

In appearance, the trees are usually slender for their height, and show less stem taper than trees in most other types of community. The crowns are frequently rather shallow, though in the temperate rainforest formation deeper crowns occur than in tropical rainforest, while in many of the more characteristic understorey species typically deep, shady crowns are found. These latter species (e.g. Annonidium Mannii in Nigeria, Micropholis spp. in Puerto Rico, various Melastomaceae in Amazonia, Anisophylla spp. and Barringtonia spp. in Malaya), because of their dense, shade-casting crowns, interfere with the development of desirable regeneration, and consequently must be regarded as weeds in forest management. The shape of the crown is often quite distinctive for any species, though this may vary during the life of the tree. Thus the tallest trees tend to have rather wide, spreading crowns, which are shallow for the height of the tree, whereas smaller trees often have rather narrow but relatively deeper crowns. Species such as Triplochiton scleroxylon and Dryobalanops aromatica possess both types of crown during various stages of their life cycle. Whilst the large overstorey trees develop the most extensive crown spreads, (Barnard, 1955, mentions trees with a crown area of up to one acre in Nigeria, though such trees are exceptional), there is a strong indication that on trees of similar stem diameter the understorey species have appreciably wider crowns than do the overstorey species. This is shown in figure 4, which summarizes the crown diameter (K/D) relationship of understorey and overstorey species in three widely separated rainforest communities, submontaine rainforest in the Luquillo Mountains of Puerto Rico, equatorial rainforest at Kemasul F.R. in Malaya, and evergreen seasonal rainforest at Sapoba F.R. in Nigeria. In all three localities the understorey species show a much steeper rise in crown width against diameter than do the overstorey species, and

TABLE 5

Size Class Distribution of Trees in Rainforest

Locality	Subformation	% Diameter Class Distribution									Stems /acre	BA /ac (sq ft)
		4"-8"	8"-12"	12"-16"	16"-20"	20"-24"	24"-28"	28"-32"	32"-36"	36"+		
Pan-Tropic (1)	-	56	23	9	4	2	2	1	1	2	180	-
Mocambo Forest, Brazil (2)	Equatorial	67	17	7	3	2	1	1	1	1	206	126
Sg. Menyala, Malaya (3)	Equatorial	55	20	7	6	4	3	2	1	2	220	158
Sapoba, Nigeria (4)	Evergreen, Seasonal	77	10	4	3	2	1	1	-	2	262	173
Luquillo Mountains, P.R. (4)	Submontane	67	16	4	5	3	1	2	1	1	467	298
Bt. Lagong, Malaya (3)	Submontane	60	18	10	5	3	1	1	1	1	231	221
Wiangarie, N.S.W. (4)	Subtropical	47	23	11	7	3	4	3	1	1	186	200
Bo Bo, N.S.W. (4)	Warm Temperate	49	21	26	3	1	-	-	-	-	364	199
Kedah Pk., Malaya (3)	Montane	84	12	4	-	-	-	-	-	-	430	112

Sources: (1) Dawkins, 1958. (2) Records of F.A.O. Mission to the Amazon, Belem. (3) Records of Forest Research Institute, Kepong. (4) Original Field data (the Bo Bo plot relates to logged stand from which some of the larger stems have been removed: in its unlogged state the proportion of smaller stems would be lower).

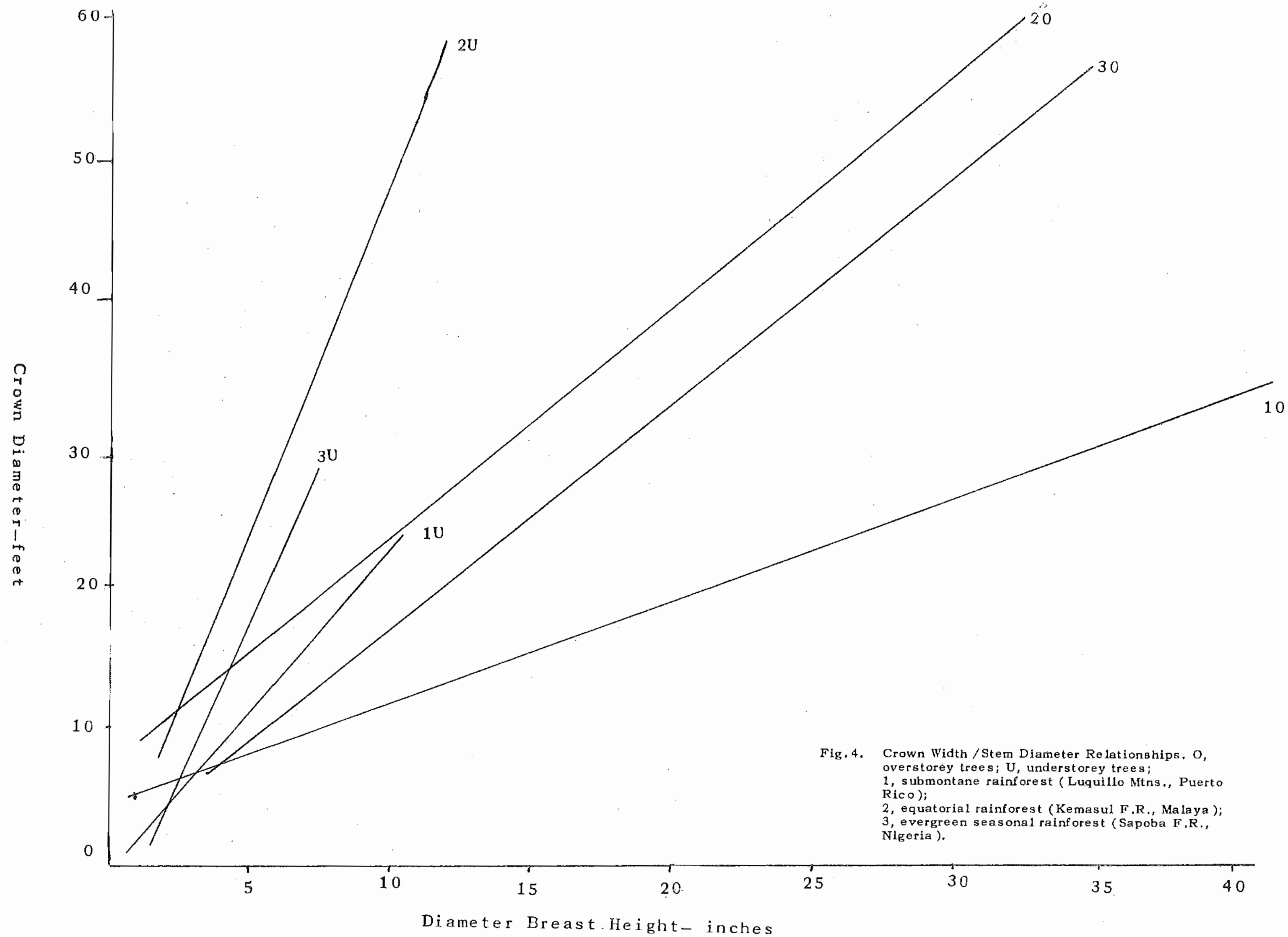

Fig. 4. Crown Width / Stem Diameter Relationships. O, overstorey trees; U, understorey trees;
1, submontane rainforest (Luquillo Mtns., Puerto Rico);
2, equatorial rainforest (Kemasul F.R., Malaya);
3, evergreen seasonal rainforest (Sapoba F.R., Nigeria).

this partly explains why the smaller trees exert a greater influence on the microclimate than the larger ones, as discussed in Chapter 2. The K/D relationship of the taller trees is a most useful value when aerial photographs are being used in rainforest assessment, since a constant relationship offers a means of estimating stem diameters from the crown diameters, which can be measured on the photographs. This use of the K/D relationship is discussed by Heinsdijk (1957-58, 1960) and by Swellengrebel (1959) *. These various crown appearances are shown in the profile diagrams in this report.

Crown shape is determined not only by its width and depth, but also by the manner and degree of branching, which can be quite characteristic for a given species. The almost whorled, wide angled branching of Terminalia superba: the dense, compact crown of Diospyros pentamera; and the unswept branches of Ceratopetalum apetalum are quite typical features for these species. Even more striking is the completely right-angled branching habit of Ceiba pentandra in Malaya #, where the structure of the crown has led to the tree being known as the "P.W.D. Tree", on the uncharitable basis that if the Public Works Department were required to design a tree, this would be the result. Richards (pp. 56-57) points out that, in tropical rainforest, branching of a higher degree than third is unusual, though temperate rainforest trees exhibit higher degrees quite commonly. As Richards states, the reduction in order of branching in tropical rainforest reaches its extreme in the palms and certain other groups, where no branch at all is found. This unbranched habit is also commonly encountered in young trees which later develop branches.

Many rainforest trees coppice freely, and even where the original stem is still healthy, individuals can often be found surrounded by a thicket of coppice saplings which frequently shoot from a swollen base of the original tree. This is illustrated by the clumps of Pithecellobium aff. microcarpum shown in figure 22 from montane rainforest in Malaya, and in Dicymbe corymbosa in British Guiana the same habit has given rise to the common name of "Clump Wallaba". Nothofagus moorei in the cool temperate rainforests of eastern Australia behaves similarly, and on the McPherson Ranges, circular groups of mature trees of this species can be found resulting from the release of the coppice when the original tree has finally died. Coppice growth sometimes is produced vigorously from the stumps of felled trees, though normally little use is made of this in rainforest management. Coppice may also occur at intervals along the stem of a tree which has been blown over, and occasionally these shoots may form a number of separate individuals when the intervening sections of the original stem have decayed: an early stage in such development is shown by one of the trees of Berlinia spp. illustrated in figure 19, the profile diagram for swampy rainforest in Nigeria.

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* Since writing this section, H.C. Dawkins has published a most interesting paper detailing the K/D relationships of various rainforest species under a variety of conditions: "Crown Diameters: Their Relation to Bole Diameter in Tropical Forest Trees". Comm. For. Rev. 42(4), 1963, pp. 318-333.

This pan-tropical Bombacaceae has a quite different appearance in Africa and tropical America.

The stem characters of rainforest trees are rather varied, and often provide useful diagnostic features for identification, as discussed by de Rosayro (1953) and Wyatt-Smith (1954a). The bark is commonly rather smooth, thin and pale coloured, though flaky, scaly and fissured barks are not unusual and may be dominant in temperate rainforest. The true colour of the bark is usually masked by stem lichens, which are probably a feature of all rainforest communties. In most rainforest trees the stem, at least above the influence of buttresses where these occur, is markedly cylindrical, but some species are typically heavily fluted for their entire length: this feature is shown by Planchonella australis, Citronella moorei, and Ehretia acuminata in the subtropical rainforest of New South Wales. Extreme cases of fluting are present in a few species where the stem appears to anastomise, with gaps sometimes showing right through the stem. This feature is of course shown by the old root tissue of stranglers, but is also present in a few species with otherwise normal growth, such as Adina sp. in Malaya and Aspidosperma spp. in tropical America. Such trees on the planalto areas of seasonal evergreen rainforest in Brazil are known as "mosquito trees", since their convoluted stems offer one of the few places for water to accumulate and for mosquitoes to breed on these otherwise waterless plateau forests.

Possibly the most striking features of many rainforest trees, particularly in the tropical formation, are the growth developments of the lower stem - the buttresses and the stilt roots. Another unusual character shown by some species growing in swamps subject to seasonal variation in the water level is the development of an abnormally swollen stem (still generally circular in cross-section) below the height periodically inundated. This feature is probably best known from the temperate North American swamp species Taxodium distichum, Nyssa aquatica and Fraxinus pennsylvanica, but is also shown by the Australian flood-plain eucalypt Eucalyptus camaldulensis, and by a number of tropical swampy rainforest species e.g. Xylopia sp. and Sapium sp. in Nigeria. Stilt roots also are most frequently encountered in swampy sites (including mangrove forests), but are not unusual in dry-land rainforest in the tropics (e.g. see figure 5, from the Brazilian planalto, for stilt roots on Licania sp.). They are found in a variety of botanical groups, but are usually confined to trees of the lower storeys, and are rare outside the lowland tropics. In some species the stilt roots subsequently grow in the vertical plane, so that their final shape closely resembles that of buttresses.

Buttresses are a most characteristic feature of many rainforest communties, and result from abnormal vertical growth made by large surface roots in the angle where these join the stem. Unlike stilt roots, buttresses are most commonly found on species which reach the upper storeys of the rainforest, and because of the difficulties which they create in measuring the trees accurately for forest assessment or growth studies, and in felling such trees*, they are of some importance in rainforest management. Buttressing is illustrated in a number of profile diagrams in this report, and is well shown by the two trees of

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* The heavily buttressed lower section of such trees is usually left in the forest, with consequent wastage of timber and increased cost in felling.

Alstonia boonei in figure 19; the phenomenon is discussed in some detail by Richards (pp. 59-74). The habit is most common in trees of the lowland tropical rainforests, being extremely rare in the temperate rainforest formation and, within tropical rainforest, tending to become rarer with both altitude and distance from the equator. Its frequency also varies with soil characteristics, buttressing being less common on deep, well drained, sandy soils than on shallow and water logged soils. Trees of many families produce buttresses, though they may be present in one species and absent in another closely related species. The shape of the buttresses often is a useful diagnostic feature in identifying rainforest trees; in the subtropical rainforests of New South Wales the high convex buttresses of Sloanea woollsii distinguish this species quite reliably from other local buttressed trees (see figure 21). However, the buttress shape may vary during different stages of the tree's growth, and indeed may even be present or absent in a single species depending upon the specific site conditions. After reviewing the evidence on buttress formation in tropical trees, Richards concludes that there is no entirely satisfactory theory to explain their development, but indicates that they are genetically controlled, and probably produced under the stimulus of tension on the roots under the influence of a warm, humid environment. Vincent (1960b) has studied the occurrence of buttressing on 2,000 trees of Shorea leprosula in Malaya, in the hope of finding a means of overcoming some of the difficulties which they cause in forest mensuration. 64% of the stems had buttresses to a height of 4 feet 6 inches (breast height), and three of them had buttresses extending beyond a height of 15 feet, but the incidence of buttressing varied with both locality and topography. Buttresses were present on 51% of the trees in hilly sites, whereas on flat land 69% of the trees of Shorea leprosula were buttressed. Vincent also found a close correlation between the height of the buttresses and the stem diameter immediately above the buttressing, but he was unable to find any useful relationship between the diameter around the buttresses at breast height and the diameter above the buttresses.

Most rainforest trees tend to be rather shallow rooted, and the feeding roots in particular are usually confined to the top few inches of the soil. Buttressed trees usually lack long tap roots, but on deep soils many rainforest trees may produce tap roots and show root activity far below the soil surface, as Schultz (1960) has recorded from Surinam. On the Benin Sands of Nigeria the holes left by the decayed tap roots some years after poisoning can be quite a hazard in walking through treated rainforest. Tap rooted species are particularly common on these sands, and are reflected by the dominance of such species as Gossweilerodendron balsamifera and Cylicodiscus gabunensis, whose occurrence may be determined by the ability of the soil to permit tap root development (Sykes, 1930). On shallow and waterlogged soils the rooting tends to be much more superficial, and on swampy sites many trees produce "breathing roots" or pneumatophores, sometimes very distinctive in shape. The knee-shaped pneumatophores of Alstonia boonei in swampy rainforest are shown in figure 19.

In most rainforest communities, a variety of leaf sizes and shapes can be found, but there is nonetheless a most apparent monotony about the foliage of rainforest trees, with a single size and shape predominating in any stand. This marked similarity in the leaves of unrelated plants is one of the most distinctive features of rainforest, and clearly has some diagnotic value, as has been discussed by Richards and by Webb (1959). The latter author found that three leaf sizes

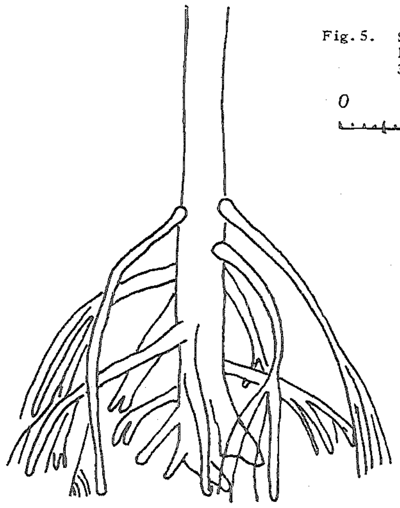


Fig. 5. Stilt roots on *Licania* spp. in Evergreen Seasonal Rainforest, Curua, Brazil. Tree 3 inches D.B.H., 30 ft. high.

(5)

TABLE 6

Foliage Features in Australian Rainforests

(After Webb, 1959)

Sub-formation	Webb's Formation	Meso-phyll	Noto-phyll	Micro-phyll	Com-pound	Entire Margin
		% approx.	%	%	%	%
Evergreen Seasonal	MVF	64	33	3	30	85
Semi-evergreen	SEVF(1)	30	40	30	20	85
Submontane	SMVF	35	55	10	30	75
Subtropical	NVF	5	85	10	35	55
Warm Temperate	SNVF	10	60	30	10	40
Cool Temperate	MMF	0	5	95	0	0

Note (1) Percentages for Semi-evergreen Rainforest refer to number of species, not number of individual stems.

occurred in the rainforests of eastern Australia, these being microphylls (225-2025 sq mm; .35-3.1 sq in), notophylls (2025-4500 sq mm; 3.1-7.0 sq in) and mesophylls (4500-18225 sq mm; 7.0-28.3 sq in): smaller and larger leaves were very rare. In any community one of these sizes tended to predominate, and Webb used this as the initial diagnostic character in his classification of Australian rainforests. Table 6, adapted from Webb, indicates some of the foliage features in the Australian rainforest subformations.

Webb's findings appear applicable throughout the rainforest regions, and show the general diminution of leaf size as conditions become generally cooler on the one hand, and drier on the other. Coupled with the smaller leaves there are fewer species with compound leaves, while with reduced mean temperatures, entire margins become progressively rarer. Other leaf features also alter. In the humid tropics, the foliage is typically evergreen and mesomorphic, the leaf apices are extended into conspicuous "drip tips", the bases of the petioles (or petiolules in compound leaves) are swollen into pulvini, and the young, expanding leaves are extremely flaccid and frequently brilliantly coloured. Under less favourable environmental conditions these features tend to alter; deciduousness becomes more frequent under drier conditions, while sclerophylly is characteristic of rainforest in cooler sites; drip tips and pulvini become less common and the vivid drooping young leaves are less marked. Within any community the leaf characteristics show some variation in the different tree storeys, tending to be larger and less sclerophyllous in the lower layers. This may be shown by a single species: shade leaves from a fallen tree of Ceratopetalum apetalum in a warm temperate rainforest in New South Wales averaged four times the surface area of sun leaves from the top of the same tree. Similarly, juvenile foliage may differ considerably from the adult foliage of a rainforest tree, the adult leaves tending to conform to the "norm" for the particular community, as shown by many Proteaceae in the Australian rainforests. This conformity of the foliage to a particular type is not confined to the trees, but is shown by most rainforest life forms, and is well illustrated by Richards (figures 13, 14, 17 and 18).

The flowering habits of rainforest trees fit less to a pattern than do the leaves, there being great variety in the size, shape, colour and arrangement of the trees. One type of flowering however is virtually confined to rainforest trees, and deserves some mention. This is cauliflory, where the flowers are born not on the small twigs, but from stems or large branches. This feature is usually confined to the understorey trees, and is largely restricted to rainforest in the tropical lowlands, being quite common in equatorial and evergreen seasonal rainforest, but rare in subtropical rainforest, and absent from the temperate rainforest formation.

Spatial Arrangement

Though to the casual visitor rainforest may appear as a completely disorganized aggregation of plants, closer study will show that these life forms show some degree of consistent arrangement in space. The arrangement takes place in two directions, vertically and horizontally, and this arrangement is of importance in distinguishing the various subformations.

The vertical arrangement of plants in rainforest is probably best portrayed by profile diagrams, and best understood by study of these. The method of constructing profile diagrams has been discussed in some detail by Robbins (1959), and this method(originally used by Davis and Richards in British Guiana) has now been employed by workers in most rainforest regions of the world. It consists of drawing to scale all trees above a certain size on a strip of forest 25 feet wide and usually about 200 ft in length. Where the width differs from 25 ft (e. g. Nigerian Federal Department of Forest Research, which has one of the most comprehensive collections of local profile diagrams in the world, uses a width of 20 feet, see Jones (1948) and Keay (1959a)), then the diagram will give the impression of greater or lesser tree density than would otherwise be the case. The minimum sized plants included are usually determined by convenience, but should be small enough to include most of the smaller trees without causing too much loss of time in sketching in masses of undergrowth. If it is felt desirable to indicate the shrub layers, this is probably best done on a separate, larger scale diagram of a section of the main profile transect. A ground plan of the transect is also often of value.

It must be stressed that profile diagrams only illustrate the vertical arrangement of the trees in a particular and limited area. An immediately adjacent transect may show quite different features, and for this reason the longer the transect, the more chance of sampling the variation in the structure of the community. Another approach is to sketch a number of adjacent transects, and present the result as a series of overlays, thus giving a three-dimensional effect: this has been done by Cousens (1951) in Malaya, using four diagrams to illustrate a strip of rainforest 66 feet wide.

Profile diagrams are of value not only in interpreting rainforest structure, but also in providing a guide to the effects of any series of silvicultural operations on the stand, and where the diagrams are accurately enough prepared, and are redrawn in the same transect after intervals of some years, in elucidating the changes in rainforest structure with time.

Where a profile diagram is examined, it is usually found that, whilst trees of many sizes are present, these tend to fall into several fairly distinct groups of height classes, with the lower groups, or storeys, containing both mature individuals of smaller trees and immature individuals of larger species. Figure 9, showing equatorial rainforest in Kemasul F.R. in Malaya with all stems above 20 feet in height sketched, illustrates this tendency. Although at first sight little spatial organization of the trees is apparent, closer study suggests that four storeys are present in this stand, with height ranges of 140 feet - 180 feet, 90 feet - 110 feet, 50 feet - 70 feet and 30 feet - 40 feet. These storeys are not evenly distributed, though the lowest is fairly continuous. More generally a gap in one storey is compensated by a dense patch in the next lowest storey. Whilst this exact pattern is not repreated in all rainforests, the discontinuity of all or most of the storeys is a common feature in most rainforest communities. In this particular diagram the tallest stems (all Shorea spp.) appear as rather scattered, individual trees, with their crowns free growing above the second storey. If this was indeed so, these trees would warrant description as emergents, and in Malaya the trees of this uppermost storey are indeed commonly called emergents. In actual fact, the diagram gives a false impression in this regard, and in

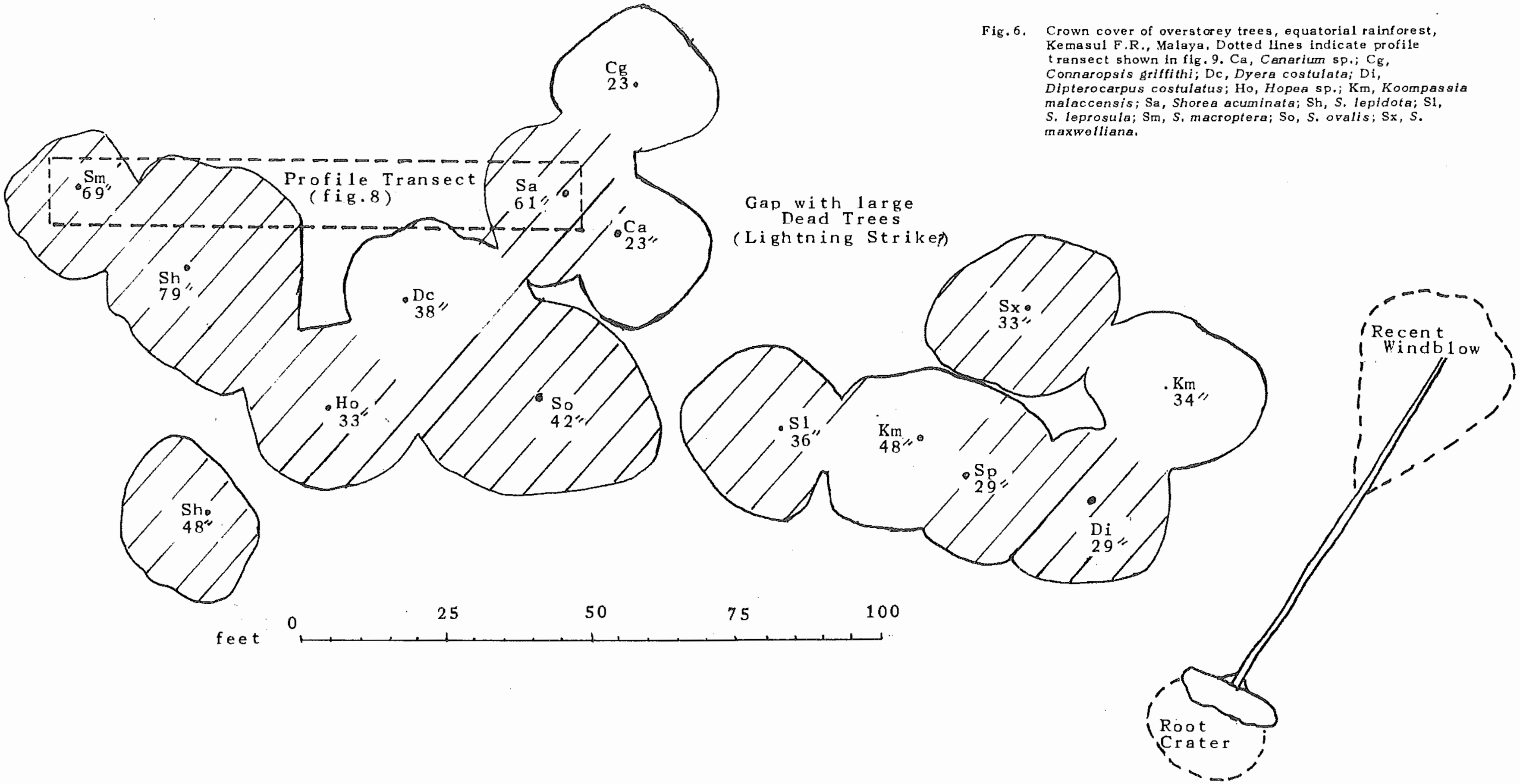


Fig. 6. Crown cover of overstorey trees, equatorial rainforest, Kemasul F.R., Malaya. Dotted lines indicate profile transect shown in fig. 9. Ca, *Canarium* sp.; Cg, *Connaropsis griffithi*; Dc, *Dyera costulata*; Di, *Dipterocarpus costulatus*; Ho, *Hopea* sp.; Km, *Koompassia malaccensis*; Sa, *Shorea acuminata*; Sh, *S. lepidota*; Sl, *S. leprosula*; Sm, *S. macroptera*; So, *S. ovalis*; Sx, *S. maxwelliana*.

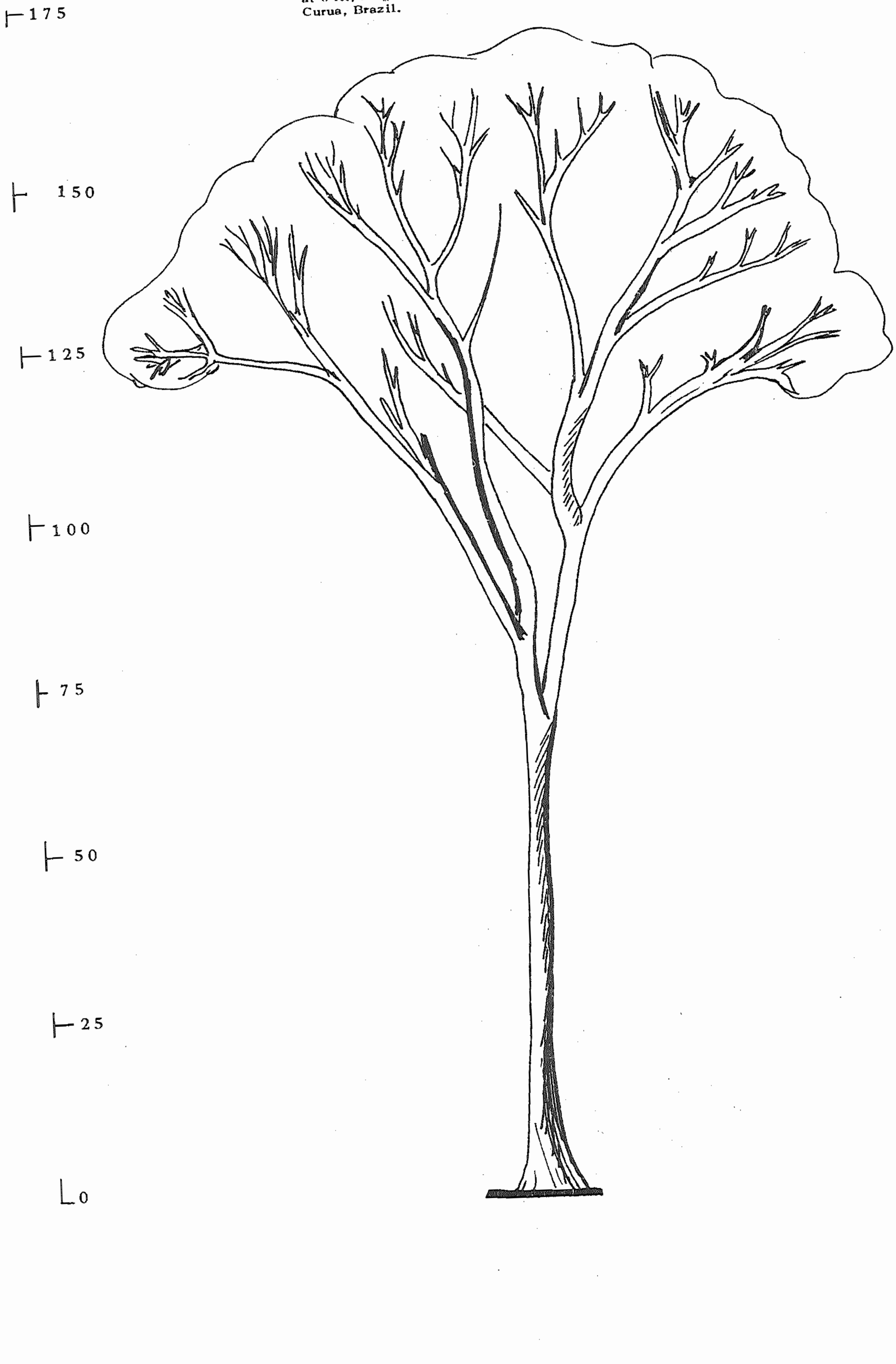
figure 6 the crowns of all the upper storey trees in the vicinity of the profile transect have been plotted to show that these largest trees form locally continuous patches, interrupted by gaps which are usually filled with smaller trees. Upper storey trees which are true emergents are certainly found in rainforest, often as relics of an earlier community (e.g. eucalypts surviving above rainforest in Australia), but the term is frequently applied loosely and incorrectly. A fine example of a true emergent tree is shown in figure 7 which was drawn near to, and on the same scale as, the Amazonian evergreen seasonal rainforest illustrated in figure 12. Such trees of Dinizia excelsa are scattered through these planalto forests, towering above and overtopping with their crowns all other trees in the vicinity. The Malayan pattern has been recognized previously, Cousens (1951) noting that the largest trees are usually surrounded by other large trees, these "peaks" being linked by "ridges" up to three chains wide to form a reticulate pattern with "wells" of smaller trees.

The reality of tree storeys in rainforest has been disputed by some workers (see Richards, pp. 22-24, for discussion), who have found that the number of trees in progressive height classes form a continuous curve, or that the storeys are difficult to identify in the field, or even in profile diagrams. However, the majority of workers appear to agree that in homogeneous patches of rainforest fairly distinct stratification of the trees and shrubs does occur, and it cannot be disputed that the rainforest trees do reach varying maximum heights, the smaller ones having somewhat different growth habits to the larger ones, as has been discussed already.

Part of the difficulty in recognizing the storeys results from the fact that rainforest is seldom structurally homogeneous over any extensive area. The gap structure mentioned above from Malaya is a feature of most, if not all, rainforest communities, and its significance will be examined in Chapter 6. Because of the past history of human interference, and the presence of large game, this heterogeneous rainforest structure if particularly evident in some of the Nigerian rainforests where the gap phase covers extensive areas and, in various forms, is long lasting. This peculiar structure (it might almost be termed lack of structure) in Nigeria has been the subject of much speculation and discussion in the past. One of the best accounts is given by Jones (1955-56), who regards the well developed patches of rainforest as the central type, which he calls High Forest, and the other physiognomic variants as phases which have been derived from this: the phases recognized are broken High Forest, open scrub, low closed scrub and tall closed scrub, as well as the more obviously young secondary forest.

The profile diagram given by Jones and the description of this (p. 574) indicate how these phases alternate. This alternation to produce a structural mosaic is also shown in figure 8 which illustrates the arrangement of phases over an area of 360 acres in a strict natural reserve on Omo F.R. In this figure, taken from the records of the Federal Department of Forest Research and based on original work of the late A.P.D. Jones, the areas indicated as "tangle" represent the two closed scrub phases of E.W. Jones. As can be seen, the High Forest phase is the most poorly represented of all three that are recognized, and the confusion that this mosaic of structural types must cause to anyone attempting to interpret Nigerian rainforest structure can be readily appreciated. It must however be stressed that the mosaic

Fig. 7. Emergent Tree of *Dinizia excelsa*. Diameter 39 inches at 8 ft.; height 170 ft. Evergreen seasonal rainforest, Curua, Brazil.



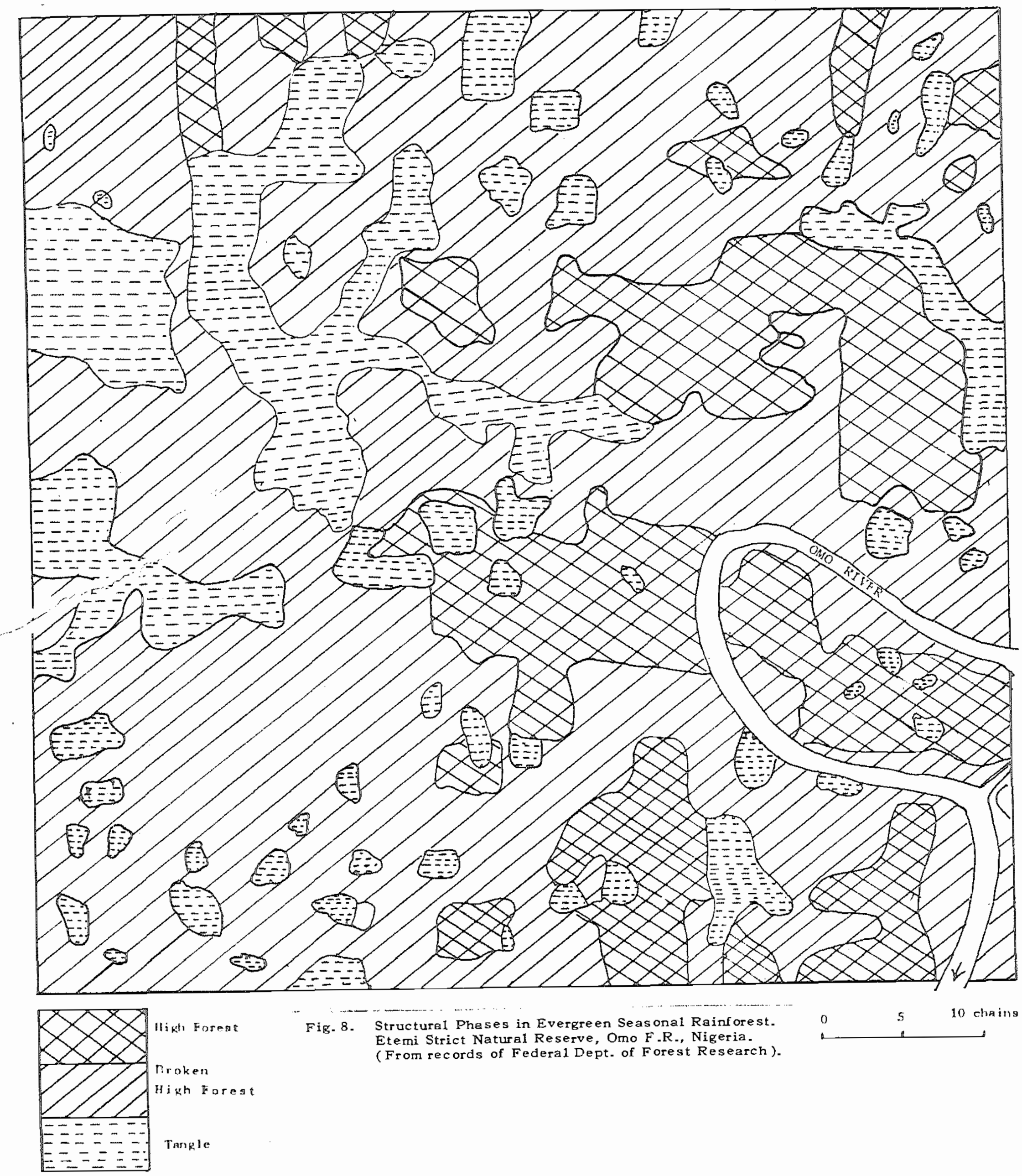


Fig. 8. Structural Phases in Evergreen Seasonal Rainforest. Etemi Strict Natural Reserve, Omo F.R., Nigeria. (From records of Federal Dept. of Forest Research).

is static in neither time nor place, and also that the effect is probably more marked in the African rainforests than in other regions.

The High Forest phase is the type which must be regarded as typical rainforest for any locality, and which shows most clearly the vertical stratification of the trees. It is also the type which foresters are most interested in managing. When such areas are examined, it is found that certain combinations of structure and physiognomy recur in widely separated regions of the world, and these can be regarded as structurally distinct subformations. In Chapter 1 it was shown that two rainforest formations can be recognized around the world, tropical and temperate, and these in turn can be split into subformations of which ten are recognized in this report. The two formations, both warranting the description of "rainforest", are distinguished by both structure and floristic origin, while the subformations differ chiefly in structure and physiognomy.

The subformations are to some extent units of convenience. Several of those recognized certainly warrant further division, while probably no two rainforest ecologists will agree as to where the line between adjacent subformations should be drawn, since the subformations merely represent sections of a constantly varying continuum. Nonetheless these stands of similar structure can be found in different regions, usually occurring under very similar environmental conditions, and they appear to respond similarly to various forms of silvicultural treatment. Thus the recognition of subformations is more than a purely academic exercise, and some consideration of these is warranted.

Tropical Rainforest Formation

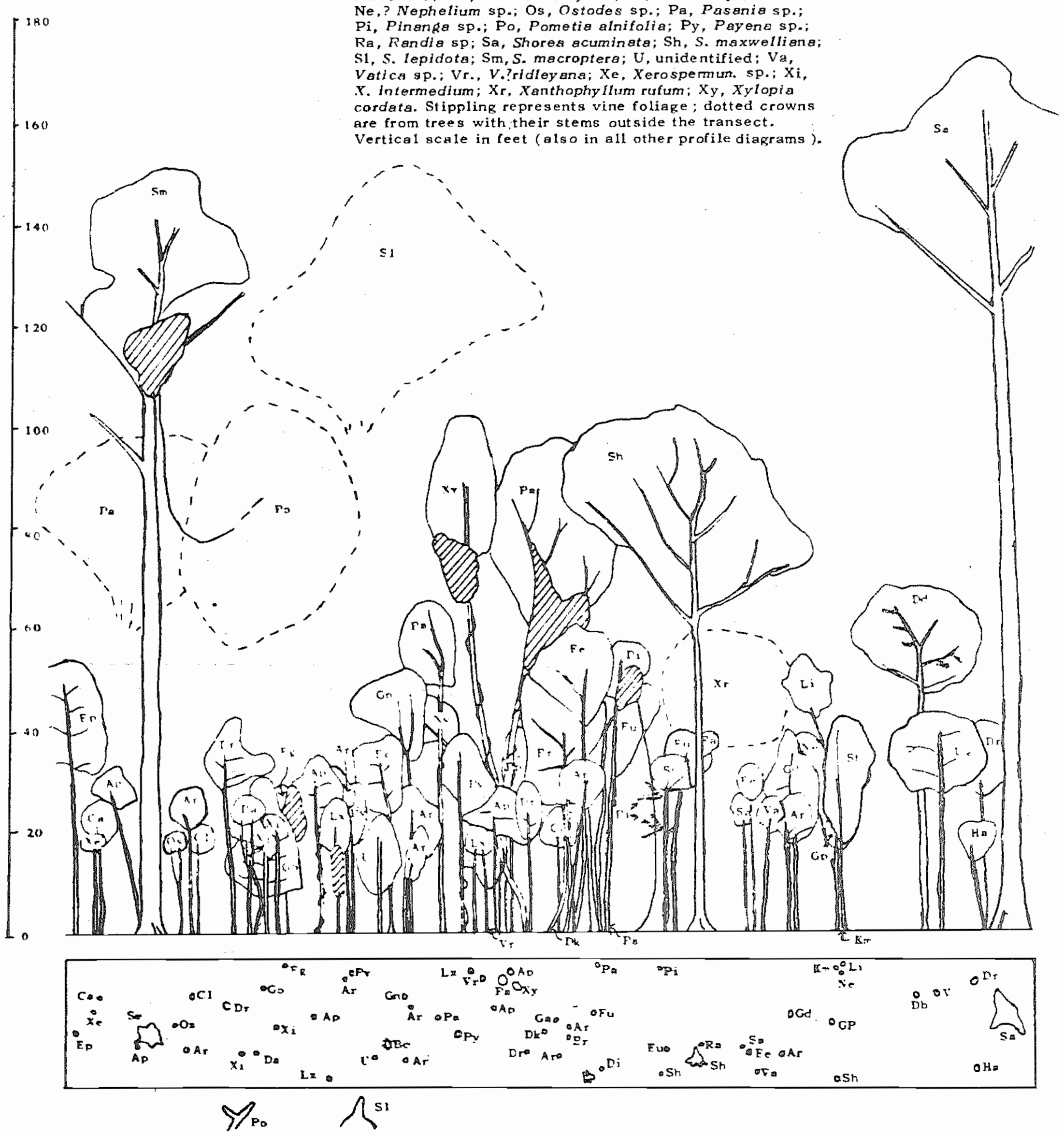
The tropical rainforest formation is composed chiefly of plants whose origins lie within the tropical regions. It is a multistoried community containing trees which are mostly evergreen, though by no means exclusively so. The trees are frequently buttressed or stilt-rooted; their leaves tend to be mesomorphic, entire, usually mesophylls in size, frequently compound, and often equipped with drip-tips and pulvini. Heavy vines are often abundant, cauliflory is common, and vascular epiphytes are normally plentiful. The tallest trees usually exceed 100 feet in height.

This formation occurs primarily in the humid tropical lowlands, though it is not confined to these sites as it extends beyond the tropics in both South America and Australia and slightly in China and India. It occurs well up in some tropical mountains, and it is found in areas with decidedly seasonal rainfall.

Seven subformations of tropical rainforest are recognized here, but this is undoubtedly a conservative count. Several of these are fairly distinct, but for the most part they are rather characteristic parts of an even more characteristic whole.

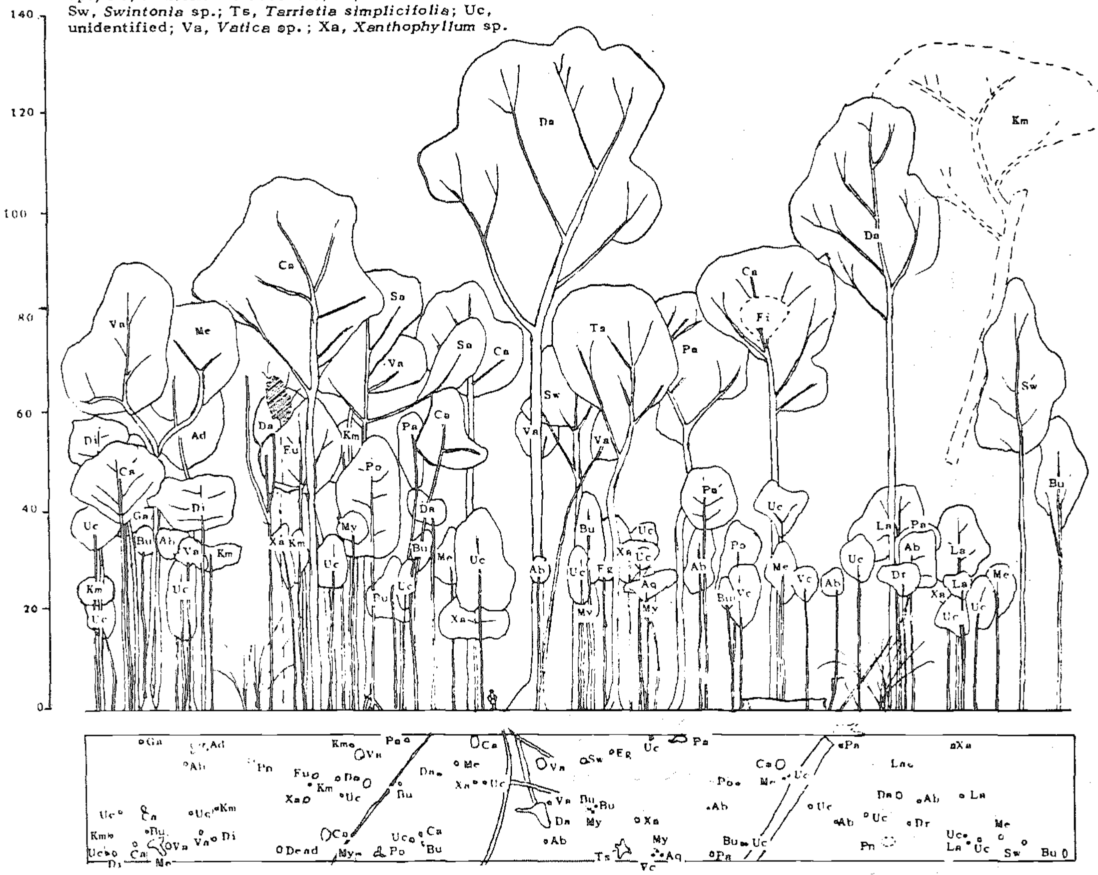
1. Equatorial Rainforest is the most luxuriant of all plant communities, and occurs under what are probably the finest growing conditions experienced anywhere in the world, Examples of this subformation are given in figures 9, 10 and 11, all from Malaya. The first and last are from the Shorea-Dipterocarpus (Meranti-Keruing) community of Wyatt-Smith (1961b), while figure 10 is from a community which tends to be dominated by a single dipterocarp, Dryobalanops aromatica. Three or four tree storeys are present, and in addition there are usually two shrub layers. The tallest trees exceed 120 feet in height, and may exceed 200 feet (Walton, 1955), usually forming a relatively continuous upper storey. True emergents are rare. The leaves of the trees are mesophylls, and deciduous species are extremely rare. Heavy vines are moderately common, and vascular epiphytes are plentiful, though usually obscured from view from the ground. Palms may be frequent in the shrub layers, but larger palms are unusual. The stocking of trees over four inches d.b.h. usually ranges between 200 and 300 per acre, with basal areas (B.As.) between 140 square feet and 230 square feet per acre. Equatorial rainforest occurs on well

Fig. 9. Profile Diagram of Equatorial Rainforest, Kemasul F.R., Malaya. Transect 25 ft. wide, 190 ft. long. Stems under 20 ft. high omitted. Ap, *Aporosa* sp. (1); Ar, *A.* sp. (2); Bc, *Baccaurea* sp; Br, *Barringtonia* sp.; Ca, *Castanopsis* sp.; Cl, *Canarium littoralis* f. *rufum*; Da, *Diospyros argentea*; Db, *D. buxifolius*; Di, *Dacryodes ? incurvata*; Dk, *Dipterocarpus kunstleri*; Dr, *Dacryodes rugosa*; Ee, *Eugenia* sp. (1); Eg, *E.* sp. (2); Ep, Euphorbiaceae; Eu, *Eugenia* sp. (3); Ga, *Garcinia* sp.; Gd, *G.? dulci*; Gn, *Gironniera nervosa*; Go, *Goniothalamus* sp.; Gp, *Gironniera parvifolia*; Ha, *Heritiera alata*; Ix, *Ixonanthes icosandra*; Km, *Knema malayana*; Li, *Litsea* sp.; Ne, ? *Nephelium* sp.; Os, *Ostodes* sp.; Pa, *Pasania* sp.; Pi, *Pinanga* sp.; Po, *Pometia alnifolia*; Py, *Payena* sp.; Ra, *Randia* sp; Sa, *Shorea acuminata*; Sh, *S. maxwelliana*; Sl, *S. lepidota*; Sm, *S. macroptera*; U, unidentified; Va, *Vatica* sp.; Vr., *V.? ridleyana*; Xe, *Xerospermum.* sp.; Xi, *X. intermedium*; Xr, *Xanthophyllum rufum*; Xy, *Xylopia cordata*. Stippling represents vine foliage; dotted crowns are from trees with their stems outside the transect. Vertical scale in feet (also in all other profile diagrams).



drained soils of moderate fertility in areas with a high rainfall and little annual drought. It is found in parts of tropical America, including the region near the mouth of the Amazon River and in the Guianas, and it is widespread in the Malaysian region of southeast Asia. The subformation is probably absent from Africa, though it may be found in parts of the Congo basin. Other profile diagrams of equatorial rainforest are given by Richards (figure 4) from British Guiana and by Burgess (1961) from North Borneo.

Fig.10. Profile Diagram of Equatorial Rainforest, Gunong Arong F.R., Malaya. Transect 25 ft. wide, 200 ft. long. Stems under 25 ft. high omitted. Ab, *Artocarpus bracteata*; Ad, *Adenanthera* sp.; Aq, *Aquilaria malaccensis*; Bu, Burseraceae; Da, *Dryobalanops aromatica*; Di, *Diospyros* sp.; Dr; *Dipterocarpus rotundifolius*; Eg, *Eugenia* sp. (1); En, *E.* sp (2); Fi, *Ficus* sp.; Ga, *Garcinia* sp.; Km, *Koompassia malaccensis*; La, Lauraceae; Me, *Melanorrhoea* sp.; My, Myristicaceae; Pa, *Palaquium* sp.; Pn, *Pandanus* sp.; Po, *Pouteria malaccensis*; Sa, *Shorea acuminata*; Sw, *Swintonia* sp.; Ts, *Tarrietia simplicifolia*; Uc, unidentified; Va, *Vatica* sp.; Xa, *Xanthophyllum* sp.



2. Evergreen Seasonal Rainforest is probably the most widely distributed of all rainforest subformations, occupying extensive areas in all three of the tropical rainforest regions. It is distinguished from equatorial rainforest chiefly by the presence of deciduous trees, which may make up to one third of the taller trees in the community, though these are not necessarily all leafless at the same time. The total height is generally less than in the preceding subformation, though trees exceeding 150 feet in height may occur as true emergents (figure 7). Three tree storeys can be recognized. Profile diagrams of this subformation are shown in figures 12, 14 and 16, while the shrub layers in the first two of these are illustrated in figures 13 and 15. The upper storey often has an uneven canopy level, which is commonly discontinuous due to past disturbance. This subformation has suffered much more through man's activities than has equatorial rainforest. Heavy vines are frequently plentiful, probably due in part to the seasonal deciduousness and, in some areas, to the previous disturbance. Figures 12 and 16 give a false impression in this regard, since both are from stands that have received climber cutting as a silvicultural operation. Epiphytes are present but not common, as are palms. Tree stocking is in the order of 200 stems per acre, with B.As. between 110 square feet and 180 square feet per acre. The subformation is found on deep,

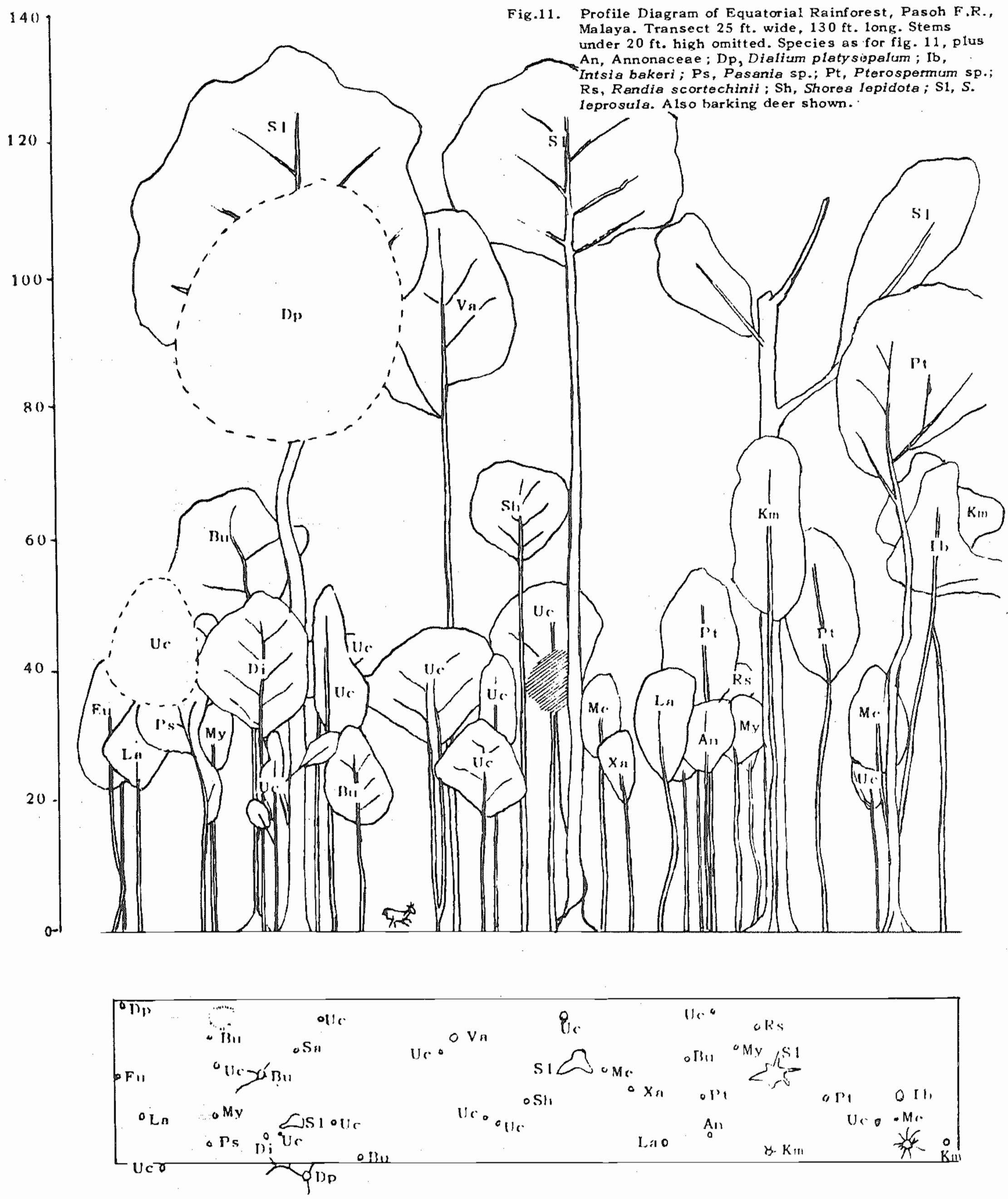


Fig.11. Profile Diagram of Equatorial Rainforest, Pasoh F.R., Malaya. Transect 25 ft. wide, 130 ft. long. Stems under 20 ft. high omitted. Species as for fig. 11, plus An, Annonaceae ; Dp, *Dialium platysepalum* ; Ib, *Intsia bakeri* ; Ps, *Pasania* sp.; Pt, *Pterospermum* sp.; Rs, *Randia scortechinii* ; Sh, *Shorea lepidota* ; Sl, *S. leprosula*. Also barking deer shown.

well drained soils in the lowland tropics, where there is a dry season which may extend for up to four months, and in some sites for even longer (e.g. parts of Amazonia). It is found through much of the central rainforest region of the Amazon basin, occurs widely through the Caribbean area, makes up most of the moister African rainforests, and is found through parts of southeast Asia and in northern Australia. Profile diagrams are given by Beard (1946a) from Trinidad, and by both A.P.D. Jones (1948) and E.W. Jones (1955-56) from Nigeria.

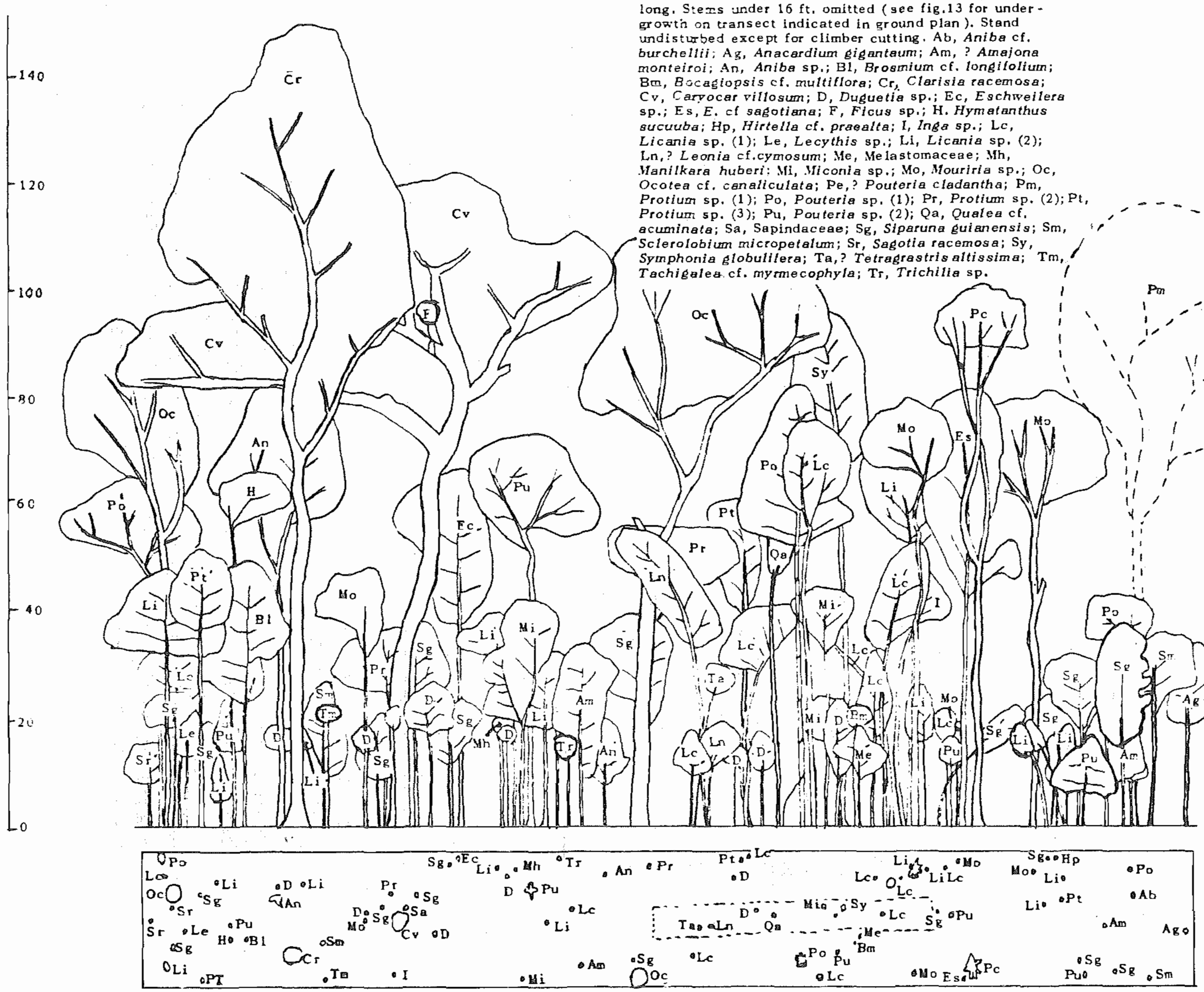


Fig.12. Profile Diagram of Evergreen Seasonal Rainforest, Curua Una River, Brazil. Transect 25 ft. wide, 192 ft. long. Stems under 16 ft. omitted (see fig.13 for undergrowth on transect indicated in ground plan). Stand undisturbed except for climber cutting. Ab, *Aniba* cf. *burchellii*; Ag, *Anacardium gigantaum*; Am, ? *Amajona monteiroi*; An, *Aniba* sp.; Bl, *Brosmium* cf. *longifolium*; Bm, *Bocagiopsis* cf. *multiflora*; Cr, *Clarisia racemosa*; Cv, *Caryocar villosum*; D, *Duguetia* sp.; Ec, *Eschweilera* sp.; Es, *E.* cf *sagotiana*; F, *Ficus* sp.; H. *Hymatanthus sucuuba*; Hp, *Hirtella* cf. *praealta*; I, *Inga* sp.; Lc, *Licania* sp. (1); Le, *Lecythis* sp.; Li, *Licania* sp. (2); Ln, ? *Leonia* cf. *cymosum*; Me, Melastomaceae; Mh, *Manilkara huberi*: Mi, *Miconia* sp.; Mo, *Mouriria* sp.; Oc, *Ocotea* cf. *canaliculata*; Pe, ? *Pouteria cladantha*; Pm, *Protium* sp. (1); Po, *Pouteria* sp. (1); Pr, *Protium* sp. (2); Pt, *Protium* sp. (3); Pu, *Pouteria* sp. (2); Qa, *Qualea* cf. *acuminata*; Sa, Sapindaceae; Sg, *Siparuna guianensis*; Sm, *Sclerolobium micropetalum*; Sr, *Sagotia racemosa*; Sy, *Symphonia globulifera*; Ta, ? *Tetragrastris altissima*; Tm, *Tachigalea* cf. *mymecophyla*; Tr, *Trichilia* sp.

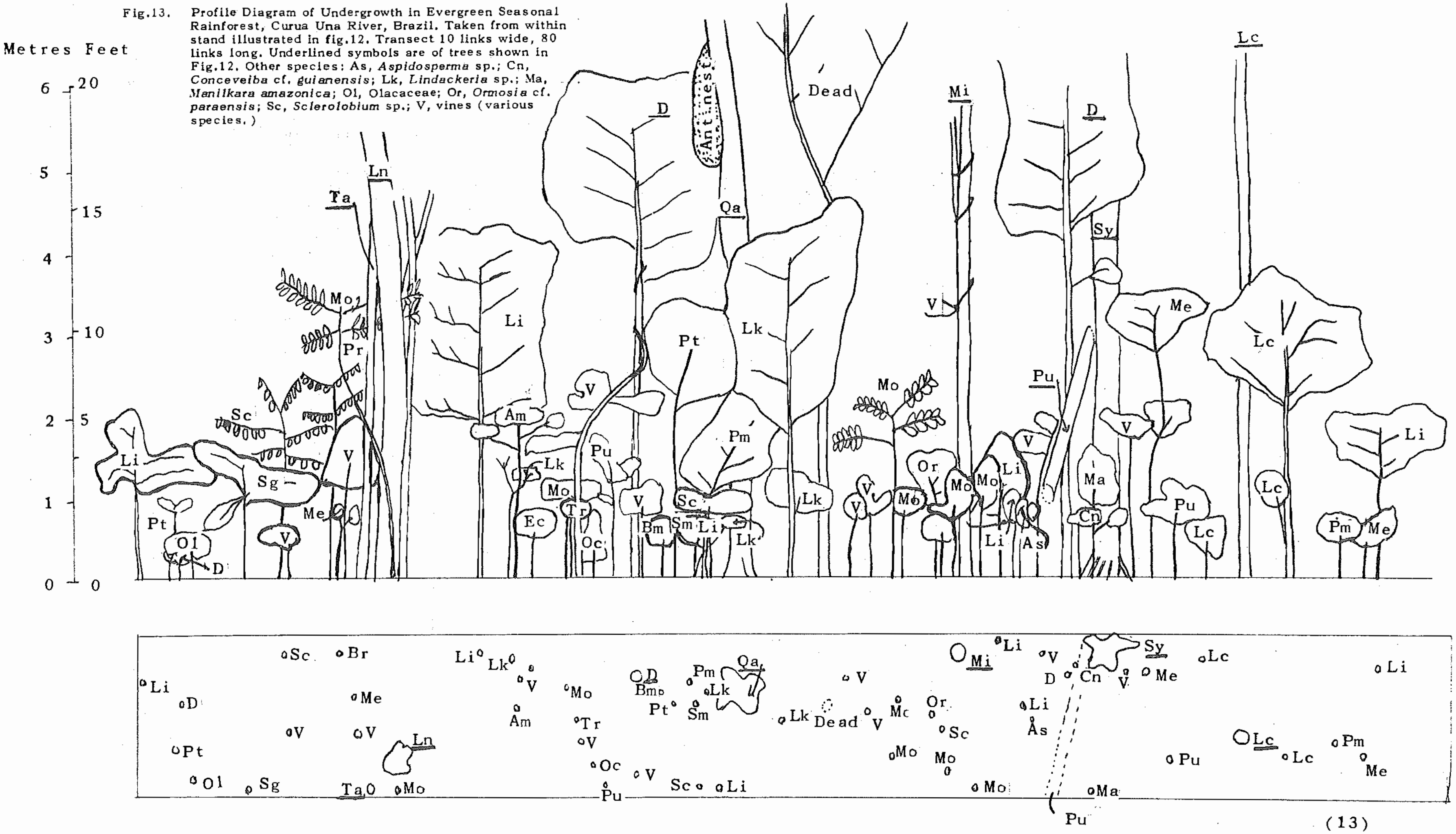
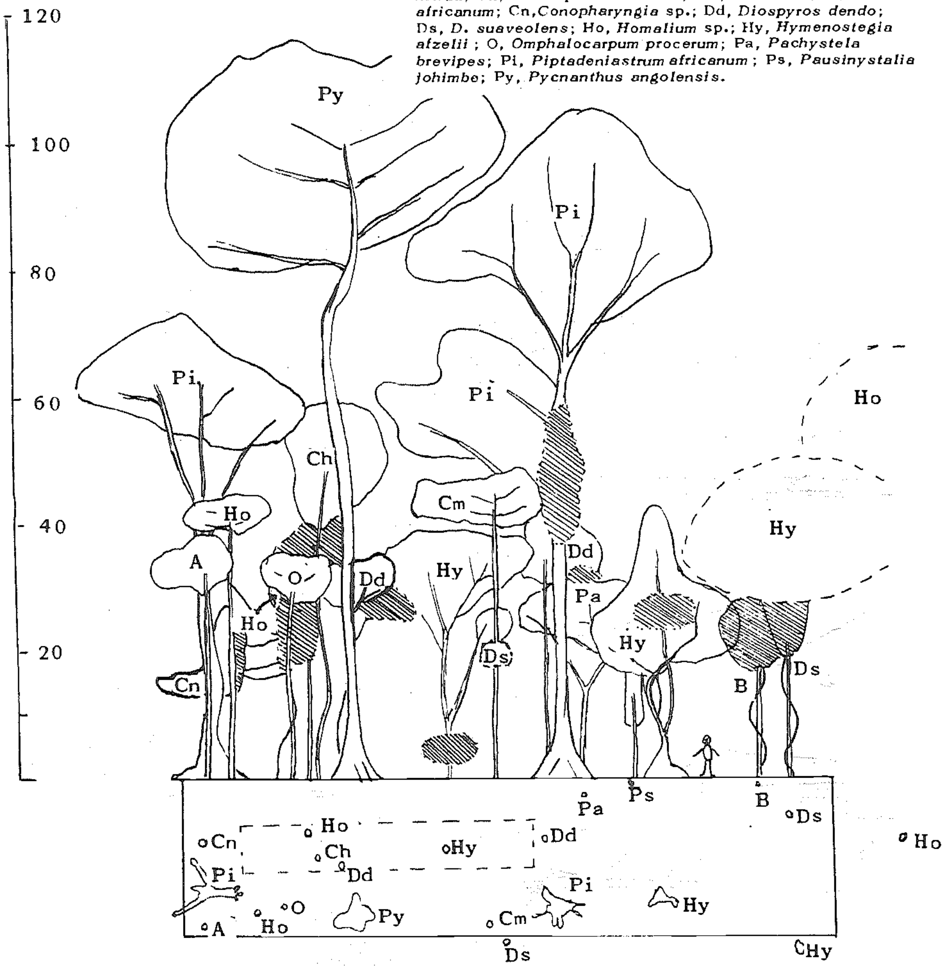


Fig.13. Profile Diagram of Undergrowth in Evergreen Seasonal Rainforest, Curua Una River, Brazil. Taken from within stand illustrated in fig.12. Transect 10 links wide, 80 links long. Underlined symbols are of trees shown in Fig.12. Other species: As, *Aspidosperma* sp.; Cn, *Conceveiba* cf. *guianensis*; Lk, *Lindackeria* sp.; Ma, *Manilkara amazonica*; Ol, Olacaceae; Or, *Ormosia* cf. *paraensis*; Sc, *Sclerolobium* sp.; V, vines (various species.)

Fig.14. Profile Diagram of Evergreen Seasonal Rainforest, Sapoba F.R., Nigeria. Transect 25 ft. wide, 100 ft. long. Stems under 20 ft.omitted. (See fig. 15 for undergrowth on transect indicated in ground plan). A, *Antiaris africana*; B, *Baphia nitida*; Ch, *Chlorophora excelsa*; Cm, *Combretodendron africanum*; Cn, *Conopharyngia* sp.; Dd, *Diospyros dendo*; Ds, *D. suaveolens*; Ho, *Homalium* sp.; Hy, *Hymenostegia afzelii*; O, *Omphalocarpum procerum*; Pa, *Pachystela brevipes*; Pi, *Piptadeniastrum africanum*; Ps, *Pausinystalia johimbe*; Py, *Pycnanthus angolensis*.



3. Semi-evergreen Rainforest is a community which is only debatedly in the tropical rainforest formation. It is lower in height than the previous subformations, with the tallest trees rarely exceeding 120 feet and frequently under 100 feet. Deciduous species make up about half the upper storey trees. Two, or more rarely three, storeys of trees can be recognized: Figure 17 is a profile diagram of an area along the sandy "flanco" soils bordering Curua Una River in Amazonia. Vines tend to be less abundant than in evergreen seasonal rainforest, and epiphytes are rare. To a greater extent than other subformations, semi-evergreen rainforest is liable to fire damage, and this has been the case in the Curua plot, where the shrub layers (except for the fire resistent stemless palms) are sparse and fire-killed trees are fairly common, some of these clearly relating to long past fires, others to fairly recent ones. Tree stocking is in the order of 200 to 300 stems per acre, with B.As. of from 90 square feet to 130 square feet per acre. The subformation is found in all three tropical rainforest regions, usually fringing the evergreen seasonal

Fig.15. Profile Diagram of Undergrowth in Evergreen Seasonal Rainforest, Sapoba F.R., Nigeria. Taken from within stand illustrated in fig.14. Transect 10 links wide, 70 links long. Hatching and broken lines indicate vines. Symbols as for fig.14, plus: An, *Anthonotha macrophylla*; F, *Fadogia* sp.; Gc, *Guarea cedrata*; Me, *Memecylon* sp.; Mi, *Microdesmis puberula*; Ra, *Randia acuminata*; Ri, *Rinorea* sp.; U, unidentified shrub spp.; V, vine (various species).

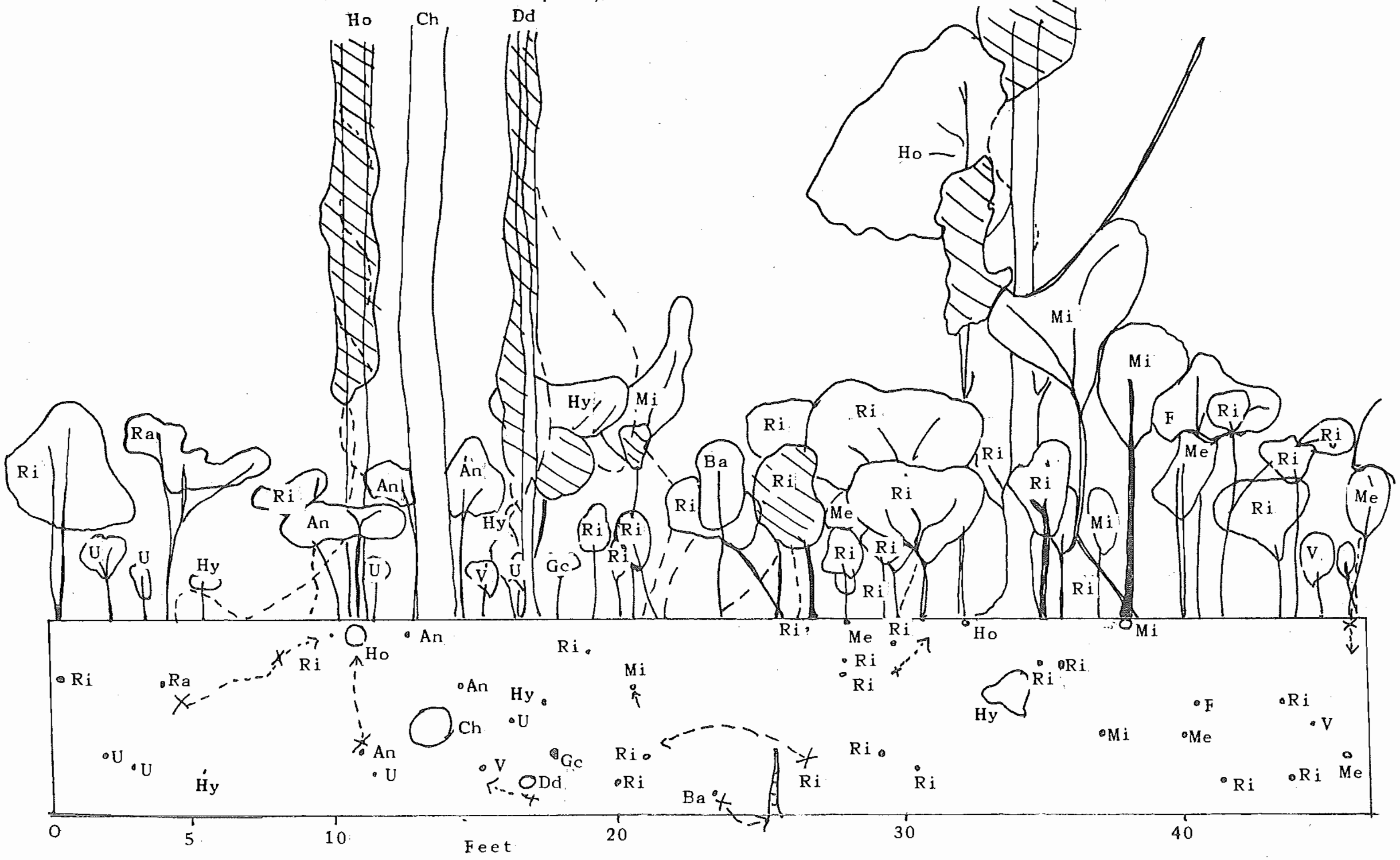
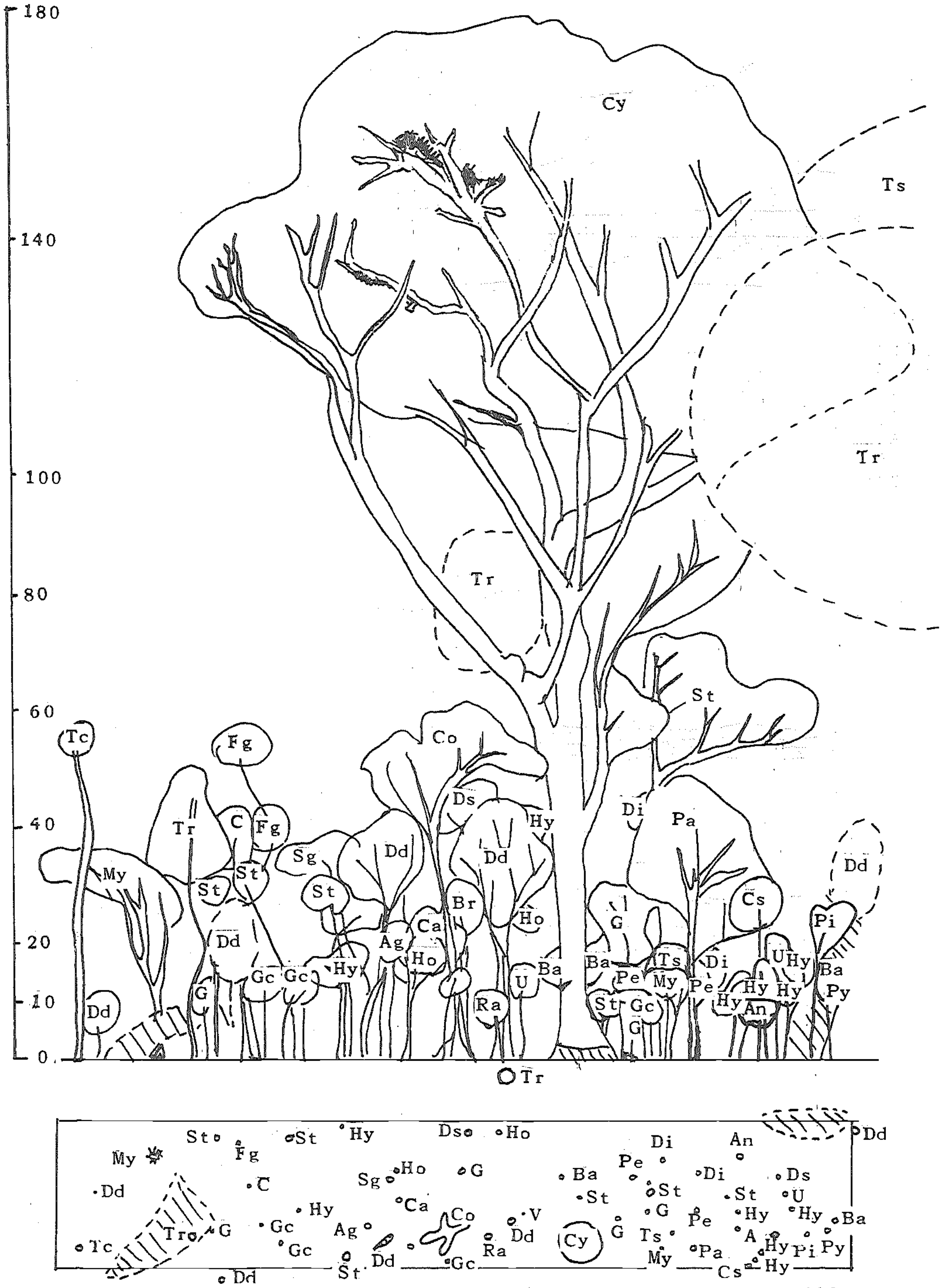


Fig.16. Profile Diagram of Evergreen Seasonal Rainforest, Sapoba F.R., Nigeria. Transect 25 ft. wide, 132 ft. long. Stems under 10 ft. omitted. Stand undisturbed except for climber cutting. Symbols as for figs. 14 and 15, plus Ag, *Angylocalyx oligophyllus*; Br, *Berlinia confusa*; C, *Ceiba pentandra*; Ca, *Carapa procera*; Co, *Cola* sp.; Cs, *Casearia* sp.; Cy, *Cylicodiscus gabunensis*; Di, *Diospyros soubreana*; Fg, *Fagara macrophylla*; G, *Gossweilerodendron balsamiferum*; My, *Myrianthus arboreus*; Pe, *Pentaclethra macrophylla*; Sg, *Strombosia grandifolia*; St, *S. pustulata*; Tc, *Treculia africana*; Tr, *Trichilia prieureana*; Ts, *Triplochiton scleroxylon*.



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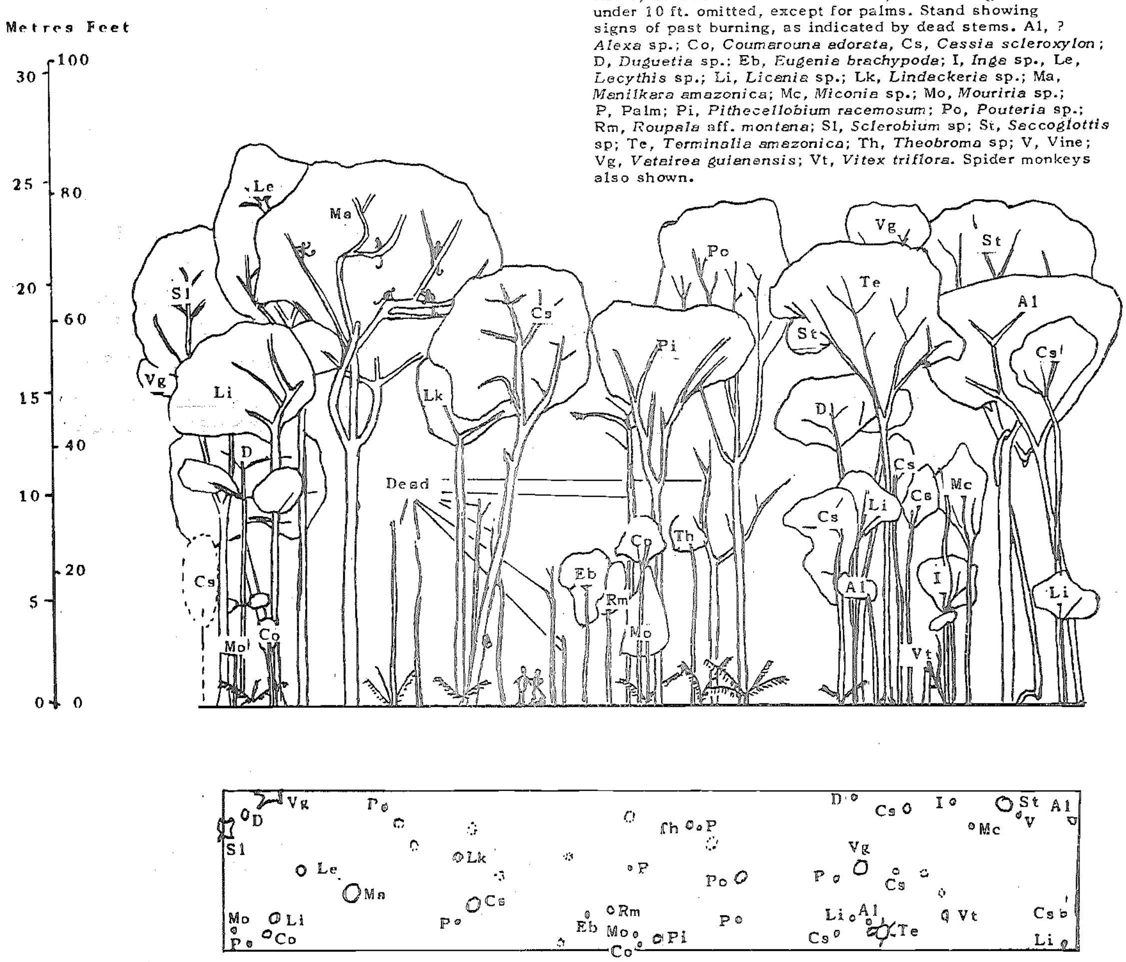


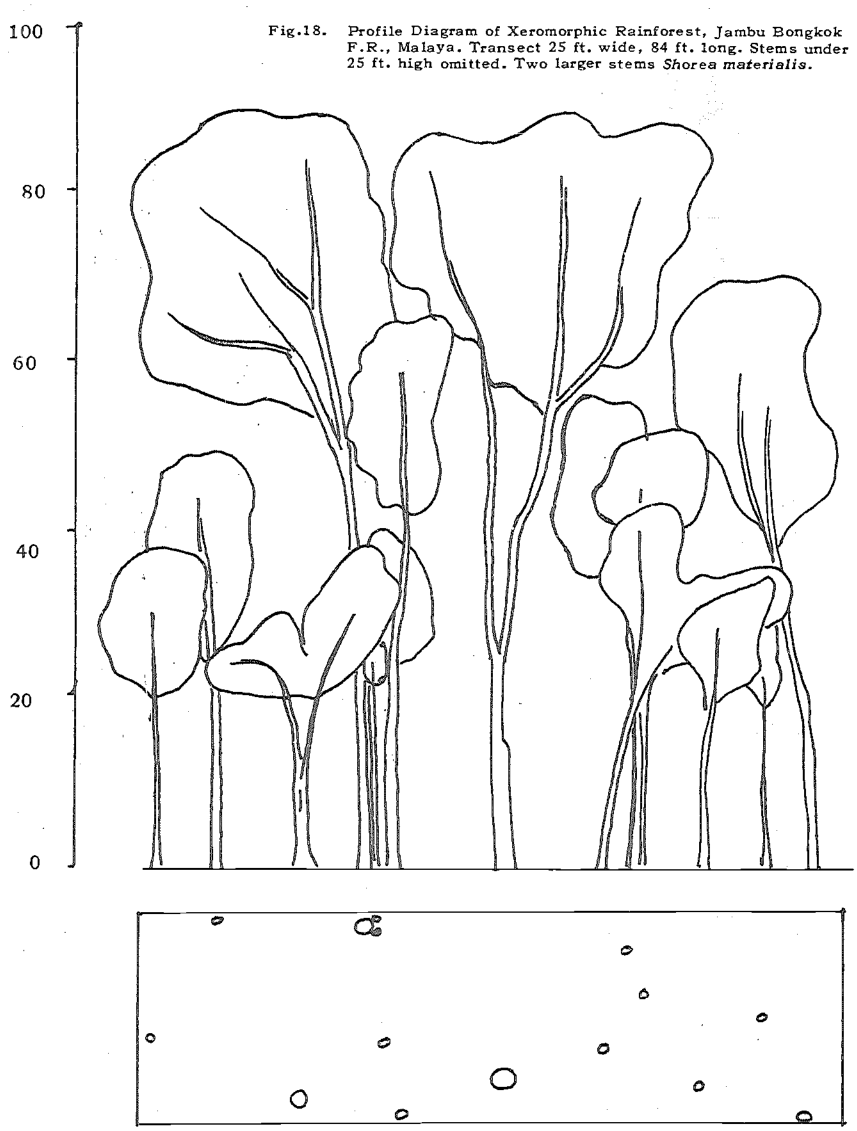
Fig.17. Profile Diagram of Semi-evergreen Rainforest, Curua Una River, Brazil. Transect 25 ft. wide, 130 ft. long. Stems under 10 ft. omitted, except for palms. Stand showing signs of past burning, as indicated by dead stems. Al, ? *Alexa* sp.; Co, *Coumarouna adorata*, Cs, *Cassia scleroxylon*; D, *Duguetia* sp.; Eb, *Eugenia brachypoda*; I, *Inga* sp., Le, *Lecythis* sp.; Li, *Licania* sp.; Lk, *Lindackeria* sp.; Ma, *Manilkara amazonica*; Mc, *Miconia* sp.; Mo, *Mouriria* sp.; P, Palm; Pi, *Pithecellobium racemosum*; Po, *Pouteria* sp.; Rm, *Roupala* aff. *montana*; Sl, *Sclerobium* sp; St, *Saccoglottis* sp; Te, *Terminalia amazonica*; Th, *Theobroma* sp; V, Vine; Vg, *Vatairea guianensis*; Vt, *Vitex triflora*. Spider monkeys also shown.

rainforests where drought becomes more severe or the soil has a lower capacity for retaining moisture. In southern Asia, the extensive forests of Tectona grandis tend to fall environmentally into the zone where this subformation would be expected, but this single species, with its gregariousness, its greater height growth and its complete deciduousness, alters the structure of the forest sufficiently to put most of these stands into a differnt formation. As might be expected, Tectona proves most satisfactory as an exotic when introduced into semi-evergreen rainforest sites, and examples of this can be seen in Trinidad, Puerto Rico and Nigeria.

4. Xeromorphic Rainforest is among the most interesting of all rainforest subformations, possessing a strong tendency towards single species dominance, and occupying rather unusual sites. In some of its structural features it more closely resembles temperate than tropical rainforest. Two tree storeys are present, the leaves are evergreen and buttressing is absent. Heavy vines are rare, but the finer, wiry vines are common in the fairly dense undergrowth. The trees are of small stature

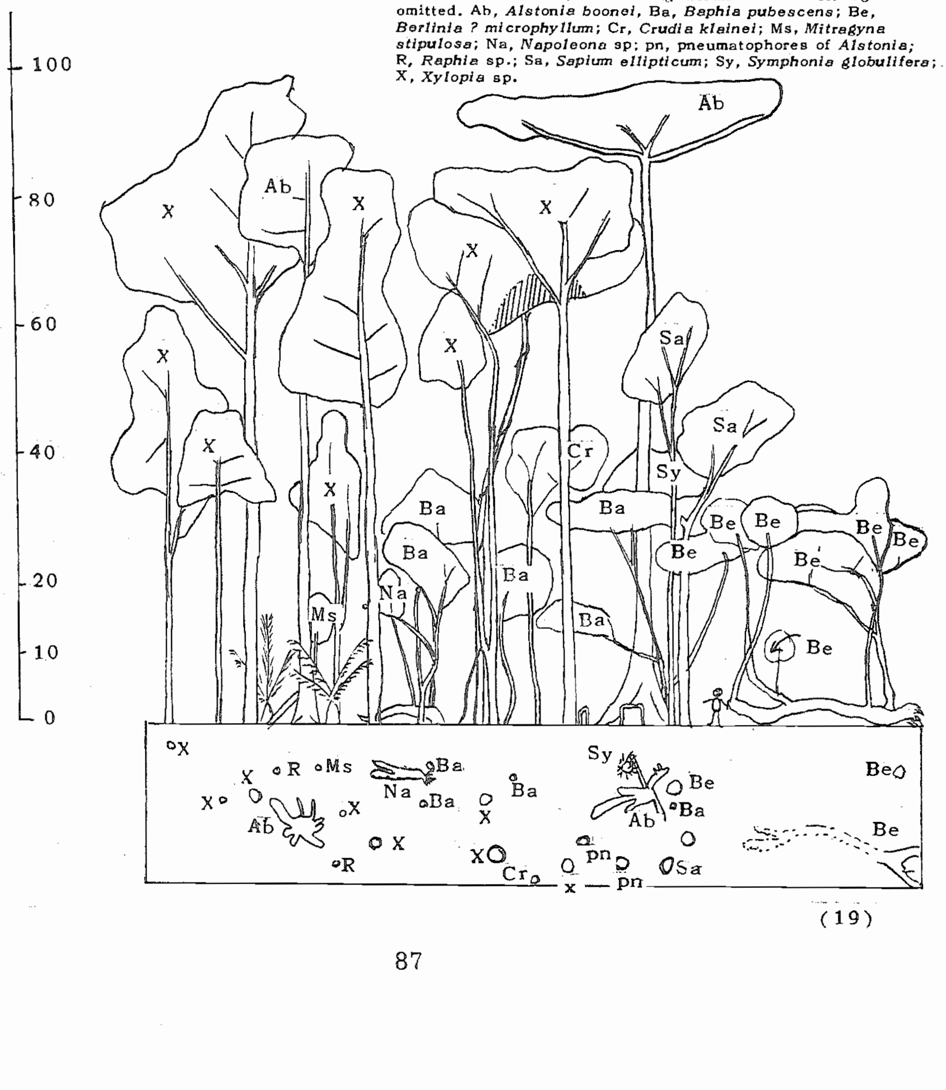
(usually under 100 feet) and the stocking is relatively low: B.A. probably seldom exceeds 100 square feet per acre. Figure 18 illustrates a small section of xeromorphic rainforest, dominated by Shorea materialis with some Shorea collina, on Jambu Bangkok F.R. in Trengganu, eastern Malaya: this is the so-called "Heath Forest" type of Wyatt-Smith (1961b). The shrub layers are dense, and are marked by much small Dracaena sp. Xeromorphic rainforest is found on very sandy soils which show a podsolic profile (Chapter 2), and it has been recorded from parts of South America and from North Borneo as well as Malaya. It does not appear to be known from Africa. Profile diagrams of similar communities dominated by Eperua falcata in British Guiana, and by Eperua leucantha and Eperua purpurea in central Amazonia, are given respectively by Fanshawe (1952a) and by Aubreville (1961).

Fig.18. Profile Diagram of Xeromorphic Rainforest, Jambu Bongkok F.R., Malaya. Transect 25 ft. wide, 84 ft. long. Stems under 25 ft. high omitted. Two larger stems *Shorea materialis*.



5. Swampy Rainforest is a term applied in this report to rainforest occurring in swampy sites, and thus is an unsatisfactory, though convenient, classification if one agrees that subformations should be distinguished only on structural featrues, and not on environmental conditions. Structurally at least two subformations should be recognized, one applying to the stands found on peaty swamp soils, with a dense stocking of small trees and a generally rather even upper canopy which may however fluctuate rather greatly in height over short distances, and the second relating to communities on the non-peaty swamp soils where larger, more widely spaced trees are found in clumps, interspersed with lower patches that are usually dominated by palms. Figure 19 illustrates the second type in an area which receives seasonal flooding in Nigeria. Both types usually possess two tree storeys, palms and pandans are common, and the trees provide rather extreme examples of buttressing, stilt roots, and in areas with seasonally variable water levels, Taxodium - style swollen butts. Pneumatophores are frequent, and vines usually abound. Light conditions are usually better right to the ground level than in most other rainforest subformations. These communities are often placed in a distinct "swamp forest" formation (e.g. Beard, 1944a and 1955), and whilst under the influence of more extreme flooding conditions they may alter to communities in which the tree storeys disappear, over large areas in all three tropical rainforest regions their floristic relations and structural features are such that is seems unreal to regard them as other than a specialized form of tropical rainforest.

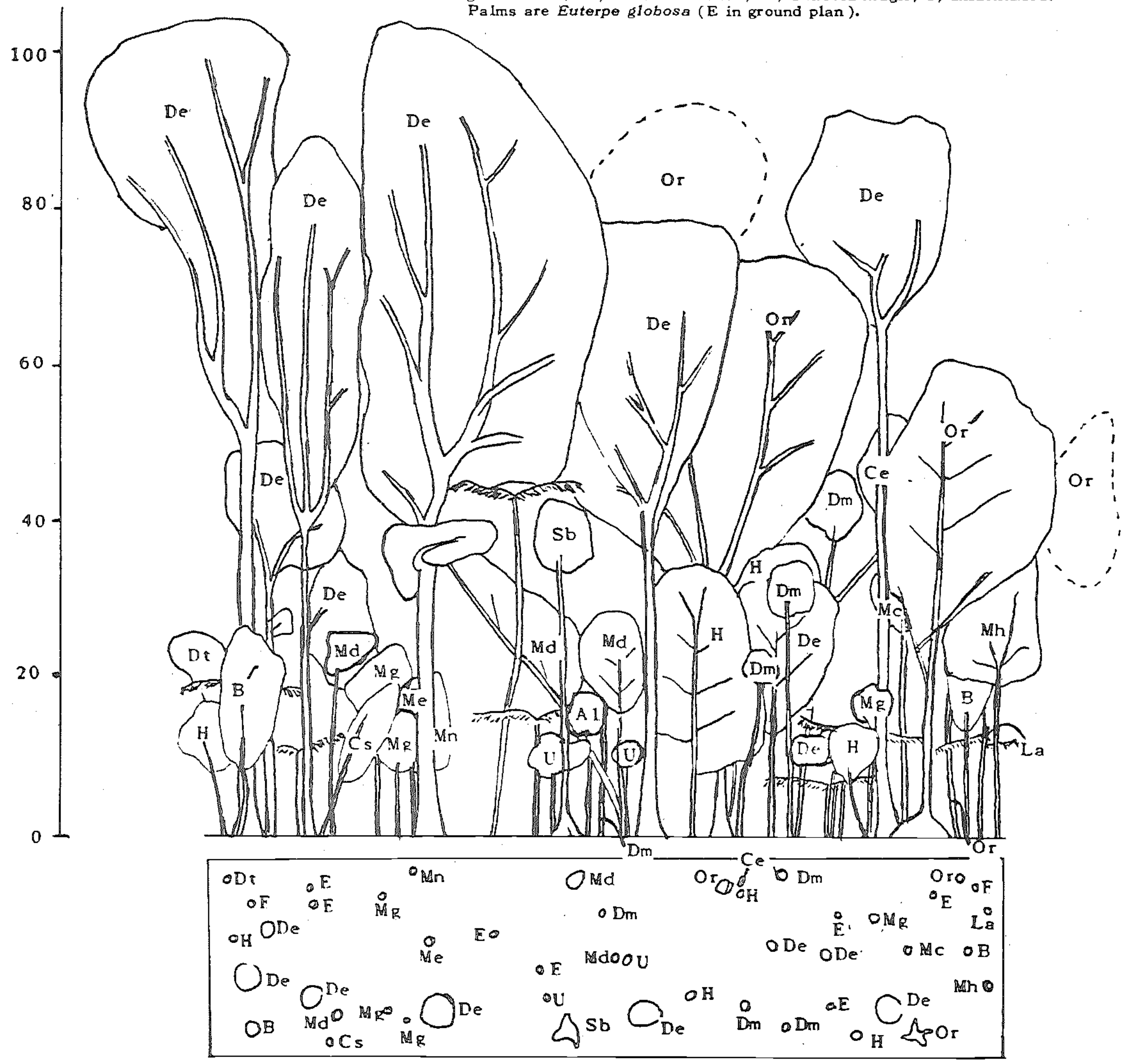
Fig.19. Profile Diagram of Swampy Rainforest, Sapoba F.R., Nigeria. Transect 25 ft. wide, 120 ft. long. Stems under 15 ft. high omitted. Ab, *Alstonia boonei*, Ba, *Baphia pubescens*; Be, *Berlinia ? microphyllum*; Cr, *Crudia klainei*; Ms, *Mitragyna stipulosa*; Na, *Napoleona* sp; pn, pneumatophores of *Alstonia*; R, *Raphia* sp.; Sa, *Sapium ellipticum*; Sy, *Symphonia globulifera*; X, *Xylopia* sp.



(19)

6. Submontane Rainforest is very similar to equatorial rainforest and merges imperceptibly into this, though in its more characteristic forms it is sufficiently distinct to warrant subformation status. It differs from equatorial rainforest in its generally lower height, in having one less tree storey, and in the much reduced frequency of buttressing and cauliflory. Epiphytes are common, and the palm-habit is usually abundant. Figure 20 illustrates such a community in the Luquillo Mountains of Puerto Rico. The upper canopy is irregular in height, with the taller trees often occurring in clumps, while emergents may be present (e.g. Agathis palmerstoni in north Queensland). Stocking is usually greater than in equatorial rainfoest, with up to 400 stems per acre greater than four inches d.b.h., and with B.As. commonly in the range 150 square feet - 240 square feet per acre, but sometimes much greater. Haley (1957) records B.As. exceeding 300 square feet per acre in north Queensland submontane rainforest. Submontane rainforest is found in all tropical rainforest regions, often as stands of considerable

Fig.20. Profile Diagram of Submontane Rainforesc, Laquillo Mountains, Puerto Rico. Transect 25 ft. wide, 100 ft. long. Stems under 10 ft. omitted. A1, *Alchomea latifolia*; B, *Byrsonima* sp.; Ce, *Cecropia peltata*; Cs, *Calycogonium squamulosum*; De, *Dacryodes excelsa*; Dm, *Didmopanaxmorototoni*; Dt, *Ditta myricoides*; H - *Hirtella* sp.; La, Lauraceae; Mc, *Micropholis chrysophylloides*; Md, *Matayba domingensis*; Me, Melastomaceae; Mg, *Micropholis garcinifolia*; Mn, *Manilkara nitida*; Or, *Ormosia krugii*; U, unidentified. Palms are *Euterpe globosa* (E in ground plan).



economic importance, in the moist mountain foothills of the tropics.

7. Subtropical Rainforest is also very similar to equatorial rainforest, and also to submontane rainforest, though usually taller in height than the latter. The main difference probably lies in the smaller average leaf size (notophylls of Webb, 1959, compared with the mesophylls in equatorial and submontane rainforest), while cauliflory and stilt roots are virtually absent. Buttressing, however, may be common, though this diminishes with distance from the equator, even within a single species (e.g. see Richards, p. 66). Figure 21 illustrates an example from Wiangarie S.F. in northern New South Wales. Stocking is similar to that of equatorial rainforest, but because the proportion of small stems is reduced (table 5), the B.A. tends to be higher, usually lying between 200 square feet and 250 square feet per acre. Subtropical rainforest has a somewhat limited distribution, occurring on fertile, well-drained soils with a high rainfall beyond the tropics. It is found in eastern Australia and southern Brazil, and is probably the subformation found in southeast China and Formosa.

Temperate Rainforest Formation

By comparison with tropical rainforest, temperate rainforest has a much simpler structure. Only two, or more rarely even one, tree storeys occur, buttressing is normally absent, heavy vines are infrequent, and cauliflory is absent. The leaf sizes are smaller (notophyll or microphyll), and the leaves are usually more sclerophyllous, frequently serrated, rarely compound, and lacking drip tips and pulvini. Epiphytes are usually very common, though vascular epiphytes are relatively less common than the non-vascular types. Canopy level is generally much more even than in tropical rainforest, but the upper canopy height is frequently much lower. Floristically temperate rainforest species mostly have their origin in temperate floras, particularly the southern, Antarctic element, though species of tropical affinities are often present.

The formation is found in moist regions with a temperate temperature regime lacking extremes of cold. It is most widely found in tropical mountains, and in the moist, temperate regions of the southern hemisphere. For the purposes of this report, three subformations are recognized, but as with the tropical rainforest formation, this is probably an underestimate.

1. Montane Rainforest normally contains two tree storeys, with the height of the taller usually ranging from about 60 feet to 120 feet. Notophyll and microphyll leaf sizes are dominant, and epiphytes, particularly the non-vascular forms, are extremely common. A thicket-like undergrowth is usually present. Figure 22 illustrates this subformation at Fraser's Hill, in Malaya. Montane rainforest occurs at higher elevations than submontane rainforest, and the ecotone between the two is usually rather narrow. At higher elevations again, in the region of almost constant cloud, the stands are reduced to thickets rich in bryophytes, and although these are clearly derived from montane rainforest, their structure is such that it becomes inappropriate to designate these as "rainforest". Palms are rare in montane rainforest, but the habit is maintained by tree ferns (mostly

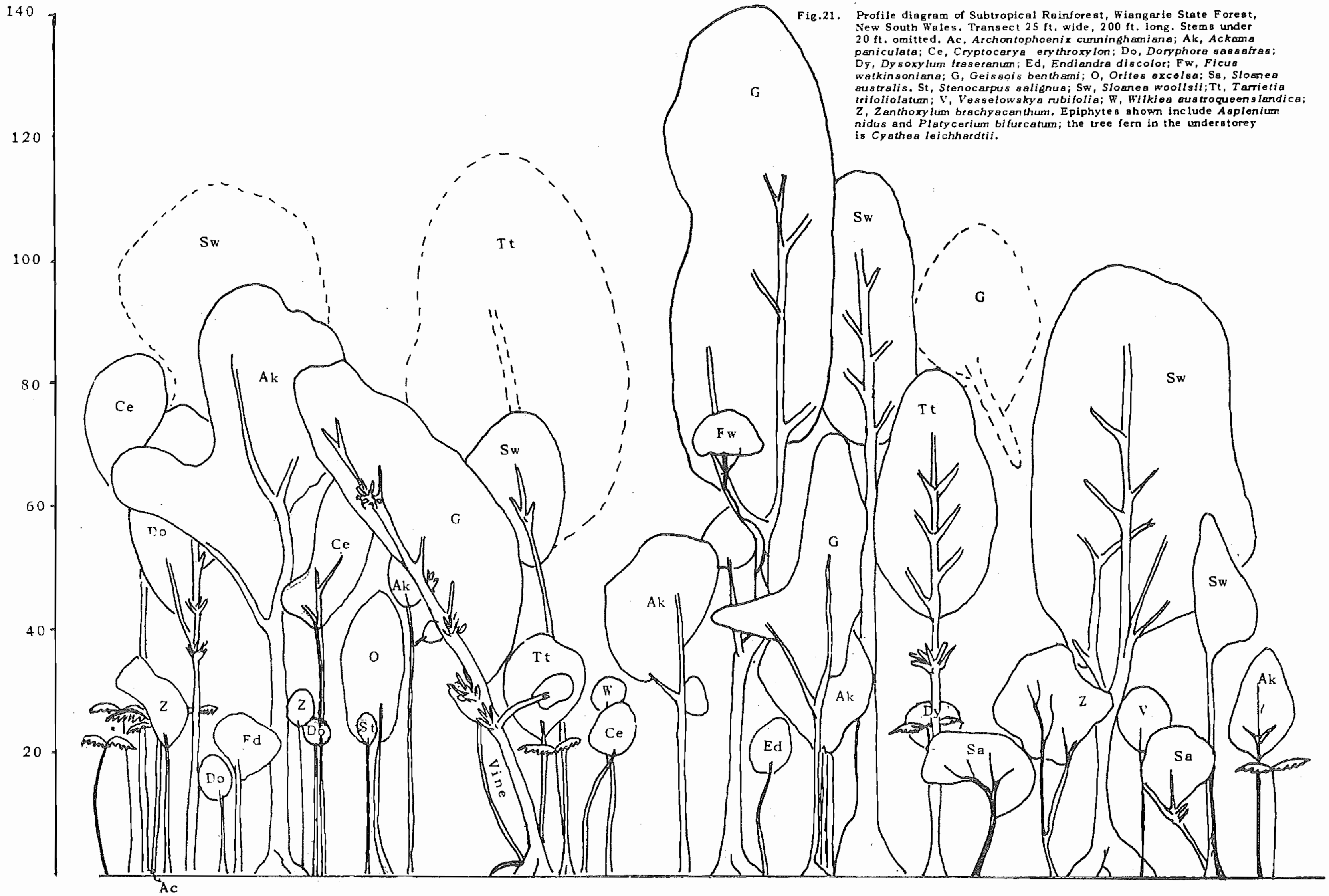


Fig.21. Profile diagram of Subtropical Rainforest, Wiangarie State Forest, New South Wales. Transect 25 ft. wide, 200 ft. long. Stems under 20 ft. omitted. Ac, *Archontophoenix cunninghamiana*; Ak, *Ackama paniculata*; Ce, *Cryptocarya erythroxylon*; Do, *Doryphora sassafras*; Dy, *Dysoxylum fraseranum*; Ed, *Endiandra discolor*; Fw, *Ficus watkinsoniana*; G, *Geissois benthami*; O, *Orites excelsa*; Sa, *Sloanea australis*. St, *Stenocarpus salignus*; Sw, *Sloanea woollsii*;Tt, *Tarrietia trifoliolatum*; V, *Vesselowskya rubifolia*; W, *Wilkiea austroqueenslandica*; Z, *Zanthoxylum brachyacanthum*. Epiphytes shown include *Asplenium nidus* and *Platycerium bifurcatum*; the tree fern in the understorey is *Cyathea leichhardtii*.

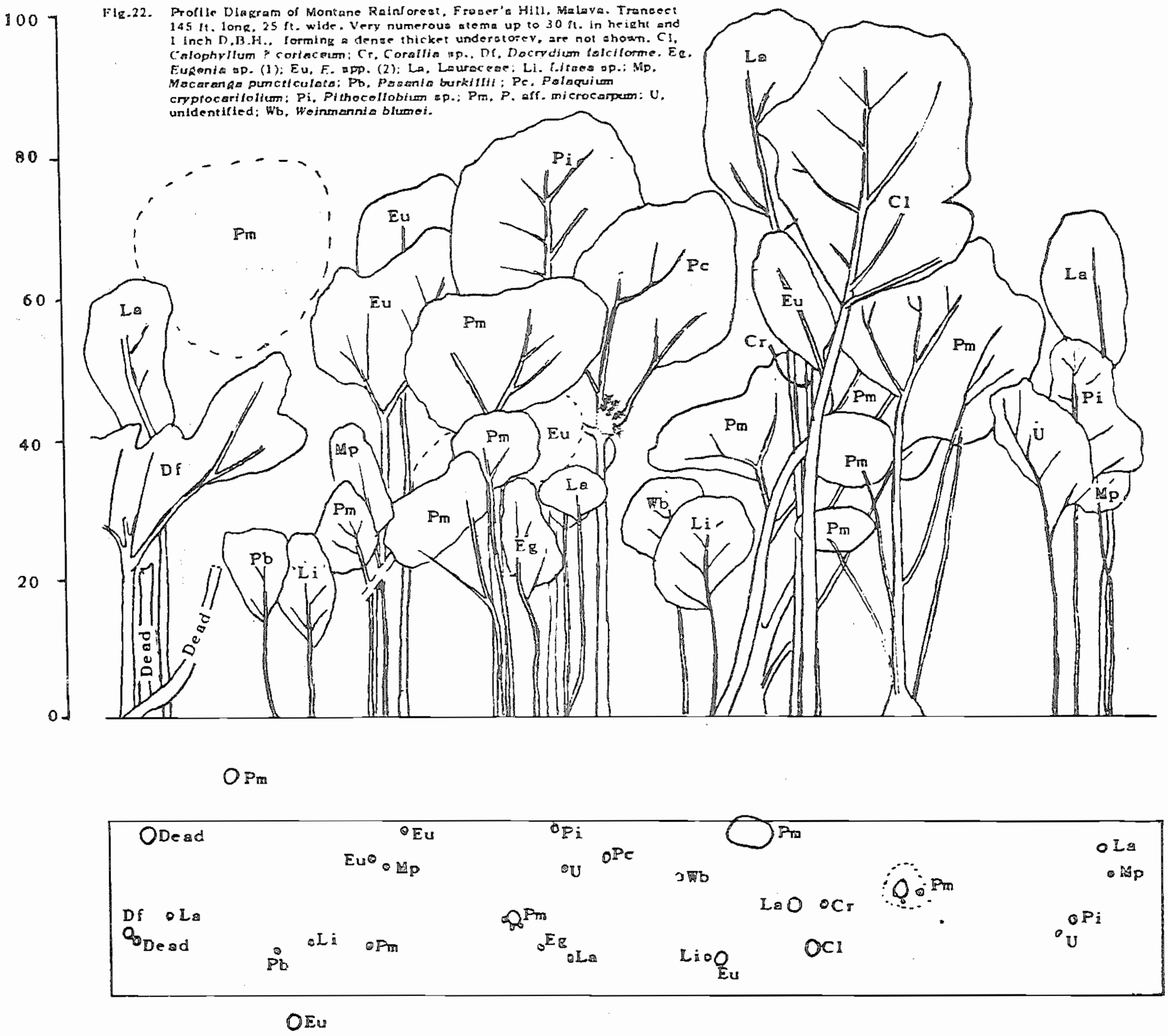
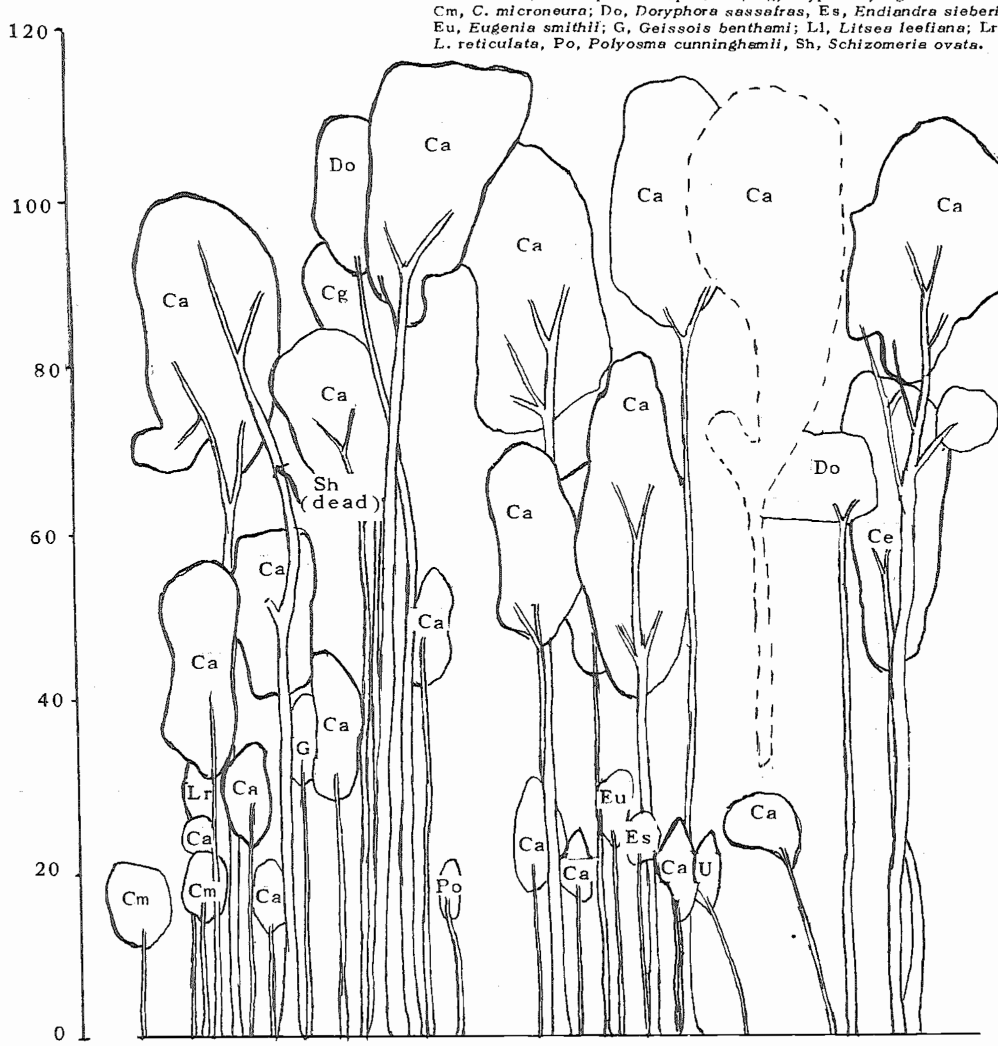


Fig.22. Profile Diagram of Montane Rainforest, Fraser's Hill, Malaya. Transect 145 ft. long, 25 ft. wide. Very numerous stems up to 30 ft. in height and 1 inch D.B.H., forming a dense thicket understorey, are not shown. Cl, *Calophyllum* ? *coriaceum*; Cr, *Corallia* sp., Df, *Dacrydium falciforme*, Eg, *Eugenia* sp. (1); Eu, *E.* spp. (2); La, Lauraceae; Li, *Litsea* sp.; Mp, *Macaranga puncticulata*; Pb, *Pasania burkillii*; Pc, *Palaquium cryptocariifolium*; Pi, *Pithecellobium* sp.; Pm, *P.* aff. *microcarpum*; U, unidentified; Wb, *Weinmannia blumei*.

Cyatheaceae) which feature in most temperate rainforest communities. Stockings range up to 400 stems per acre, with B.As. usually between 100 square feet and 200 square feet per acre. Montane rainforest is found in mountainous areas throughout the tropics. Profile diagrams from Trinidad and Venezuela are given respectively by Beard (1946a), and Lamprecht (1954).

2. Warm Temperate Rainforest tends to be taller than other temperate rainforest subformations, occasionally exceeding an upper canopy height of 130 feet. Two tree storeys are present, leaf sizes are typically notophyll, and buttressing may occur rarely. Epiphytes are less abundant than in the other subformations, and tree crowns are rather narrow. This subformation is illustrated in figure 23, from Moonpar S.F. in New South Wales where the stand is dominated by Ceratopetalum apetalum. Warm temperate rainforest is only known definitely from eastern Australia and New Zealand, Robbins (1962) providing profile diagrams (e.g. figures 20 and 22b) from the latter country. In Australia it occupies sites that are either cooler or on less fertile soils than subtropical rainforest (Baur, 1957). In the latter case, the boundary between the two is sharp, but in the former case the subformations show an

Fig.23. Profile Diagram of Warm Temperate Rainforest, Moonpar S.F., New South Wales. Transect 100 ft. long, 25 ft. wide. Stems under 20 ft. omitted. Ca, *Ceratopetalum apetalum*; Cg, *Cryptocarya glaucescens*; Cm, *C. microneura*; Do, *Doryphora sassafras*, Es, *Endiandra sieberi*; Eu, *Eugenia smithii*; G, *Geissois benthami*; Ll, *Litsea leefiana*; Lr, *L. reticulata*, Po, *Polyosma cunninghamii*, Sh, *Schizomeria ovata*.



extensive merging ecotone. It is probable that the subformation also occurs in South America and South Africa. In New South Wales the stocking of warm temperate rainforest ranges between 200 and 300 stems per acre, and the B.A. between 220 square feet and 300 square feet per acre.

3. Cool Temperate Rainforest is very similar to warm temperate rainforest but the leaf size is reduced to microphylls, height is generally lower, trees of larger diameter and wider crowns usually occur, epiphytes are more common, and the second tree storey may be absent. A stand in New South Wales is illustrated in figure 24. Here, as in most occurrences of this subformation, a Nothofagus sp. (here Nothofagus moorei) clearly dominates the community, and the high B.A. which these stands carry is largely made up of these large southern beeches. In New South Wales, cool temperate rainforest commonly has a B.A. of 300 to 350 square feet per acre, the highest B.As regularly encountered in any native forest community in the state. Cool temperate rainforest is found in moist, temperate sites in southeastern Australia, New Zealand

Fig.24. Profile Diagram of Cool Temperate Rainforest, Point Lookout, New South Wales. Transect 100 ft. long, 25 ft. wide. Cr, *Cryptocarya rigida*; Do, *Doryphora sassafras*; Nm, *Nothofagus moorei*; V, *Vesselowskya rubifolia*.

and South America. In some of the South American communities winter-deciduous species enter into the composition of the stand as subordinate trees, and these communities should probably be placed in a different subformation. In the northern hemisphere, evergreen forests of broadleaved trees (Quercus, Lauraceae, Schima, Magnoliaceae, etc.) are found in similar environmental conditions to the southern cool and warm temperate rainforests, and with close floristic affinity to some of the tropical montane rainforests. These should probably be regarded as a northern form of temperate rainforest, presumably in one or more new subformations, as was recognized by Schimper (1903).

General Features of Rainforest

The preceding sections have summarized the features that distinguish the various rainforest subformations, and whilst it must again be stressed that these subformations are largely units of convenience, taken from a larger mass of luxuriant vegetation that is ever subtly changing, they do serve to indicate that stands of very similar structure recur around the world in response to similar environmental changes. In all, the basic features of rainforest remain - a dense, multistoried, tree-dominated community; essentially evergreen; mesophytic; usually rich in vines and ephiphytes, but within these limitations great variations in structure can and do occur. Equatorial rainforest shows the most complex structure, with up to four tree storeys, some of the tallest heights, and a multitude of life forms present, though the stocking and B.A. are not as high as in some rainforests found under cooler conditions: it seems as though one of the facts of ecology is that reduced mean temperatures result in an increase of B.A. in forest stands. These equatorial rainforests occupy the humid tropical lowlands where a regular dry season of any length is lacking. As the rainfall is lowered, and the period of water stress extended, the height of the stands is lowered, fewer storeys can be recognized, deciduous species become more common, and epiphytes are fewer, as shown by evergreen seasonal and semi-evergreen rainforest. More adverse soil conditions also result in simplification of the structure, again with lower height and fewer storeys, and usually with appreciably smaller trees which, however, tend to be evergreen: the nature of the soil greatly affects the incidence of buttressing and other butt formations on the trees in these communities as shown by xeromorphic and swampy rainforest. Reduced temperatures react less markedly on rainforest structure, but leaf size becomes smaller, buttressing decreases, and in sites that are appreciably exposed, the height is lowered. These changes extend beyond the tropical rainforest formation into temperate rainforest, which often merges imperceptibly into the adjoining submontane and subtropical rainforest stands. The storeys are further reduced in number, leaves become still smaller, buttressing disappears, while where there is a marked cold winter, deciduousness again becomes evident.

These changes suggest formation series in the sense of Beard (1944a), with three series that are primarily climatic (lowland tropical, with increasing severity of drought; humid tropical, with increasing altitude; humid, with increasing latitude), plus several subformations that reflect edaphic changes. However, such a view is essentially an oversimplification since inherent to it is the implication that, as one environmental feature alters, all others either remain unchanged (e.g. soil in a climate series), or else change in a manner that is linearly related to the first feature (e.g. annual rainfall bears a linear correlation with length of dry season). In fact, neither of these implications is correct, as was shown in Chapter 2, and as a result, no subformation can be strictly related to only one feature of the environment. Within any subformation considerable variations in structure do occur, and any ecological "splitter" could readily classify a host more subformations. This all adds support to the concept of rainforest being a continuum, but it in no wise detracts from the value of recognizing subformations which reflect the more gross changes in the environment, as has been done above. These structural units have considerable utility in the management of rainforest.

CHAPTER 4

FLORISTIC COMPOSITION

> "The humid tropical forest with very few exceptions is a most complex mixture with hundreds of tree species growing intimately together, of which the commercially usable species only furnish a very small percentage". Foggie (1960)

Richness of Rainforest

It has already been indicated that rainforest is phenomenally rich in species of trees, while other life forms add to its floristic complexity. However there is considerable variation between individual stands of rainforest, and this is clearly shown in Fig. 25, which contains species-area curves for stems over 4 inches D.B.H. in 12 different sites. The most impoverished of these sites, montane rainforest in the Luquillo Mountains of Puerto Rico (Tropical Forest Experiment Station, 1950), contains 51 tree species on a total of 10 acres. By comparison the richest, equatorial rainforest on Rengam F.R. in Johore, Malaya (Cousens, 1951), contains 143 species on one acre and 227 on 2½ acres.

This floristic richness appears to vary through two causes, one depending upon the wealth of the regional flora and the other upon the suitability of the site for the trees from this flora to grow. Thus in Fig. 25 the first four curves are from Malaya, which is recognised as being the richest area of rainforest species in the world (Richards, p.230); the tropical American sites (curves 5, 6, 8) occupy an intermediate position; with the African (Nigerian) sites (curves 7 and 11) rather lower. The Puerto Rican sites (curves 9 and 12), with their limited, insular flora, and the subtropical Australian site (curve 10), with its attenuated rainforest flora, contain still fewer species. Further than this, the sites become less rich in species in any area as the environmental conditions become less optimal. In the Brazilian stands, the equatorial rainforest at Mocambo (curve 5) shows the most species for a given area, and has a very similar curve to that given by Schultz (1960, Fig. 61) for equatorial rainforest in the Mapane region of Surinam. Evergreen seasonal rainforest at Curua (curve 6) shows fewer species, and semi-evergreen rainforest (curve 8) still fewer. Similarly swampy rainforest in Nigeria (curve 11) has fewer species than evergreen seasonal rainforest (curve 7), and montane rainforest in Puerto Rico (curve 12) fewer than the submontane rainforest (curve 9).

Temperate rainforest stands contain fewer species than tropical rainforest: curve 12 illustrates this for the montane subformation, while cool temperate rainforest may have fewer than 10 species of trees present over extensive areas, and thus is poorer in tree species than many Northern Hemisphere summergreen mesophytic forests. Nonetheless floristic richness is one of the more outstanding features of the rainforest formations.

The species present in any rainforest stand are

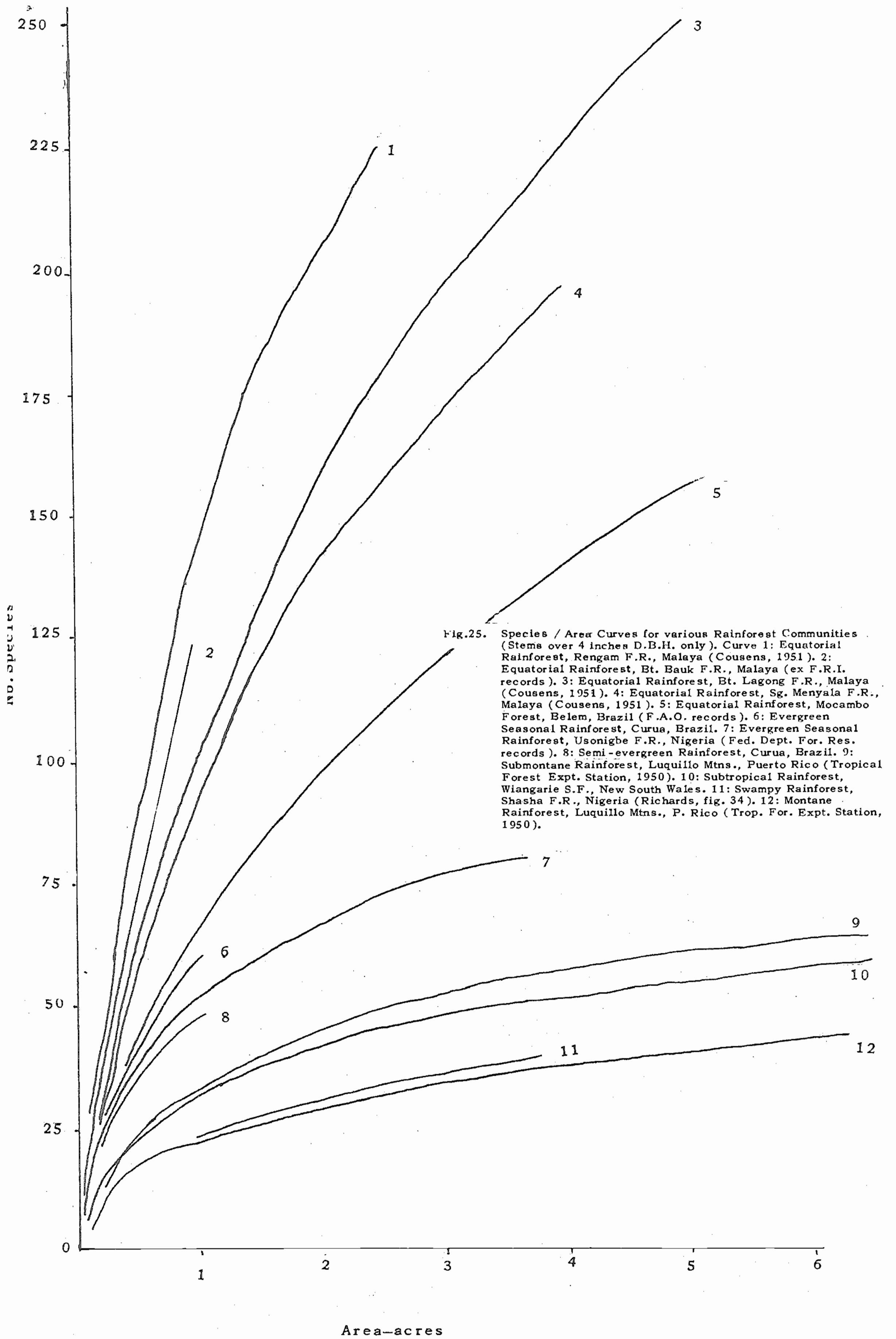


Fig.25. Species / Area Curves for various Rainforest Communities (Stems over 4 inches D.B.H. only). Curve 1: Equatorial Rainforest, Rengam F.R., Malaya (Cousens, 1951). 2: Equatorial Rainforest, Bt. Bauk F.R., Malaya (ex F.R.I. records). 3: Equatorial Rainforest, Bt. Lagong F.R., Malaya (Cousens, 1951). 4: Equatorial Rainforest, Sg. Menyala F.R., Malaya (Cousens, 1951). 5: Equatorial Rainforest, Mocambo Forest, Belem, Brazil (F.A.O. records). 6: Evergreen Seasonal Rainforest, Curua, Brazil. 7: Evergreen Seasonal Rainforest, Usonigbe F.R., Nigeria (Fed. Dept. For. Res. records). 8: Semi-evergreen Rainforest, Curua, Brazil. 9: Submontane Rainforest, Luquillo Mtns., Puerto Rico (Tropical Forest Expt. Station, 1950). 10: Subtropical Rainforest, Wiangarie S.F., New South Wales. 11: Swampy Rainforest, Shasha F.R., Nigeria (Richards, fig. 34). 12: Montane Rainforest, Luquillo Mtns., P. Rico (Trop. For. Expt. Station, 1950).

TABLE 7

Frequency of Tree Species in Rainforest Plots

No. of Species Represented by: (No. trees)									
	Sub-formation:	Equatorial	Equatorial	Equatorial	Evergreen Seasonal	Semi-Evergreen	Sub-Montane	Sub-Tropical	Montane
	Locality:	Bkt. Lagong, Malaya	Rengam, Malaya	Mocambo, Brazil	Usonigbe, Nigeria	Curua Una, Brazil	Luquillo Mts., P. Rico	Wiangarie, N.S.W.	Fraser's Hill, Malaya
	Plot Area:	5.0 acres	2.5 acres	4.94 acres	3.67 acres	0.5 acres	0.7 acres	9.6 acres	0.13 acres
1		103	103	63	17	17	5	9	6
2		36	40	25	16	5	3	6	4
3-4		45	25	20	12	7	8	9	1
5-8		32	14	13	14	6	1	13	2
9-16		24	2	21	10	1	4	8	1
17-32		8		7	4		2	9	
33-64		2		2	4		1	5	
65-128		1		3	4		1	7	
129-256								1	
257-512								1	
Most Common Species:		Hydnocarpus filipes	Strombosia rotundifolia	Eschweilera odora	Annonidium mannii	Cassia scleroxylon	Euterpe globosa	Ackama paniculata	Pithecellobium aff. microcarpum

TABLE 8

Families and Genera Common to Rainforest Plots

Locality	Subformation	Area-Acres	Number on Plot Spp.	Gen.	Fam.	No. Genera in Common with 5.	4.	3.	2.	1.	No. Families in Common with 5.	4.	3.	2.	1.
1. Bkt. Bauk, Mal.	Equatorial	1.0	123	80	35	1	5	7	10						
2. Wiangarie, N.S.W.	Subtropical	9.6	66	56	31	1	3	1							14
3. Sapoba, Nigeria	Evergreen Seasonal	1.0	64	56	24	0	8							11	18
4. Mocambo, Brazil	Equatorial	4.94	154	89	39	8							18	15	23
5. Luquillo, P. Rico	Submontane	0.7	24	23	19							11	8	7	8

by no means equally represented, and these differences in commonness are indicated in table 7 where the number of individual trees of each species present in measured plots is shown.

The sites represented in table 7 are not truly comparable since in only two cases (Bukit Lagong and Mocambo) are the samples of the same size. Clearly in larger plots the more common species will be represented by progressively more stems. Cousens (1951), working from the theoretical approach of Preston (1948), has suggested that the species' commonness follows a Gaussian (lognormal) curve and that once an adequate sample has been taken it will be found that most species are of moderate commonness, with relatively few that are either very rare or very common. The Wiangarie data, based on a large sample of what can be expected to be a fairly limited flora, suggests such a distribution; the other samples are apparently too small for the modal "octave" to appear and the samples represent only one end of the Gaussian curve. Only in the Wiangarie plot has the minimal area been exceeded.

Floristic Origin

The origins of rainforest flora have been briefly discussed in Chapter 1, where it was suggested that two main elements in rainforest plants can be recognised, one of pan-tropic origin and the other of southern, or Antarctic, origin. Whilst this approach is a gross oversimplification it does serve to indicate more clearly a certain relationship between the two rainforest formations and the plants that occur within them.

In tropical rainforest few tree species are common to any two of the three great regions of occurrence. Ceiba pentandra is exceptional in this regard, being found (apparently as a native) in all three regions, although the southeast Asian strain appears to warrant at least varietal status. However many genera do occur in two, and quite frequently even in all three, regions, while the majority of families occur in more than one region. In table 8 the number of genera and families occurring in 5 plots in widely separate tropical rainforest stands are listed, and the numbers of both, common to two or more of the plots, are indicated.

Differences in both the sample area and the intrinsic richness of the flora in different localities result in any comparison berween these five sites being unsoundly based However despite this the similarities between these localities are quite striking. Of 266 genera encountered. some 29 are common to two sites, 3 (Parkia, Pithecellobium, Sloanea) are common to three sites, and one (Diospyros) is common to four sites. Other mutually present genera occur in all sites but were absent from the plots, while closely allied genera such as Fagara/Zanthoxylum, Piptadenia/Piptadeniastrum, Planchonella/Sideroxylon would boost the number of genera common to two or more plots still higher. Inclusion of stems under 4 inches D.B.H. would add even more common genera. As might be expected, the closest similarity lies between localities in the same major region, viz. Bukit Bauk and Wiangarie, and Mocambo and the Luquillo Mountains, but even distant areas show many genera in common.

Still more striking are the family occurrences. Some 70 families (as recognised by Willis (1948) except for raising the three leguminous subfamilies to full family status) occur in the 5 plots. Nine of these, two from the Luquillo Mountains and seven from Wiangarie, can be excluded as being of essentially temperate affinities present in these two rather ecotonal subformations, and of the remaining 61 essentially tropical families, 16 are present in all three of the major tropical rainforest regions (southeast Asia/ Australia; Africa; Tropical America), 21 are present in two of the regions, and 24 are restricted to only one region. Of the final 24 families many would be found to occur more widely if larger plots had been taken. Relatively few are confined to only one region, though among these are several economically important families (Dipterocarpaceae, Vochysiaceae, Caryocaraceae).

Similar likenesses are present in widely disjunct occurrences of temperate rainforest, again suggesting common origins for these floras. Characteristic families here include the Cunoniaceae and Podocarpaceae, though the temperate rainforest appears to have received more local enrichment from other sources, as typified by the capsular-fruited Myrtaceae in southeast Asia, the Proteaceae in the southern hemisphere, and certain Fagaceae in all areas. Some Fagaceae, notably Nothofagus, are very characteristic of temperate rainforest, but other genera (especially Quercus and its close relatives Pasania and Lithocarpus), while very common in some temperate rainforests, appear to have evolved from tropical forms: although these genera are typical of temperate rainforest in the tropics and in the northern hemisphere, their ultimate origins seem to lie in the tropical rainforest, and the same is probably true for some other families, e.g. Lauraceae and Hamamelidaceae, which are common in temperate rainforest. Despite this, however, temperate rainforest tends to have a characteristic floristic relationship around the world.

Composition of Rainforest Stands

As indicated above rainforest is of very mixed and complex composition. Table 7 indicates how, in tropical rainforest, many species occur, a few relatively commonly, many rarely, and many of intermediate frequency. In addition to their numerical frequency, some may be truly rare and occasional over vast areas; some may be rare or absent over large areas yet in restricted local sites be very common, usually due to the influence of some indentifiable environmental factor; and some may be constant and relatively common over considerable areas. This has already been discussed in some extent in Chapter 2, and will be considered again in chapter 6.

The numerically most common species in any truly mixed rainforest stand are usually the smaller sized stems. This is shown by Richards (table 28) and Wyatt-Smith (1949), who both indicate the most common species larger than 4, 8, and 16 inches D.B.H. In all cases the most common species larger than 4 inches D.B.H. is one that never normally reaches the uppermost tree storey. Of far greater interest to foresters is the relative frequency of the larger trees, which are usually those of economic importance, and this is usually indicated more effectively by basal area, which bears a fairly direct relationship with merchantable

TABLE 9

Most Common Species in Three Stands

(Stems over 4 inches D.B.H.)

Locality, Subformation and Plot Area	In Order of No. Stems— Species	% Stems	In order of B.A. — Species	% B.A.
1. Usonigbe, Nigeria. Evergreen, seasonal 3.7 acres	Diospyros suaveolens	15.4%	Annonidium mannii	11.2%
	D. dendo	9.0	Diospyros suaveolens	9.9
	Annonidium mannii	7.9	Drypetes gossweileri	5.0
	Diospyros albiflavescens	3.6	Piptadeniastrum africanum	3.8
	Angylocalyx zenkeri	3.1	Diospyros dendo	3.3
2. Wiangarie, N.S.W. Subtropical 9.6 acres	Ackama paniculata	18.6%	Ackama paniculata	22.6%
	Doryphora sassafras	7.9	Sloanea woollsii	14.5
	Sloanea woollsii	6.9	Tarrietia trifoliolatum	13.3
	Tarrietia trifoliolatum	6.8	Geissois benthami	9.2
	Geissois benthami	6.1	Dysoxylum fraseranum	5.5
3. Luquillo, Puerto Rico Submontane 0.7 acres	Euterpe globosa	39.0%	Dacryodes excelsa	54.4%
	Dacryodes excelsa	16.3	Euterpe globosa	13.6
	Ormosia krugii	7.0	Ormosia krugii	9.4
	Micropholis garcinifolia	6.3	Micropholis garcinifolia	5.0
	Didymopanax morototoni	4.3	M. chrysophylloides	4.5

volume and probably also with the amount of competition which the various species are exerting within the stand. Schultz (p.160) has considered the use of B.A. as a criterion of relative importance and has discarded it because it tends to diminish the significance of the smaller, but nonetheless highly characteristic, species in the stand and to give what he considers undue weight to less frequent species of large diameter. This is to some extent true, but the reverse argument is equally true. Probably both sets of values together give the best indication of the major floristic composition of these mixed stands, and in table 9 such values are given for three stands. This shows how the order of frequency can be appreciably altered depending on whether the number of stems or the B.A. is used as the criterion of dominance. This writer feels that B.A. gives a more accurate measure of this value.

The first two plots in table 9 bring out another common feature of tropical rainforest stands, namely the absence of clear dominance by any one species, or even by any small number of species. Although a few species are more plentiful than the others, they cannot be said to dominate the stand in the way that most other forest communities are clearly dominated by one or two species. Whilst not true of all rainforests, this feature is widespread in tropical rainforest growing under moderately favourable environmental conditions. However where the environment becomes less favourable, e.g. under more extreme climatic conditions or adverse soil conditions, fewer species occur in the community (see fig.25) and there is a greater tendency for one or a few of these to assert clear dominance.

The typical rainforest of very mixed composition offers more than a few problems to the ecologist attempting to identify associations or other floristic groupings over large areas, yet such identification is of more than theoretical interest to the silviculturist. As Schultz (p.210) states, "...the forests differ very strongly in the number of individuals by which commercially important species are represented, and accordingly a proper classification of the forests into more or less homogeneous sociological units (forest types) necessarily would be the first step towards practising scientific forestry". This has long been appreciated, and it is not coincidence that most of the attempts to recognise floristic groupings in rainforests have to date been made by forest officers. Schultz stresses the difficulties inherent in this classification, and concludes that any attempt must be largely arbitrary and based upon the leading (numerically most abundant) species of diagnostic value. In mixed rainforest these leading species are rarely dominants in the accepted ecological sense (see table 9), but they do appear to characterise communities within larger rainforest belts where certain species (usually of present or potential commercial value) occur regularly and with some constancy under the influence of fairly similar environmental conditions.

Some attempts to apply the more classical European methods of phytosociology to rainforest have been made. Emberger, Mangenot and Miege (1950a, 1950b) used these techniques in the rainforests of the Ivory Coast, where they recognised two associations, *Turraeanthus africana* - *Heisteria parvifolia* on the Mio-Pliocene sands and *Diospyros* (4 spp.) - *Mapania* (3 spp.) on the Precambrian schists. After studying these communities in the manner of Braun - Blanquet (1932) the authors concluded that these rainforest communities show in their associations the same essential characteristics as temperate associations.

Most efforts at classifying rainforest have however been made by more arbitrary methods. Where the communities have a tendency towards true dominance by one or a few species (an occurrence more widespread in tropical rainforest than is often realised) this arbitrary classification of forest types is fairly straightforward and simple, but where such a tendency is absent some form of statistical basis is necessary, and this has frequently been provided by the routine forest assessments carried out by most forest services. Often even this approach fails to pinpoint any truly characteristic leading species of silvicultural interest, but in most such cases a number of species within one or two genera can be found to provide leading genera, which usefully take the place of leading species. This was the case in the second Ivory Coast association mentioned above, and a similar approach has been also used in other major rainforest regions.

The communities recognised in this manner are probably best termed "forest types": their interpretation as associations or other sociological groupings recognised by ecologists must usually await further study and often appears to be based upon individual opinion. Thus in New South Wales Baur (1957) termed the types "associations" and then grouped related associations into "alliances", while by contrast Fanshawe (1952a) in British Guiana and Heinsdijk (1960) in Amazonia have termed the larger groupings "associations" and the recognised types became "facies", "faciations" or "lociations".

Heinsdijk's work in Amazonia offers a most valuable lesson in the method of recognising order from the apparent confusion of a vast rainforest area. During some 7 years with the F.A.O. Mission to the Amazon at Belem, Heinsdijk was responsible for carrying out forest assessments in the dryland rainforests to the south of the Amazon River for some 800 miles along the river from Belem west to the Rio Madiera and southwards until the assessment parties were stopped by poor access or (in this age of space exploration!) by hostile natives: a total area of some 60,000 sq miles (equal in size to England and Wales). In this area four blocks were assessed, each bounded by two of the major southern tributaries of the Amazon. Within each block a number of forest types were recognised, structurally from aerial photographs and for greater breakdown by the presence or absence of certain key indicator species, determined by strip assessment. These types were given names based on some local geographic or topographic feature. Thus in the block lying between the Rio Tapajos and the Rio Xingu six types were recognised, classified firstly on their location on either the flanco (dryland riverside flats) or the planalto (inland low plateau), the planalto typically carrying a higher quality forest. The six forest types recognised were as follows:

1. Planalto I type: First planalto type assessed

2. Planalto II type: Differs from 1 by the abundant appearance Carapa guianensis and Vouacapoua americana.

3. Planalto III baixo type: Differs from 2 by the almost complete absence of Carapa and the abundant presence of Geissospermum sericium.

4. Planalto II baixo cipeal: Small areas, easily distinguished on aerial photographs, marked by few trees but by dense and abundant climbers, stranglers and shrubs.

5. Flanco I type: First flanco type assessed; much Manilkara paraensis.

6. Flanco II type: Differs from 5 by absence of Manilkara paraensis.

The Flanco I type was further subdivided into two sub-types on the basis of stocking and tree size, Flanco I B being consistently of lower quality than Flanco I A type. Fig. 26 shows the distribution of these types in this block, where some 6000 sq miles were assessed, and the appearance of the Planalto II and Flanco I A types is shown by the profile diagrams in Figs. 12 and 17 respectively. Several of the types in this block were also found in adjoining blocks assessed by Heinsdijk. At the conclusion of the assessment of the entire area, Heinsdijk found that all blocks were typified by a relatively high number of stems of Pouteria spp., averaging about 5 stems larger than 10 inches D.B.H. per acre. This was the most constant and numerous group present, though towards the east Eschweilera spp. were also becoming more numerous. Heinsdijk therefore concluded that the entire area could be regarded as belonging to a Pouteria association, in which he recognised 8 facies, one of which was the result of anthropogenic influences. Four of these facies occurred within the Rio Xingu - Rio Tapajos block, type 1 being in the Virola facies, tupe 2 in the Vouacapoua - Carapa facies, types 3, 4 and 6 in the Vouacapoua - Geissospermum facies and type 5 in the Manilkara paraensis facies. In the east he expected to be able to distinguish a separate Pouteria - Eschweilera association.

Similar studies to these have now been made in a number of rainforest areas. Possibly the most detailed has been that of Fanshawe in British Guiana where, from the equatorial rainforest subformation in the northern lowlands alone, he recognised two associations (Eschweilera - Licania and Eschweilera - Dicymbe), 10 faciations and 7 lociations. Three of the five types discussed by Richards (p.236) from British Guiana are given by Fanshawe as being faciations of the Eschweilera-Licania association, these being Richards' Mixed Forest (Esch. sagotiana faciation), Greenheart Forest (Ocotea rodiaei faciation) and Morabukea Forest (Mora grongrijpii faciation): Richards' Wallaba and Mora Forests fall into different sub-formations. Other studies in which forest types have been recognised include those of Beard (1946a) for Trinidad; Beard (1949) for the Windward and Leeward Is.; Wadsworth (1951) for the Luquillo Mountains of Puerto Rico; Taylor (1960) for Ghana; de Rosayro (1942) for Ceylon; Pitt-Schenkel (1938) for the Usambara Mountains of Tanganyika (montane rainforest); Wyatt-Smith (1961b) for Malaya; and Baur (1957) for New South Wales. No similar attempt has yet been made over an extensive area of Nigeria, but Lamb (1941) observes that in one survey of a forest reserve in southern Nigeria four associations were recognised.

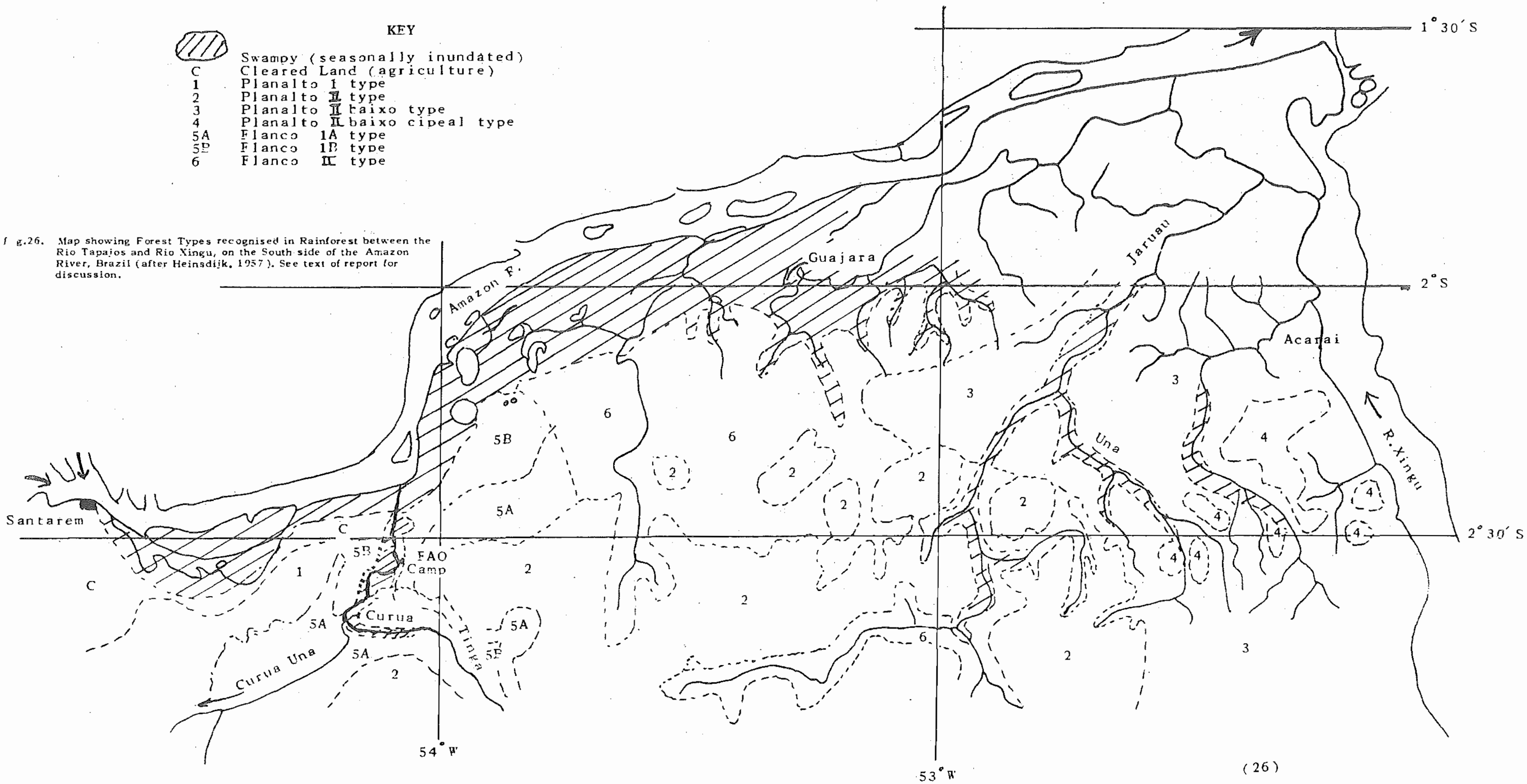


Fig.26. Map showing Forest Types recognised in Rainforest between the Rio Tapajos and Rio Xingu, on the South side of the Amazon River, Brazil (after Heinsdijk, 1957). See text of report for discussion.

(26)

This indicates that despite the apparent confusion and complexity of many rainforests it is possible to recognise valid floristic units within these, and it appears that these units have considerable silvicultural significance. It also appears, however, that in most rainforest areas many species occur widely and that the recognition of forest types, associations, facies or other units depends very largely upon the behavious of a few key species. As Schultz (p. 212) states, rainforests provide excellent examples "of the principle of species' individuality (i.e., that each species responds uniquely to external factors and enters the community as an independent member) and of the principle of community continuity (i.e. that the composition of the plant cover changes continuously in space)". Most rainforest communities indeed suggest the existence of a continuum from which the recognition of associations must to some extent always remain a matter of arbitrary convenience.

Single Species Dominance

Whilst the greater proportion of rainforest communities are of very mixed composition and lacking in a single obviously dominant species, stands with a tendency towards single dominance are by no means exceptional. Numerous examples of these are given by Richards (pp. 254-261) from various areas of tropical rainforest, whilst such stands are even more common in temperate rainforest: in southeastern Australia, for example, the temperate rainforest stands are typically dominated by either Ceratopetalum apetalum or a Nothofagus sp., and a similar situation applies in New Zealand and probably in southern South America.

The dominant species in these stands is characteristically an upper storey species with relatively large dimensions for the stand. These are features which attract the forester, who usually prefers to have to handle relatively large volumes of a single species per acre. However, the degree of dominance exerted by the leading species varies considerably. Richards (p.257) quotes one area in the former Belgian Congo where Macrolobium dewevrei comprised 94% of all stems over 8 inches D.B.H. in the stand, but such frequency is exceptional: more usually the dominant species comprises less than 50% of the stems of this size. Table 10 indicates the percentage of stems of the dominant species in a number of stands with a fairly clear cut single dominant and, as can be seen, it is usually only in the largest size class that anything approaching true single species dominance is expressed.

In the case of the Malayan Dryobalanops community the "dominant" is more poorly represented in the larger sizes than are the other leading species listed, and it is clearly a dubious point whether this community should be regarded as possessing a single dominant. Nonetheless this represents a fairly typical example of "Kapur Forest", and one is tempted to conclude that the more economically desirable the species in question, the lower the proportion needed for the species to dominate the stand - at least to the satisfaction of the forester. By analogy, a rich deposit of gold ore contains much less of the precious metal than does a poor deposit of iron ore contain the common metal!

TABLE 10

Percentage of Stems of Dominant Species in Rainforest

Country	Dominant Species	% Stems of Dominant Species in Stand		
		4" D.B.H.+	8"+	16"+
British Guiana	Mora excelsa	23%	32%	67%
British Guiana	M. gronggrijpii	26	24	61
British Guiana	Ocotea rodiaei	9	19	43
British Guiana	Eperua falcata	21	32	67
Puerto Rico	Dacryodes excelsa	16	43	82
Uganda	Cynometra alexandri	27	59	80
Malaya	Dryobalanops aromatica	11	18	24
Malaya	Shorea curtisii	21	30	67

Sources: British Guiana from Davis and Richards (1933-34); Puerto Rico, Original; Uganda, Eggeling (1947); Malaya, records of F.R.I., Kepong

Stands with a single dominant are frequently found on sites with less favourable environmental conditions than the stands with a more mixed composition in the same locality. Thus in the Moraballi creek area of British Guiana, of the five communities studied by Richards the Mixed Forest occupies the best soils, whilst the two most strongly single dominant communities (Wallaba and Mora Forests) occupy the most unfavourable soils in the locality: Wallaba (Eperua falcata) the highly porous and strongly leached podsols, and Mora (Mora excelsa) the shallow and poorly aerated swamp soils (Richards, p. 242). In New South Wales Ceratopetalum apetalum is clearly the dominant species in the warmer, northern parts of the state on soils that are markedly less fertile than those occupied by the more mixed rainforests that have usually a Tarrietia sp. as the leading species; C. apetalum also dominates rainforests in the south of the state where the climate is less favourable (Baur, 1957). As discussed previously in connection with Fig 25, fewer species are present in communities with relatively unfavourable environmental conditions than in those on better sites in the same locality. It seems that, in these less rich communities, there is greater chance of one species being able to utilise the site, and the reduced competition, more efficiently, and thus to dominate the stand, than where the site is more favourable.

An unfavourable site is however not the only cause of rainforests with a single dominant. A number of communities with a tendency this way have been shown to be long lived phases in a succession towards the climax. Species behaving in this manner include Goupia glabra in Surinam (Schultz, pp. 220-1), Aucoumea klaineana in Gabon (Becking, 1960), and Octomeles sumatranus in New Guinea (B.W. Taylor, pers. comm.). In other cases it appears that the growth habits of the dominant species, even on very favourable sites, enables it to compete more successfully than any of its associates. Features of such species appear to be:

1. fairly frequent and heavy seeding,

2. young stages which are relatively shade tolerant,

3. an ability to utilise any changes in the stand (creation of gaps, etc.),

4. tall ultimate size,

5. fairly dense crowns, and of course

6. a liking for the site.

Species in this category would include Mora excelsa in Trinidad, Shorea curtisii and Dryobalanops aromatica in Malaya, Cynometra alexandri in Central Africa, Eusideroxylon zwageri in Borneo, Castanospermum australe in eastern Australia, and probably Parashorea malaanonum in North Borneo. Two of these species (Eusideroxylon and Castanospermum) are confined largely to flat land adjoining rivers, apparently due to their large seeds which restrict the extension of their stands (Richards, p. 259; Baur, 1957). The behaviour of Mora excelsa in Trinidad has been examined by Beard (1946b). This species is widespread in the rainforests of British Guiana, but only becomes gregarious on the swampy flats.

In Trinidad however, it shows a particularly high degree of dominance (50% of stems over 4 inches D.B.H. and 90% of stems over 20 inches D.B.H.) in certain areas which appear environmentally identical with those elsewhere occupied by the mixed Carapa - Eschweilera association. Beard explains this by suggesting that Mora is a relatively recent arrival in the island and, with its great reproductive power and tall height, is actively invading and suppressing the older local community.

The number of species present in any stand with a single dominant is usually less than in mixed stands, partly due to the less favourable conditions often experienced and partly also to the fact that as one species is more frequently represented there is less room for others (Richards, p.260). However, this reduction is not always marked: the Dryobalanops plot from Bukit Bauk F.R., Malaya (table 10) contains 123 species larger than 4 inches D.B.H. on one acre, while some of the Malayan Shorea curtisii communities may be even richer in species (Wyatt-Smith, 1948 and 1949). These stands however are rarely so strongly dominated by the one species as those where fewer species occur: where gregariousness is marked, the floristic richness is typically low.

Dominance by Higher Taxonomic Groups

While single species dominance is the exception rather than the rule in rainforest communities, the dominance of a number of related species (same genus or, more commonly, family) is of rather frequent occurrence. This phenomenon often appears in stands which already have a tendency towards single species dominance, but it also quite commonly occurs in communities which have no clear dominant at the speç ies level.

In the first case the leading species is associated with several other fairly common species which are closely related: Richards (p.261) notes this with the family Leguminosae for the Eperua falcata and Mora excelsa communities in British Guiana, and the same feature appears in the Ceratopetalum rainforests of New South Wales, where the dominant species is commonly associated with up to four other species of Cunoniaceae, the family frequently providing more than 75% of the stand's basal area. Family dominance is also marked in those Malayan rainforest communities with a tendency towards single species dominance (e.g. Shorea curtisii and Dryobalanops forest types), but the southeast Asian rainforests are more notable for the dominance of the family Dipterocarpaceae even where there is no obvious single dominant species. These rainforests provide the most striking example of family dominance to be found over extensive areas, a number of plots from Malaya showing that the dominant family commonly provides from 15 to 35% of the stems larger than 4 inches D.B.H., and from 40 to 60% of the basal area in virgin stands, while as a result of silvicultural treatment the proportion of dipterocarps can be increased even further (see Chapter 10). Examples from other regions are less striking, but still show the same trend: the Fagaceae in some of the more mixed temperate rainforests of New Zealand and South America, Sterculiaceae in semi-evergreen rainforest in West Africa, Meliaceae in some of the moister West African rainforests, and Leguminosae in parts of tropical America.

The manner in which a number of species from the one genus may occur together in rainforest to form a numerically significant proportion of the stand has already been discussed in connection with Heinsdijk's Pouteria association from Brazil and the Diospyros - Mapania association from the Ivory Coast. A particularly striking example of this is provided by the Mocambo Forest plot near Belem, in Brazil, where, in a 5 acre plot containing 154 species, 13 species of Protium make up 23% of the stems in the stand and 6 species of Eschweilera make up a further 19%. Another example is shown by the Meranti-Keruing forest type (light hardwood Shorea spp. - Dipterocarpus spp.) of Wyatt-Smith (1961b) in Malaya, though here the dominant genera are restricted to the upper storey of the rainforest (see Fig. 6); a similar example is shown by the Flindersia spp. of north Queensland. Such generic dominance is closely allied to family dominance.

Related also to this generic dominance is the occurrence in widely separate localities of stands dominated by one or more different species from the same genera. Such vicarious species are of interest to students of the past distribution and migration of rainforest, and they are fairly widespread. Possibly the most striking is the occurrence of Nothofagus in South America, New Zealand, eastern Australia and New Guinea. In the Usambara Mountains of Tanganyika montane rainforest is dominated by Ocotea usambarensis and Podocarpus spp. (Pitt-Schenkel, 1938); 2000 miles to the south in the Knysna region of South Africa occur stands dominated by Ocotea bullata and different Podocarpus spp. (Phillips, 1928). The New South Wales rainforests dominated by Ceratopetalum apetalum find their analogues 1000 miles north on the Atherton Plateau of Queensland in stands where C. succirubrum is associated, as in New South Wales, with other Cunoniaceae, Wilkiea sp., Daphnandra sp. and Doryphora sp. Communities with Podocarpus and Weinmannia among the common dominants are found in such widely disjunct localities as the Malayan highlands, New Zealand (Robbins, 1961), the northern Andes (Lamprecht, 1954) and Jamaica (Asprey and Robbins, 1953). The montane rainforests of Malaya with their dominance of oaks (Quercus, Pasania, Castanopsis) and various laurels and such associated genera as Podocarpus and Bucklandia, are repeated on a much larger scale in China, Formosa and Japan (Wang, 1961). The xeromorphic rainforests on podsolised sands in British Guiana, with their dominant Eperua falcata, are found in the upper Amazon valley with E. leucantha and E. purpurea as dominants (Aubreville, 1961). These related communities in most cases occur where at least some of the environmental conditions are very similar between the different sites: Eperua on the tropical podsols; Ceratopetalum under similar temperature and rainfall conditions on relatively infertile soils derived from sedimentary deposits; Nothofagus on very cool, moist, misty sites; and so on. Frequently the occurrence of the related species, with similar growth habits and appearance, results in stands with extremely similar structure: the appearance of a rainforest stand depends not only on the environmental conditions, but very markedly on the nature of the species making up the stand.

This relationship between floristic composition and structure is shown most strongly where the dominant species have certain distinctive characteristics, and the occurrence of a truly dominant species with some particular habit of growth may be sufficient to alter the subformation of the rainforest stand. Thus the dominance of tall, deciduous trees of Tectona grandis in many southern Asian forests necessitates excluding these forests from the tropical rainforest formation, even though similar sites in other parts of the world are occupied by a rainforest subformation. Similarly the dominance of Nothofagus provides, with the presence of this one genus virtually all the distinctive characters of cool temperate rainforest. In Trinidad Beard (1946b) includes both the mixed Carapa - Eschweilera association and the strongly single dominant Mora association in the one structural group (equivalent to evergreen seasonal rainforest of this report), but the profile diagrams given by Beard (and repeated as Fig. 7a and 7b by Richards) suggest that the presence of Mora has altered the structure of the forest sufficiently to warrant placing these communities in a different subformation.

The Silvicultural Significance of Floristic Composition

The forester responsible for managing rainforest with the primary aim of producing timber with a ready market has more than an incidental interest in the composition of the rainforests in his charge. Apart from the obvious importance of knowing which merchantable species are present and in what quantities, the recognition of forest types can greatly simplify the practice of sound silviculture. Different communities are apt to respond in different ways to a particular silvicultural technique and, by appreciating the differences in composition of rainforest within any area, adequate treatments can be applied to each with greater likelihood of success than where the differences are unrecognised. Recent experience in many rainforest areas points to the truth of this (Chapter 10): the Malayan uniform system was devised for the lowland Meranti-Keruing forest types, and in the Shorea curtisii and Dryobalanops types the technique must be modified, while in the Kempas - Kedongdong (Koompassia - Burseraceae) type it is being replaced by enrichment planting. Similar changes in technique in different communities of rainforest are occurring in Trinidad, British Guiana, Nigeria and other countries (see Chapter 10).

Stands showing a tendency towards single species dominance have a particular appeal to the forester, especially where the dominant is of some economic value. Such stands are usually easier to treat than forests of more mixed composition, and in a number of areas the oldest successful attempts at managing the rainforests are to be found in the gregarious stands: instances are the Ocotea rodiaei (Greenheart) forests of British Guiana (Fanshawe, 1952b), the stand of Dryobalanops on Kanching F.R. near Kuala Lumpur in Malaya, and the Ceratopetalum forests of New South Wales. In more mixed communities the tendency in treatment is to favour a few species only, usually ones of fairly rapid growth and proven value, and thus to aim at converting the stands towards dominance by a few species. Some notable successes have been obtained using this principle (Chapter 10). Such stands differ greatly from those that preceded them, yet basically they belong to the same associations. The effect of most treatment in the natural forests is to simplify the composition and increase the proportion of a few valuable species selected from the usual complexity of the original stands.

CHAPTER 5

RELATION OF RAINFOREST TO OTHER VEGETATION TYPES

> "It is certainly reasonable to regard the broad-leaved evergreen forests of the tropics as the generalised type, and the deciduous forest of temperate regions as fitted to adverse winter conditions, just as the thorny vegetation of desert regions is suited to a dry climate." Brown (1919).

Broad Relationships

Rainforest of both formations does not exist in an isolated condition. Apart from a few insular areas where rainforest covers the entire land mass, in all areas of occurrence rainforest ultimately adjoins some plant community that does not fit the definition of rainforest adopted in this report. Often the junction between rainforest and its neighbour is a merging one that cannot be precisely defined, though under the influence of a strong biotic or edaphic environmental factor the boundary is frequently very sharp. The adjoining communities are very varied; some show floristic affinities with the rainforest, while others are floristically most distinct; structurally they range from other types of forest through woodland to grassland.

Before briefly considering these other vegetation types it is desirable to recapitulate the relationships between the various rainforest subformations. As defined (Chapter 1) rainforest is a closed community of essentially, but not exclusively, broad-leaved, evergreen, hygrophilous trees, usually with two or more layers of trees and shrubs, and with dependent synusiae of other life-form. Within this broad definition two formations can be recognised, each with a number of fairly distinct subformations. For the purposes of this report a total of 10 subformations are recognised, though this is undoubtedly an underestimate (Chapter 3). These occupy nearly one tenth of the earth's land surface, being most widely distributed in the humid tropics but extending far beyond the tropics in areas with ample moisture and relatively mild winters. The subformations show certain more or less linear relationships with each other: commencing with equatorial rainforest in the constantly moist tropical lowlands, an increasingly severe dry season causes a change through evergreen seasonal to semi-evergreen rainforest; increasing altitude produces submontane and montane rainforest; increasing latitude produces subtropical, warm temperate and cool temperate rainforest; impeded drainage results in swamy rainforest; excessively drained, infertile soils in the humid tropics carry xeromorphic rainforest. Thus with equatorial rainforest as the focal point, five series can be recognised, each series resulting from a change in one of the environmental factors. Since there are many more than five environmental factors it could be expected that many more series do in fact exist, each reflected by some major or minor change in the forest structure and composition. This is doubtlessly correct, and as has already been stressed, rainforest in any region is best regarded as a constantly changing continuum.

The five series listed above merely represent the more widespread and apparent lines of change within this continuum. With a major change along some other line, or by continuing beyond the end sub-formation in the above lines, the resultant vegation can usually not be classed as rainforest, and it is with these other communities that this chapter is concerned.

This "series" approach is similar to that developed by Beard (1944a, 1955) for tropical America. Beard recognised 5 formation series, or 6 if one distinguishes between salt and fresh-water swamps: the other four series covered well drained sites with a seasonal climate (seasonal series), well drained sites with a constant moisture stress(dry evergreen series), increasing elevation (montane series), and ill-drained sites subject to alternate flooding and desiccation (seasonal swamp series). These series have been constructively criticised on certain grounds, but the approach is a practical one and with modifications the system has been widely used in the Caribbean, where it was devised (Beard, 1946a and 1949; Fanshawe, 1952a; Asprey and Robbins, 1953), and has also proved of value in other areas (Taylor and Stewart, 1956, in New Guinea; Whittaker, 1960, in California; Robbins, 1962, in New Zealand). Its greatest value is in studies of a limited area; its main disadvantage that it is two dimensional and does not allow for an environment which changes in several unrelated directions at once, as for example in increasing elevation whilst simultaneously getting changing patterns of rainfall, or in increasing latitude (not covered by Beard's strictly tropical classification) while changing both rainfall and soil fertility. This is a serious disadvantage, but one that is difficult to overcome by any but a most complex system.

The relationships of tropical rainforest to other vegetation types are discussed in some detail by Richards (Chapters 15 and 16, and in part Chapters 13 and 14). No point is served in repeating the data collated by Richards, but his conclusions summarise the main points which are to be mentioned here.

Reduced Rainfall or Severe Dry Season

The moister types of lowland, dryland rainforest in the tropics (equatorial and, to some extent, evergreen seasonal rain-forest) are mostly located in the moist climatic belt astride the equator. As one moves away from the equator, the general tendency is for both the average rainfall to decrease and the annual dry season to become more severe. This change is reflected within the rain-forest zone by the transition from equatorial to evergreen seasonal and finally to semi-evergreen rainforest: the seasonal formation series of Beard. As the climate becomes still more severe, rain-forest cannot exist save in restricted, particularly favoured sites typified by the creek bank "gallery forests" found through many of the subhumid regions of Africa and tropical America. In the more wide-spread and less favoured sites beyond the rainforest limits various types of vegetation can be found, but where there are no marked soil changes or strong biotic pressures (as come from constant grazing or repeated fires), the semi-evergreen rainforest seems usually to become lower in height, its upper storey becomes more open and the proportion of deciduous trees increases. Such communities, although clearly related to rainforest, cannot be described as rainforest: this is Beard's "deciduous seasonal forest", which is equivalent to the "dry deciduous forest" of Champion (1936a) in India. Similar communities are rare in the repeatedly burnt and farmed rainforest margins of Africa, but even in densely populated Nigeria isolated stands of this type can be found, and it would appear that this is the climatically controlled type of vegetation beyond rainforest throughout most of the tropics. With increasing drought these forests tend to become more open and of lower height, till they form the thorn woodlands known from all tropical continental regions.

Although this is apparently the normal series under conditions of increasing dry season and limited biotic interference, over vast areas lowland rainforest in the tropics is bounded not by seasonally deciduous forest, but by grassland with scattered trees and shrubs. This is savanna, and it occupies immense areas of tropical Africa as well as extensive areas in tropical America and parts of southeast Asia. The trees of the savanna are usually small, evergreen, spreading crowned, and resistent to fire; often the species are closely related to species found in the rainforest (Keay, 1959a), but frequently distinctive species occur in the savanna, giving it a most characteristic appearance (e.g. certain palms in parts of Brazil, Pinus caribaea in Central America, P. merkusii in Thailand, Indo-China and Indonesia). There is evidence that some areas of savanna result from local features of the soil. This appears particularly to be the case in Trinidad (Beard, 1946a), and probably also in some of the "campos" areas of the Amazon basin, and it has led Beard (1953) to suggest that the American savannas are primarily edaphically controlled: in his vegetation classification Beard includes savanna in the formation series on ill-drained sites subject to alternating flooding and desiccation. However there is very strong evidence that, over most of its range, savanna is the result of frequent burning and other destructive biotic practices. Given adequate protection for long enough in these sites it can be converted to a community similar to one or other from the seasonal formation series, including rainforest itself in suitable sites where a seed source is still present (Charter and Keay, 1960). This feature is being utilised in the open pine savannas of north eastern Nicaragua, where protection results initially in the formation of fairly dense P. caribaea forests and ultimately in reversion to rainforest (B.W. Taylor, 1962 and pers. comm.). It is most doubtful whether anywhere savanna in its more typical forms is an undisturbed community resulting primarily from climatic influences.

The somewhat unique status of the Asian Tectona forests was mentioned in Chapter 4. Some of these (the "dry Teak forests") undoubtedly fall into the seasonally deciduous forest category, but the moister stands occupy sites which elsewhere carry rainforest, and the dominance of this one deciduous species is the cause of their rather anomalous position. Where Tectona forms only a small proportion of the stems in the "moist Teak forests", and where its associates are mostly evergreen, these forests should probably be included in the semi-evergreen rainforest subformation; elsewhere they form a rather specialised type of seasonally deciduous forest.

Thus it appears that within the tropics the rainforest belt typically borders on to a deciduous type of forest as moisture becomes limiting. However, over very large areas excessive burning, grazing and farming have converted this to savanna, which in some regions extends from the climatic margin well into the rainforest belt itself e.g. the Sobo Plains of Nigeria (Keay, 1959a), the Nicaraguan pine savannas (Taylor, 1962), and the New Guinea "kunai" (Imperata cylindrica) grasslands (Robbins, 1961). Whilst most savanna appears to be produced as a result of these biotic influences, there is evidence from a number of areas that less favourable soil conditions also result in a savanna type of vegetation, or else in communities, considerably different from the usual seasonal series, which under the influence of fire and grazing are readily converted to savanna. These latter communities include the dry evergreen series which Beard explains on the grounds of constant moisture stress on excessively drained sites, but which may result no less from excessively infertile soils: xeromorphic rainforest as understood in this report falls within this formation series of Beard's. It is also possible that an extremely unreliable rainfall, as opposed to the usually most reliable wet and dry seasons of the tropics, may produce a form of dry evergreen forest or woodland in the tropics.

Increasing Altitude

The vegetation of mountains rising from within the tropical rainforest belt is described in some detail by Richards (pp. 347-368) and forms Beard's montane formation series. The general pattern appears similar in all regions, though as explained in Chapter 2 the whole series becomes compressed on isolated peaks so that the upper limit of rainforest on mountains close to the equator may occur from below 4000 ft., as for example on Kedah Peak, in Malaya, to above 10,000 ft. as in the northern Andes (Lamprecht, 1954) and parts of New Guinea (Robbins, 1961). The terminology of this series has been rather confused by recent workers, Beard (1944a, 1955) using a set of terms which others (notably Richards, p. 364) have also used but applied to communities at higher altitudes. Beard's terms are basically those used here.

The lowest elevations of tropical mountains normally support equatorial or evergreen seasonal rainforest, though the East African mountains at least tend to rise from a drier environment which supports a presumably biotically induced savanna. As altitude increases the lowland rainforest changes first to submontane and then, more markedly, to montane rainforest as already described. Higher still, in sites subject to almost constant mist, the montane rainforest becomes reduced in height to the stage where the stand no longer qualifies as rainforest though the community is clearly derived from montane rainforest. This is the montane thicket of Beard and the "cloud forest", "mist forest" or "elfin woodland" of other workers, rarely exceeding 30 ft in height, drenched by the perpetual mist, and swathed in mosses and liverworts. In exposed sites this community may be reduced to a height of less than 10 ft in stands that really warrant the title of elfin woodland. If the mountains rise higher the mist belt is ultimately passed through and the climate becomes drier and sunnier while the vegetation for a while becomes taller in the zone of the high mountain forests, which are frequently rich in conifers. These in turn pass to a zone of shrubby vegetation, often composed of giant herbs (e.g. the African mountain Lobelia and Senecio spp.), and hence to alpine tundra and the region of permanent snows.

This basic pattern of vegetation can be found in all tropical regions where the mountains attain sufficient height, but in addition other types of vegetation may also be found, often associated rather intimately with the montane rainforest. Two of these were included by Beard in his original classification of tropical American vegetation (1944), but omitted in his 1955 revision as not being "climatic climaxes". One of these was the "palm brake", which is a most conspicuous feature of many Caribbean mountains. In the Luquillo Mountains of Puerto Rico this vegetation, dominated by Euterpe globosa, occurs over some 11% of the forest area on the steep slopes with shallow, unstable soils. It is a single storied community up to 50 ft. in height, made up mostly of palms with a scattering of other species from the submontane and montane rainforests. Its occurrence is closely related to the erosion rate, the palms dominating the early succession on landsllips and by their dense shade delaying the invasion of other species (Wadsworth 1951). On stabilised slips the palms in time diminish in number and the community is replaced by one or other of the rainforest subformations. It seems probable that the "bamboo brakes", which are frequently found in somewhat similar situations in African and Asian rainforests, result from a similar cause.

Beard's other community, omitted in 1955, was the mountain pine forest, which is found in parts of tropical America (e.g. the Pinus pseudostrobus forests of Central America and the P. occidentalis forests of Haiti) and which has its equivalent in south-east Asia (e.g. P. insularis in the Philippines, P. khasya in Burma). These stands, often valuable forestry assets, appear to be the montane equivalent of the lowland pine savannas, owing their origin to frequent fire. In Nicaragua, for example, there appears strong evidence that continued protection from fire and other forms of disturbance leads to their replacement by montane rainforest, while their distribution shows a strong correlation with the areas formerly under intensive settlement and agriculture (B.W. Taylor, pers. comm.). Elsewhere continued disturbance by man has created grasslands in the submontane and montane rainforest zones. These are clearly akin to the lowland grassland savannas, and are well illustrated by the extensive highland grasslands of New Guinea, commonly dominated by Miscanthus floridulus (Robbins, 1961). The New Guinea submontane rainforests are also noteworthy for the occurrence in a few areas (Bulolo-Wau region, Jimmi Valley) of a high overstorey of Araucaria spp., whose presence really warrants the separation of these communities on structural grounds into a distinct rainforest subformation. As described by Womersley (1958), "the closed canopy of broad leafed evergreen mesophytic trees is similar if not identical in structure with the non-Araucaria foothill and mountain forests* .... Out of this closed canopy tower the lofty crowns of the A. cunninghamii and A. hunsteinii (syn. A. klinkii). These are not simple emergent individuals .... we have here a new layer to our forest, comprised of a single species, occasionally two species, which often exceeds the height of the rainforest by as much as its own height above ground". These forests, which obviously belong within the tropical rainforest formation, show close relationship with the eastern Australian Araucaria stands and with the Agathis stands found elsewhere in the southwest Pacific. Womersley interprets these as a "living-fossil" vegetation slowly being swamped by the tide of broadleaved forest, an interpretation very similar to that invoked by Robbins (1962) to explain the podocarp - broadleaved forest relationships in the temperate rainforest of New Zealand.

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* Submontane rainforest, as understood in this report.

Other less common vegetation types also are found in some tropical montane areas. Asprey and Robbins (1953) record a montane sclerophyll thicket on the leeward slopes of the Blue Mountain ranges of Jamaica. This attains a height of about 30 ft and is rather open canopied: similar communities can be found at the western end of the Sierra Central in Puerto Rico (e.g. Maricao State Forest), and doubtlessly elsewhere in the tropics. The community bears some resemblance to the high mountain forests found above the constant cloud layer on higher tropical mountains, and apparently results from conditions less humid than are needed to produce montane rainforest: as stated earlier, environmental conditions do not vary in such a constant manner as Beard's approach suggests.

Excessive Moisture

Most rainforest occurs on well drained soils, but as is to be expected with a vegetation type occurring under a high rainfall regime, the formation frequently advances into sites where the soil is inundated for all or much of the year. Where the vegetation is still able to maintain a rainforest structure, these communities have been here classed as swampy rainforest, a rather broad type which should probably be divided into several distince subformations on structural grounds. As the extent of inundation becomes more severe, however, the structure changes and results in a large number of distinct plant communities which depend for their existence on such features as the depth and period of inundation, the degree of water movement, and the minute local changes in topography.

Beard (1955) distinguished two formation series for these poorly drained sites, a swamp series where the soil was constantly wet and a seasonal swamp series subject to alternate flooding and desiccation. This is an oversimplification: Taylor (1959) recognises eight different formation series from the coastal lowlands of northeastern New Guinea, while further series are believed to exist in the New Guinea highlands (Taylor and Stewart, 1956). Taylor's work represents one of the most comprehensive comparative studies on the relationships of the plant communities found on ill-drained sites under a lowland tropical rainforest climate, and the formation series which he recognises probably have their equivalents in other tropical swamp regions. Four of the series occur under the influence of fresh water, two under the influence of salt water and the final two under the influence of brackish water.

Of the fresh water swamp series, the permanent swamp sequence occurs where the water-table is always at or near the surface. The boundary with rainforest is sharp, the sequence commencing with a tall, two layered swamp forest in which the understorey usually contains Metroxylon sagu, the sago palm. Sometimes the overstorey consists of almost pure Campnosperma sp., but more usually it is of mixed composition. This gives way in turn to a lower, more open swamp woodland, then a swamp savanna of scattered trees over a dense, tall grass layer, and finally to a herbaceous swamp of various Cyperaceae, up to 12 ft high, bound together by pitcher plants (Nepenthes spp.). Taylor suggests that the sequence may be determined by the depth of peat, the herbaceous swamp occurring where the peat exceeds 6 ft in depth. However, the occurrence of swampy rainforest in Malaya and Sarawak on peat of much greater depth indicates that the cause may be more complex than this.

The fluctuating swamp sequence is found on mineral soil in areas fed by streams which flood frequently. This merges gradually into rainforest on the better drained sites. The sequence starts with a tall, two storied seasonal swamp forest which passes to open seasonal swamp forest as the upper storey (up to 90 feet high) becomes more scattered over the dense understorey. The upper storey finally disappears to leave seasonal swamp woodland consisting of a single, dense storey of Metroxylon up to 40 ft high: the "sago swamps". This in turn gives way to a herbaceous swamp, here composed of Phragmites karka and other grasses up to 12 ft in height. Taylor considers this sequence to be determined by the depth and period of flooding. He notes that the herbaceous swamps are rare in this sequence, only occurring on sandy soils where the soils periodically dry out to some depth. Under these conditions the herbaceous swamp is a true climax, "though an almost identical community can also occur as a pioneer stage in a succession following flooding".

The semi-seasonal swamp sequence occurs in very low lying areas which, however, receive little influx of water during the dry season. The sequence is similar to the fluctuating swamp series in that it passes from seasonal swamp forest to open seasonal swamp forest, seasonal swamp woodland and finally to herbaceous swamp. However in the earlier stages Pandanus spp. replace the Metroxylon, while the herbaceous swamp is dominated by sedges, not grasses.

Taylor's final fresh water series is the seasonal swamp sequence, found on mineral soil subject to distinct seasonal inundation. It differs from Beard's seasonal swamp series in being less arid during the dry season. It often contains small permanent lakes with aquatic vegetation, surrounded by herbaceous swamp of Saccharum spp. up to 3 ft high. This community in turn is enriched by the entry of scattered trees and then changes rapidly to a seasonal dryland forest.

The main salt water series is the tidal mangrove sequence which occurs between the dryland rainforest and the sea. The boundary with the rainforest is very sharp, passing to a one -, or less commonly two -, storied mangrove forest up to 80 ft high. On the New Guinea coast the mangrove forest shows a floristic zonation, with Heritiera littoralis dominating the stands nearest the dryland, then Bruguiera gymnorrhiza, and finally Rhizophora mucronata at the seaward edge, where it bounds a lower, more open mangrove woodland dominated by Ceriops tagal.

Within the mangrove forest region a separate series, the mangrove marsh sequence, occurs, apparently under the influence of changing salinity. The communities here are all dominated by Avicennia alba c.f. marina and vary from a dense, single storied mangrove woodland up to 40 ft high to a rather inaptly named mangrove thicket of scattered trees up to 20 feet high with extensive areas of bare swamp between the trees.

The brackish water sequence is found in the transition between some of the fresh water swamp forests and mangrove forests. Two stages are recognised in the sequence, a mangrove-fern savanna of scattered mangrove trees (Avicennia alba, Bruguiera gymnorrhiza) over dense ferns up to 3 ft high, and a fern-tall tree savanna of scattered trees up to 90 ft high, and often including Hibiscus tiliaceus, above a dense fern layer of Acrostichum speciosum.

Taylor's final sequence, the estuarine sequence, occurs near the mouths of rivers where there is a frequent interchange of fresh and salt water. It is typified by a swamp thicket of Nipa fruticans occurring as a narrow strip along the rivers.

These various sequences are all composed of climax communities, an interpretation opposed to that of, for example, Richards (pp. 283-312) who regards these communities as seral. True successions certainly do occur, but they usually lead not to the presumptive "climax" rainforest, but to one of the communities mentioned above, depending upon the local environmental features. Richards describes swamp communities from various parts of the tropics and it appears that only minor modifications are needed to fit these into Taylor's classification.

Although not dependent on poor drainage for its occurrence, mention should be made here of the narrow strip of littoral woodland found facing the sea in areas where well drained sandy shores occur. These are typified by the "Barringtonia formation" of the southwest Pacific, a dense thicket up to 60 ft in height, and occasionally taller, dominated by Barringtonia speciosa and containing quite a large number of other trees and numerous vines. On the seaward side this faces the even more widespread (pantropic) Ipomoea pes-caprae community of sand-binding vines along the beach; inland it merges into rainforest. Its occurrence is determined by the salt-laden seawinds. Richards (p.298) notes that littoral woodland, with its zonation from the beach inland, shows potential stages in a succession, but so long as the shore line is stable "it seems unlikely that the succession will become actual". This again is a climax community. Initially in the south west Pacific region, and more recently throughout other tropical coasts, Casuarina equisetifolia is a common species dominating extensive well drained coastal areas in pure stands. These appear to result from disturbance, the Casuarina replacing the littoral woodland on recently exposed sand ridges or where fire has destroyed the Barringtonia community. More deliberate activity by man has resulted in large areas of cocanut palms also having replaced littoral woodland.

The vegetation types replacing or adjoining rain-forest in sites subject to frequent inundation or constant sea-wind exposure are clearly most complex, and an understanding of their ecology is essential not only to forest management but to many aspects of sound land use. Many of the natural communities are of considerable economic value: some of the forests which can be classified as rain-forest provide valuable timber species; mangrove forests yield among the highest financial returns per acre of any tropical forests; while to the native inhabitants the many palms of these swamp communities yield a host of necessary products, ranging from thatch for their homes and starch (sago) as a staple food-stuff to "cigarettes" from young Nipa leaves, palm wine and toddy for their solace.

Increased Latitude - the Northern Hemisphere

The great belts of tropical rainforest lying astride the equator are mostly bounded, with increasing latitude, by vegetation dependent upon a marked dry season, as already discussed. Some extensions of tropical rainforest beyond the geographic tropics occur, notably in the subtropical rainforest formation of eastern Brazil and eastern Australia, and in a few cases these form a connecting series with the temperate rainforest formation, as in Australia. Such extra-tropical extensions are largely confined to the eastern seaboard of the subtropical continental land masses. Because of distinct floristic histories, the relationships between these latitudinal variants of rainforests and associated other types of vegetation differ in the northern and southern hemispheres, and are best considered separately.

In the northern hemisphere there are small extensions of rainforest north of the Tropic of Cancer in northern Mexico and Florida, but the main occurrence occurs in two regions of Asia. The smaller of these is in eastern India and East Pakistan, in the region of Assam, where the rather extensive tropical rainforest belt spreads over the tropic to the foot of the Himalayan Mountains. These lowland rainforests, even beyond the tropic, appear to belong to the equatorial or evergreen seasonal formations, and as they start to ascend the mountains they give way to a montane series which is fairly typical of the tropical montane sequence in its lower zonation, but at higher altitudes gives way to moist forests of deciduous trees and conifers with clear affinities to many northern temperate deciduous and coniferous forests (Champion 1936a).

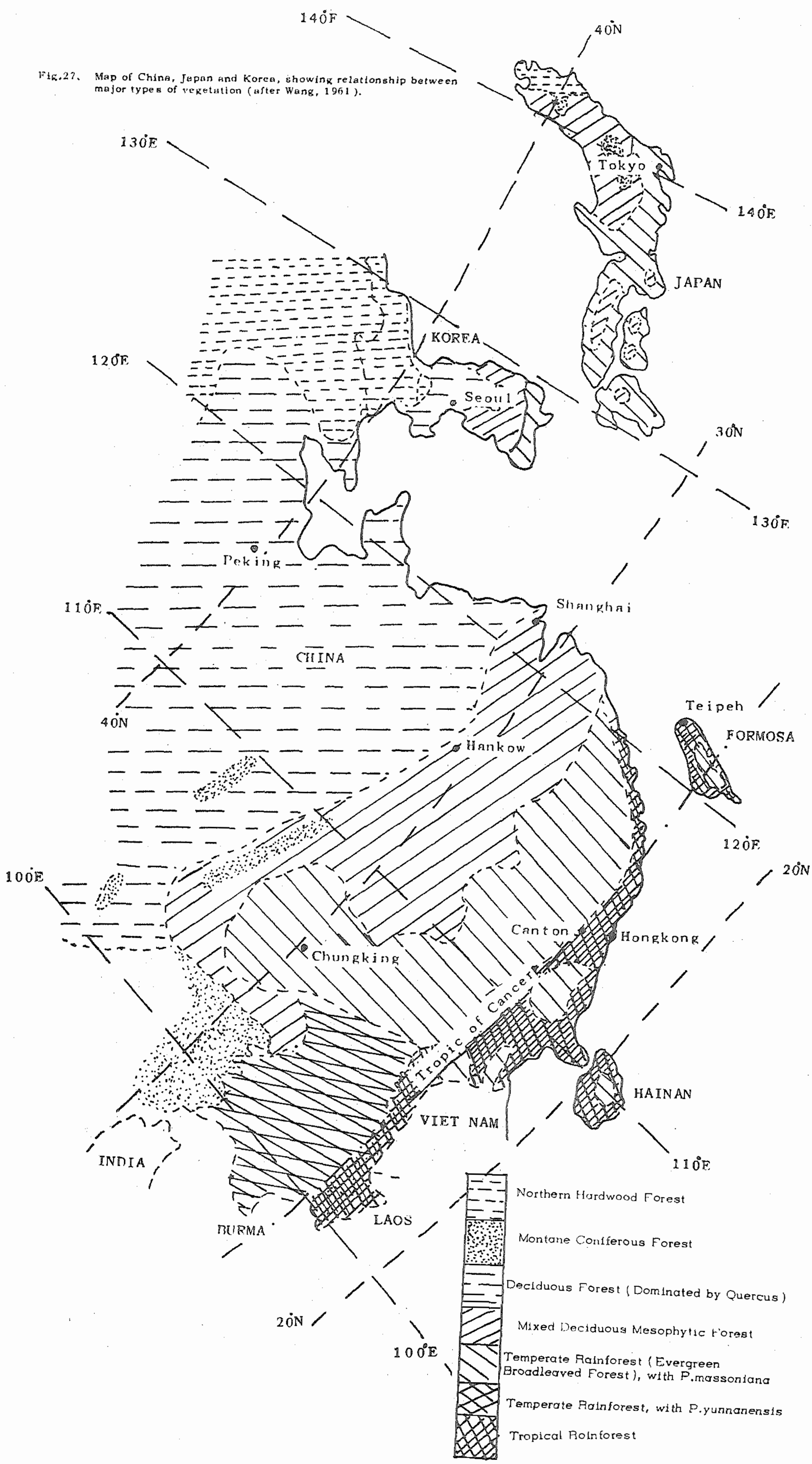
The second Asian region of extra-tropical rainforest is found in China and Japan, and the relationships here have been recently discussed by Wang (1961). Tropical rainforest, floristically related to that in southeast Asia and probably structurally similar to the southern hemisphere subtropical rainforest, extends in a narrow strip along the Chinese coast to about lat. 26°N. Dipterocarps are represented in these forests by species of _Vatica_ and _Hopea_. The same type of forest is found in the coastal areas of Hainan and Formosa. Northwards from this tropical rainforest, and on highland areas within it (e.g. Central Formosa and Hainan) is found a broad belt of what Wang terms evergreen broad-leaved forest. Compared with the tropical rainforest, buttressing is absent in these stands, but the lianes are fairly common. This forest is composed of evergreen oaks and their relatives (_Quercus_, _Pasania_, _Castanopsis_), with other genera present including _Schima_, _Liquidambar_, _Bucklandia_, _Podocarpus_ and various Magnoliaceae, Lauraceae and Theaceae. These forests also occur in southern Korea and the southern islands of Japan. Floristically these stands are very similar to the montane rainforests of Malaya, and structurally they are clearly a type of temperate rainforest which, as stated previously, should probably have a separate subformation for these northern rainforests. In Southern China Wang distinguishes two types, based on the dominance of either _Pinus massoniana_ (in the east) or _P. yunnanensis_ (in the west) in secondary forest, which usually results from fire.

The northern temperate rainforests merge to the north into a mixed mesophytic forest which is essentially winter-deciduous, though some broad-leaved evergreen species also occur. These stands are rich in Quercus and other Fagaceae and also include the natural occurrences of Metasequoia glyptostrobioides and Ginkgo biloba. In China and Korea these mixed mesophytic forests pass into a drier temperate broad-leaved deciduous forest dominated by Quercus, and this in turn, towards Manchuria, passes to a mixed northern hardwood forest of Acer, Tilia, Betula, Fraxinus and others. In Japan the mixed mesophytic forest adjoins the mixed northern hardwood forest without the intervening deciduous Quercus forest which is probably, at least in part, a response to poorer moisture conditions. Mountainous areas in the mixed mesophytic forest belt and further north support a montane coniferous forest of Picea, Abies etc. The distribution of these various forest types in China is shown in Fig. 27.

This Chinese vegetation pattern is repeated almost exactly in North America, the main type lacking being the temperate rainforest. Tropical rainforest occupies small areas in southern Florida, but this is replaced further north by a broad belt of pine forests consisting of various combinations of Pinus elliottii, P. palustris, P. taeda and P. echinata. These pine forests appear through most of this belt to be the result of repeated fire: they are a subtropical and temperate equivalent of the tropical American pine savannas. Protected from fire they are, in the more southern areas, replaced by an evergreen community of Quercus and various Lauraceae, but it is doubtful whether the deep sands of this region could ever support a stand warranting the definition of rainforest. The climax vegetation of protected sites in the south eastern U.S.A. would probably bear the same relationship to the northern temperate rainforests of China, as xeromorphic rainforest does to equatorial rainforests, with the exception that the structure of the forest would forbid its being classified as rainforest. Northwards the pine forest belt adjoins the mixed mesophytic forests of the Mississippi "Delta" and the southern Appalachians. These differ virtually only at the species level from the similar Chinese forests. Structurally they are very close to temperate rainforest, but differ in their habit of losing their leaves each winter. These mesophytic forests are closely associated with drier, deciduous oak forests in the more xeric sites and pass with altitude to forests of Abies and Picea. Further north they are replaced by northern hardwood forests which again, at the generic level, are very similar to those of China.

Thus, in the areas where it can be studied, the northern hemisphere shows the extension of tropical rainforest into the subtropics, with montane rainforest at higher elevation. With increase in latitude these montane rainforests descend to the lowlands, to produce a mixed temperate rainforest floristically and structurally akin to much of the montane rainforest of the tropics. Disturbance, by fire or other causes, converts this temperate rainforest to pine forest, while unfavourable soil conditions result in a drier type of evergreen forest. At higher latitudes winter deciduousness becomes more apparent and, whilst retaining its structure and much of its floristic relationships, the temperate rainforest changes to mixed mesophytic forest. This in turn is replaced at higher altitudes by conifer forest, in drier sites by a less luxuriant deciduous oak forest, and at still higher latitudes by a

Fig.27. Map of China, Japan and Korea, showing relationship between major types of vegetation (after Wang, 1961).



more northern type of mixed deciduous forest.

Increased Latitude - the Southern Hemisphere

South of the equator temperate rainforest has a widely disjunct occurrence in southern South America, New Zealand, southern Australia and South Africa, while tropical rain forest extends south of the Tropic of Capricorn in Brazil, eastern Australia and on a minor scale in Madagascar. Only in Australia can the full connecting series between tropical and temperate rainforest be readily traced, and the vegetation pattern here is made more interesting by the presence of a third floristic element which frequently meets the two rainforest elements in direct competition for the one site.

The relationships of the Australian rainforests have been discussed by Webb (1959) who, following a well established Australian custom, regards any community which is essentially of Indo-Malaysian or Antarctic floristic affinities as "rainforest", thus distinguishing them from the autochthonous, typically eucalypt-dominated, communities. Webb introduces a new nomenclatural system for these "rainforest" communities, but these can fairly readily be related to communities recognised by workers in other parts of thd world.

Along a purely latitudinal transect at low altitude in the moister sites, where rainforest as understood in this report could be expected to develop, one finds evergreen seasonal rainforest in the north (down to about 24°S), and this is replaced successively by subtropical rainforest (to about 32°S), warm temperate rainforest (to about 40°S), and cool temperate rainforest (in Tasmania). Although quite distinct, these communities tend at their margins to merge together, while in the ecotonal zone between subtropical and warm temperate rainforest there is a broad band (28°S to 34°S) where the two subformations can occur together, fertile soils favouring the former and less fertile soils the latter, as shown in northern New South Wales (Baur, 1957).

Superimposed on this latitudinal transect is an altitudinal series of rainforest communities showing a classical Humboldtian relationship. Thus cool temperate rainforest, with its dominance of Nothofagus, occurs at sea level in Tasmania (lat. 43°S), at about 2000 ft in eastern Victoria (lat. 37°S), at about 4000 ft in southern Queensland (lat. 28°S) and, whilst absent from north Queensland, reappears at about 9000 ft in New Guinea (lat. 6°S) (Robbins, 1961). The other subformations show a similar sliding relationship so that, for example, the coastal sub-tropical rainforest of northern New South Wales is very similar to the submontane rainforest of north Queensland, where the most elevated submontane rainforest stands show also some kinship, structural and floristic, with the warm temperate rainforest of southern New South Wales. This is similar to the pattern already noted in the northern hemisphere, and it appears that the montane rainforest of the tropics has a mixed composition, one element of which (Quercus, Pasania, Hamamelidaceae, Magnoliaceae) tends to "slide" towards sea level to the north, while the other element (Nothofagus, Podocarpus, Cunoniaceae) "slides" to the south.

With reduced moisture the Australian rainforest communities are usually replaced by some type of eucalypt dominated community, but in a few localities, from the far north of Queensland down to about 32°S, small stands can be found composed of species with clear Indo-Malaysian affinities. Thus in northern Australia Webb records mesophyll vine forests (evergreen seasonal rainforest), semi-evergreen mesophyll vine forest (semi-evergreen rainforest) and deciduous vine thicket (equivalent to Beard's deciduous seasonal forest) under conditions of increasing moisture stress, and from southern Queensland and northern New South Wales Webb recognises a series commencing with notophyll vine forest (subtropical rainforest) and then passing through araucarian notophyll vine forest, araucarian microphyll vine woodland, microphyll vine woodland to semi-evergreen thicket.

The araucarian vine forest occupies a somewhat anomalous position in this series, which represents increasingly unfavourable moisture conditions on soils of high fertility (typically derived from basalt). Where subtropical rainforest is able, in the prolonged absence of fire, to invade the eucalypt dominated forests which usually adjoin it, the earliest stage in the invasion is normally marked by much regeneration of Araucaria cunninghamii and, over a more limited area, of A. bidwillii. Thus fairly early stages in this imposed succession take on the appearance of araucarian vine woodland, and the later stages, when mature rainforest has developed beneath a relict overstorey of araucarias, appear as araucarian vine forest (see Cromer and Pryor, 1942). Unable to regenerate in the shade of mature subtropical rainforest, the araucarias are normally absent from ultimate climax rainforest in these fertile, humid sites.

However, the araucarias are also found in some stable, climax forests. They dominate some of the northern, warm temperate rainforests, which are more open than subtropical rainforest, to produce what is structurally similar to araucarian notophyll vine forest: these can be seen on the eastern Dorrigo Plateau of New South Wales. They also occur over fairly extensive areas where moisture limits the development of subtropical rainforest. In these latter sites, araucarian microphyll vine woodland* is the climax vegetation. Thus araucarian vine woodland can be present both as an early stage in an imposed succession to subtropical rainforest, and as a climax community in a series produced by reduced moisture availability, the series subsequently proceeding along the lines indicated by Webb. This series is a sub-tropical equivalent of the tropical seasonal series of Beard, and except for the presence of the distinctive Araucaria spp. the communities of this subtropical sequence closely resemble those of the tropical series.

No similar sequence has been recognised in the more southern parts of Australia and extending from temperate rainforest into the less humid regions. Apparently the Antarctic floristic element is more effectively restricted by moisture stress than is the pan-tropic element. On the other hand cool temperate rainforest may show a structural reduction to thicket (the microphyll mossy thicket of Webb) in sites where exposure to wind is excessive and where

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*Equivalent to the "Dry Rainforest" of Baur (1957).

there is a high incidence of cloud or mist; this is to be found both at low altitudes, as in parts of western Tasmania; and at high altitudes further north, as at Point Lookout in northern New South Wales.

Sequences, such as those described above, showing an obvious derivation from the rainforest flora are, however, the exception rather than the rule in eastern Australia. Over the greatest proportion of its range rainforest borders not these related communities but communities composed essentially of the autochthonous floristic element and generally characterised by the dominance of Eucalyptus spp. Although a few species of Antarctic or Indo-Malaysian affinities have evolved to the stage where they enter into the composition of the eucalypt forests (e.g. Ceratopetalum gummiferum), and conversely a few species of autochthonous affinities enter into the climax rainforests (e.g. Grevillea robusta, Tristania spp.), the distinction between the two groups of floristic elements is in most cases marked, so that one finds the situation where two clearly defined floristic elements are in an active competition for the one site. The factor determining which of these elements will gain the ascendency of these sites is almost invariably fire, which favours the locally derived sclerophyllous vegetation against the more mesophytic communities. Because of fire the distribution of rainforest in eastern Australia is much more restricted than is indicated by the occurrence of favourable climatic and soil conditions, while the occurrence of other communities, related to rainforest but found under conditions of lower or more seasonally distributed rainfall, is even less common: such drier conditions favour the spread of fire, which in turn favours the development of sclerophyllous vegetation.

The eucalypt-dominated forests adjoining or associated with rainforest vary considerably in both composition and structure. Various classifications have been suggested (Beadle and Costin, 1952 . Williams 1955) for these communities which may vary from low, open woodlands akin to savanna as in parts of north Queensland, through taller, almost closed canopy woodlands, to the magnificent forests of E. regnans in Victoria and Tasmania where the dominant tree may exceed 300 ft in height. In addition to these forests on sites which are equally suited to rainforest, eucalypt forests are also found as climax vegetation on sites unsuited to rainforest. Conspicuous among such sites in the more humid regions are areas of very low soil fertility, where the vegetation is a low, fairly open forest of Eucalyptus spp. over a dense sclerophyllous shrub layer; these stands are usually classed as dry sclerophyll forest.

The relationships between the eucalypt forests and the rainforest in any site depend greatly upon the frequency and fierceness of the fires. Sometimes the two adjoin along a remarkably sharp boundary which indicates frequently repeated fires which, however, are unable to encroach into the humid microclimatic conditions of the rainforest. The sclerophyll forest in such sites usually has a grassy understorey (often of Imperate cylindrica) and the stands are similar to savanna elsewhere, except that the eucalypts may exceed 100 ft in height and form forest conditions. These stands have much in common with the pine savannas discussed earlier, and indeed in many respects Eucalyptus is the ecological and silvicultural equivalent in Australia of Pinus in the Northern Hemisphere. Often however the eucalypts occur as an overstorey to rainforest in which the highly intolerant eucalypts are unable to regenerate. These stands indicate less frequent fires, between which the rainforest is able to invade the eucalypt forest, only to retreat at the next conflagration. Gilbert (1959)has discussed these "mixed forests" and his remarks apply to much of the rain-forest-sclerophyll forest ecotone in Australia. On sites suitable for rainforest in the Florentine Valley of Tasmania Gilbert notes five stages:

1. Where an area remains unburnt for 350-400 years (the life span of the main local eucalypts), cool temperate rainforest of Nothofagus cunninghamii and Atherosperma moschata develops.

2. Where an area is burnt infrequently, but at intervals of less than 350 years, the forest is destroyed by each fire but ultimately develops as a mixed forest of eucalypts (chiefly E. regnans) above the rainforest species.

3. With fires occurring once or twice a century the mixed forest is replaced by eucalypt forest above Acacia, Olearia and Pomaderris spp., instead of the rainforest species.

4. Fires occurring at 10 to 20 year intervals produce a replacement of E. regnans by E. obliqua and E. delegatensis, which are more fire tolerant species.

5. Very frequent fires result in a savanna-type vegetation of grass (Poa) beneath an overstorey of such fire-resistent species as E. ovata and E. viminalis.

The species and to some extent the structure of these various communities differ in various parts of Australia, but the general sequence observed by Gilbert can be recognised in most areas where the two floristic elements adjoin, and the mixed forests which are always only a temporary phase are a very characteristic feature of the eastern Australian forest pattern. Some workers (e.g. Fraser and Vickery, 1938; Cromer and Pryor, 1942) have interpreted these mixed forests as a response to climatic change or inherent soil differences, but present evidence leaves little doubt that they are most usually an effect of fire.

The picture of the communities which adjoin rain-forest in Australia is thus a complicated one in which latitudinal and altitudinal change, increasing moisture stress, varying patterns of fire frequency and intensity, and the influence of a competing floristic element all play significant roles. Such complicating factors are not present to the same extent in the other southern hemisphere land masses where rainforest occurs.

In Africa the limited occurrences of rainforest south of the Tropic of Capricorn mostly adjoin steppe or savanna, as do most of the rainforest belts within the African tropics (Keay, 1959b), and it appears that fire, aided probably by the former high game population of the continent, has provided the main limitation on rain-forest distribution and on the development of types of vegetation other than those composed primarily of grasses. In South America a different pattern exists. Rainforests extend in a discontinuous strip along the eastern (Atlantic) coast to slightly south of the Tropic and this can be classified as seasonal evergreen and semi-evergreen rainforest in the north and as subtropical rainforest in the south. Hueck (1957) shows this strip of rainforest as adjoining caatinga in the north and "subtropical forest" further south; caatinga includes both deciduous seasonal forest and thorn woodland as occur in Beard's seasonal formation series, while the "subtropical forest" observed west of Sao Paulo shows a very strong similarity to Webb's microphyll vine woodland. This similarity to the Australian subtropical seasonal sequence is heightened to the south of Sao Paulo by the presence of a large belt of forest dominated by Araucaria angustifolia; these forests are almost the exact equivalents of Webb's araucarian microphyll vine woodlands in Australia. The extreme south of this eastern rainforest strip is bounded by grassland (pampas) which owes its presence partly to heavy soils and probably partly to fire. This grassland regions divides the eastern subtropical rainforests from the temperate rainforests of the southern Pacific coast; unlike Australia, South America shows no continuity between the tropical and temperate rainforest formations, and Hueck notes that the small, isolated forest region of southern South America differs markedly in its floristic origin from the much more extensive northern forest region. The temperate rainforests, which include some deciduous species (e.g. Nothofagus obliqua) and which towards their northern range in the Andean foothills contain Araucaria araucana, mostly adjoin sites where, due to exposure or soil, conditions are unfavourable for tree growth. Only at their northern limit do they abut another tree-dominated community, an open evergreen, sclerophyllous woodland similar to the woodlands found in northern hemisphere Mediterranean climates. This separates the temperate rainforests from the coastal deserts of northern Chile.

Rainforest Relationship Pattern

In this chapter an attempt has been made to sketch the way in which rainforest is related to the various plant communities which adjoin it, and also to account for the distribution of rainforest and these other communities. Although the details differ in different regions, certain broad patterns can be recognised and these tend to be repeated wherever similar conditions occur. Several of these relationships have been discussed in some detail: the effects of reduced moisture availability and of excessive moisture within the tropics, the effect of increasing altitude in tropical mountains, and the effects of increasing latitude both north and south of the equator. A number of important principles are involved in these relationship patterns. To the ecologist there is significance in the manner in which a given floristic element reacts in the same way to conditions which change in any direction from the optimum, as illustrated by the tropical montane, seasonal and swamp sequences, by the southern sub-tropical moisture stress sequence and by the northern latitudinal sequence; there is significance in the very close relationship shown between the altitudinal and latitudinal sequences; there is significance in the different behaviour of unrelated floristic elements under similar conditions as indicated by the northern and southern latitudinal sequences, and by the autochthonous element in Australia, with its suggestion that similar environmental influences in different parts of the world may not result in similar types of vegetation; there is significance in the ecological similarity between Eucalyptus in Australia and Pinus in the northern hemisphere; and there is significance in the wide application of Beard's formation series approach, with its implications of vegetation in any area acting as a continuum and being derived from adjoining communities, as suggested by Brown in the chapter quotation.

For the forester there is interest in the fact that many of the associated communities, although occurring under less favourable conditions, are of greater value than the rainforest itself: mangrove forests in some areas, the Asian Tectona forests, and many of the pine and eucalypt-dominated forests are cases in point. The ecological similarity between Pinus and Eucalyptus is also of interest to the forester, and it is no coincidence that these two genera are those most widely used in deliberate schemes throughout the world to convert sites capable of supporting rainforest to pure stands (see Chapter 9).

But perhaps to both ecologist and forester the most important point brought out is the effect of fire on determining both the limits of rainforest and the type of community which replaces it. It is probably correct to state that a greater length of inland rainforest boundary is determined by fire than by all other factors together. Where suitable species are available to take advantage of this fire effect, as with Pinus and certain Eucalyptus, the resultant fire induced stands may be of great forestry importance. Where such species are lacking, the resultant vegetation may be nothing but a serious problem to the forester. The importance of fire in limiting rainforest distribution can never be overstressed.

CHAPTER 6

THE RAINFOREST LIFE CYCLE

> "The seedlings must be able to persist even if they do not grow....... A place in the sun is only attainable ... when through the agency of old age, of the weight of climbers .... or of lightning, cyclone or man, a break is made in the canopy, and then the race is to the swift and the strong." Champion (1929)

The Basis of Silviculture

Beard (1947) has described ecology as "forestry's fundamental science" and proceeds to state that "silviculture is not a science in its own right but is applied ecology". This precept, as it relates to rainforests, is the guiding principle of this report, and in the preceding chapters the general ecological influences affecting rainforest behaviour and development have been discussed: the environmental requirements and tolerances of rainforest vegetation, its structural characteristics, its floristic composition and the effect on these of increasingly unfavourable growing conditions.

Before passing on to a consideration of rainforest management itself, it is necessary to relate these ecological influences together in an examination of the life cycle of climax rainforest, for here indeed lies the basis for successfully managing rainforest vegetation - or indeed any vegetation. As defined (Chapter 2), climax vegetation occurs when the general character and composition of the vegetation remains broadly the same over a given area for a period at least as long as the life span of the longest living individual. Such climax vegetation is not a static community, but rather one that is immensely dynamic, showing constant change in any small area selected for study. The plants within the community flower and produce seed; the seed is dispersed and germinates; many of the seedlings are destroyed or die, but some survive for periods of varying length; the more mature plants grow and compete with each other until old age or some calamity cause their death; the gaps produced by the dead trees form foci for a burst of new growth by the seedlings and immature trees in their vicinity, and so the life cycle of the plants, and in a sense of the forest itself, is constantly being repeated. And since this life cycle concerns essentially regeneration and growth, an understanding of the factors involved is of the utmost importance to the silviculturist, who also is primarily concerned with regenerating the more desirable species and ensuring that they maintain their optimum rate of growth through to maturity.

Flowering and Fruiting

The species found within rainforest vary considerably in their flowering and fruiting habits. Richards (p.44) quotes T.A.W. Davis from British Guiana as saying: "Seed production is usually seasonal in the canopy but in the undergrowth flowers and fruit are often borne almost continually in small quantities or at irregular but frequent intervals". This picture is probably true for most areas where the climate shows relatively slight seasonal variation. However, where there is a more marked seasonal effect, either from cold winter or a definite dry season, the individual species tend to produce flowers, and subsequently seed, over a more limited period of each year. Thus whilst the very constant climatic conditions of Malaya result in the presence of many "everflowering" species (Richards, p.201), in Ghana, with a distinct dry season, most species flower only during a given, relatively short period of the year (Taylor, 1960). Similar seasonal flowering occurs in the subtropical and temperate rainforests of New South Wales. In Ghana the few species which can produce flowers over most of the year are either under-storey trees growing where the microclimate results in fairly equable conditions throughout the year (e.g. Blighia sapida, Homalium letestui) or secondary rainforest species such as Trema guineesis and Musanga cecropioides.

Many of the more important rainforest trees show irregular flowering. This is reflected in even more irregular seed-ing, since flowering may, on occasion, be accompanied by conditions unfavourable to pollination or be followed by heavy loss of immature fruit by insects, larger animals or other causes. Landon (1957) notes that the principle rainforest species of Malaya, mostly dipterocarps, fruit very irregularly, usually at 2 to 5 yearly intervals, while the montane Shorea platyclados has been observed to go 17 years between successive flowerings (Malayan Forestry Department, 1961). Triplochiton scleroxylon in Nigeria is notoriously irregular in its flowering and seeding, and many other rainforest trees behave in the same pattern. There is some evidence that with at least some of these species the irregular flowering is related to unusual climatic conditions (Mackenzie, 1961; Kirkland, 1961); where such a relation-ship can be demonstrated, the forester can with some reliability forecast good seed years and where necessary carry out any requisite silvicultural operations to take full advantage of the seed when it falls.

Most rainforest trees produce ripe fruit fairly soon after flowering. Development periods in excess of 6 months are unusual, and even trees with large, heavy fruits such as Bertholletia excelsa produce ripe fruit within a year of flowering. Exceptional in this regard are some of the conifers, such as Araucaria spp., which may take up to two years before the seeds ripen. Where the climate has a regular dry season most species shed their seed either at the end of the dry season or during the first half of the wet season. At higher latitudes many species produce their ripened seed during the autumn (Kirkland, 1961; Travers, 1961).

The general flowering and fruiting habits of rain-forest trees are thus very varied. Understorey species and many secondary species appear able to produce viable seed over much of the year, but the larger and more important forest trees are at best seasonal and may be highly irregular in their fruiting; if fresh seed fall had to be relied upon to produce new crops, organised silviculture in many rainforest areas would be impossible.

Seed Dissemination

Rainforest plants show many of the well recognised devices for seed dispersal, but with a marked emphasis on animal dispersal (edible seeds) and, in the uppermost tree layer, on wind dispersal. Table 11, derived from data provided by Dr E.W. Jones, indicates the prevalence of the main seed dissemination mechanisms in Nigerian rainforest trees.

Similar proportions are probably found in most rainforest areas, though the importance of wind dispersal may be greater in some areas, notably the dipterocarp - dominated rainforests of southeast Asia and the Flindersia- Proteaceae - Tarrietia rainforests of north Queensland. Keay (1957) has studied the frequency of wind dispersed species by life forms on approximately 4 acres of rainforest near Ibadan in Nigeria, and his results are shown in table 12. The restriction of wind dispersal, as a means of distributing rainforest seed, to the plants in the tallest layers of the forest is clearly shown by these results. Keay notes that many of these wind-dispersed species either are characteristic of the early pioneers on land which is reverting to forest after farming, or else are species which as seedlings can tolerate shade for some years, but which are unable to develop further unless gap conditions occur (e.g. Khaya ivorensis, Piptadeniastrum africanum). Because of this Keay believes that in undisturbed Nigerian rainforest wind dispersed species would be less common than his figures indicate. Many wind dispersed species in other regions show similar characteristics to these.

Jones (1955-56) observes that few wind-dispersed rainforest species have really efficient dissemination mechanisms, even species such as Ceiba pentandra, with its small seeds with cottony down (kapok), producing most of their seedlings close to the parent tree. On the other hand animal dispersal appears most efficient.

Animal dispersal occurs in two main ways, either by birds, bats or, less commonly, arboreal mammals eating the fruit from the tree, or by the fruit dropping to the ground and then being distributed by terrestial animals, as happens with the cassowary-distributed seeds of Elaeocarpus grandis in north Queensland and with the squirrel- and rat-distributed fruit of Eugeissona triste in Malaya (Wong, 1959). The former of these methods is by far the more widespread, and is sufficiently efficient to lead Moore (1957) to state that regeneration under the Tropical Shelterwood System in Trinidad bears no apparent relationship to the species forming the shelterwood in the vicinity; the regeneration develops from seed either already in the ground or brought in by birds and bats which perch on the shelterwood trees. The efficiency of animal distribution is shown rather well in Puerto Rico, where the coastal species Calophyllum antillanum has been introduced into the submontane rainforests of the Luquillo Mountains. The fruit of this species is a favourite food of several birds and bats, and seedlings of C. antillanum were observed quite commonly up to 25 chains from the nearest tree of seed-producing size. Unfortunately this effective method of dissemination also accounts for the spread of such undesirable plants as the mistletoes (Loranthaceae) and the strangling Ficus spp.

TABLE 11

Seed Disperal Mechanisms, Nigeria

(Data Provided by E.W. Jones)

	Upper Storey Trees		Middle Storey Trees		Lower Storey Trees	
	No. spp.	%	No. spp.	%	No. spp.	%
Wind Dispersed	18	46%	4	9%	3	8%
Edible	18	46	32	71	29	74
Explosive	1	3	1	2	1	3
Non-Specific	1	3	6	13	4	10
Doubtful	1	3	2	5	2	5
TOTAL	39	101%	45	100%	39	100%

TABLE 12

Wind Dispersed Species on Gambari F. R., Nigeria
(on 400 x 400 ft plot, from Keay, 1957)

Life Form	No. Species	Wind Dispersed Species Number	%
Emergent Trees	16	9	56.3
Lianes (fruits borne high)	25	12	48.0
Upper Storey Trees	28	7	25.0
Lower Storey Trees	39	1	2.2
Shrubs, Treelets	37	-	-
Lianes (fruits borne low)	5	-	-
TOTAL	150	29	19.3%

By contrast, some rainforest species rely on gravity to distribute their relatively heavy seeds. Such species are often restricted to low topographic positions, as illustrated by Castanospermum australe and Elaeocarpus grandis in New South Wales, and by Eusideroxylon zwageri in Borneo. The regeneration of species such as these is usually limited to small areas around the parent trees, unless flooding causes the seeds to be more widely dispersed. Most rainforest species, however, have relatively effective dispersal mechanisms.

Germination

The seeds of rainforest species vary greatly in their longevity. Some, including most dipterocarps, lose their viability extremely rapidly. Barnard (1954) records Shorea resinanigra as having an 88% germination on collection, 92% after a week of storage and nil after two weeks. At the other extreme Gilbert (1959) produces evidence to suggest that Acacia dealbata, a species which regenerates profusely in the Tasmanian cool temperate rainforests after burning, may retain its viability for upwards of 400 years in the soil.

Most species certainly appear to germinate soon after seed fall, particularly when moisture conditions are favourable, and to retain their viability for only a short period, but exceptions to this are fairly numerous. Some species are practically viviparous and germinate almost as soon as they fall e.g. most dipterocarps, many Meliaceae, Ceratopetalum apetalum; after a good seed year the ground in the vicinity of these trees may be virtually covered by seedlings. Other species may require special treatment before germination can occur. With some animal-dispersed species, passage through the animal may provide this treatment which, if not essential, at least hastens germination e.g. Trema guineesis(Taylor, 1960); in others mechanical damage by animals to the seed coat speeds germination; Wong (1959) records this for Eugeissona triste in Malaya. Heat may provide the necessary incentive for germination in many species that require some pre-treatment. Thus R.W.J. Keay (pers. comm.) states that the palm Elaeis guineesis will only germinate when the temperature exceeds that found in the dampened-down microclimate of Nigerian rainforest undergrowth; the species thus never regenerates in mature rainforest, but is common in sites that have been the scene of shifting cultivation. Many species that are characteristic of disturbed rainforest sites behave somewhat similarly to Elaeis, though it is by no means certain that response to the increased warmth, from opening up the stand, is the sole cause of this behaviour.

It is commonly suggested that the dense growth of weed species found following disturbance of rainforest sites results from seed invasion after the disturbance has occurred, but the evidence is in fact against this. Keay (1960) collected soil samples from beneath "relatively mature parts" of two Nigerian forest reserves and allowed any seeds in the soil to germinate in a nursery at Ibadan. Both samples produced a prolific growth of seedlings, including 14 species of trees of which 10 species (and 156 individuals out of a total of 167) were species typical of regrowth forest. The most numerous of these tree species was Musanga cecropioides, whose seed is normally difficult to germinate (Jones, 1955-56; Taylor 1960). In addition to the trees, many shrubs, climbers and herbs were also represented. It is clear that most of these plants came from seed already in the soil and, from the nature of the forests where collected, it appears that much of the seed must have been in the soil for quite a lengthy period awaiting suitable conditions to germinate. Increased temperature and possibly increased light appear to be the most likely factors causing this surge of germination.

This ability for seed to remain viable in the soil for some time and then to germinate after disturbance appears characteristic of many secondary rainforest species; Acacia dealbata, mentioned earlier from Tasmania, is another example. However, species with almost the opposite characteristics also are found among the species that rely upon disturbance for their regeneration. Typical of these are those eucalypts which normally occupy rainforest sites after the rainforest canopy has in some way been destroyed, such as E. deglupta in New Britain, E. grandis in eastern Australia and E. regnans in southern Australia. Such species apparently do not remain viable for long in the soil: "eucalypt seed will germinate beneath the canopy of an undisturbed rainforest understorey .... There is, however, no survival beyond the cotyledon stage" (Gilbert, 1959). With favourable conditions of temperature and moisture the germination may be extremely rapid: during the humid summers of subtropical New South Wales, E. grandis seed will germinate within a week of reaching the soil, and in disturbed sites (burnt or heavily logged) may average one foot a month in height growth for the first few years, thus enabling this very intolerant species to keep in advance of the rampant weed growth (A.G. Floyd, pers. comm.). E. deglupta may show even faster height growth.

From this some pattern can be discerned in the germination of rainforest seeds. Species characteristic of disturbed sites commonly possess seeds which remain viable for some period in the soil, but which only germinate when the environmental conditions of the site have been altered by disturbance; germination then may be extremely rapid. These species often are unable to germinate in shaded conditions (Schultz, p.240). At the same time some species of disturbed sites (e.g. eucalypts, and many secondary species in Surinam; see Schultz, p. 224) are those with little seed stored in the ground, but which shed rather copious seed through much of the year, thus germinating and growing rapidly when conditions are favourable. This second type of behaviour is to some extent duplicated by a very important group of rainforest trees which may be termed "gap-opportunists . Like the eucalypts these are relatively intolerant trees with seed of short viability. Unlike the eucalypts, their seed production is more spasmodic, but this is countered by the seedlings being fairly persistent and able to survive, without showing any appreciable development, under quite dense undergrowth between seedfalls. If during this period the canopy is opened, say by an old veteran tree blowing over, the seedlings in the vicinity of the gap are able to make immediate response with vigorous height growth. Species falling into this group include many of the most desirable rainforest species such as many Meliaceae, Dipterocarpaceae and the Flindersia spp. Finally there is a fairly large group of species, mostly the more tolerant ones, whose seed is probably not stored to any extent in the soil, but where germination is frequently delayed and may not occur for some months after seed fall, in some cases for a year or even more (e.g. Bertholletia excelsa, Gmelina leichhardtii). Unlike the first group of pioneer species, seed from these trees may be unable to germinate in the full light of disturbed forest; G. Gilbert (quoted by Jones, 1955-56) records Guarea cedrata after 3 months as showing no germination in full light, 40% in moderate shade and 60% in deep shade. Seedlings from this last group of species tend to be both persistent and tolerant, but regeneration of them is seldom plentiful: as Schultz (p.226) points out, the wastage of seeds is enormous, the majority of the seed failing to germinate though showing a high germination percentage at the time of seedfall. Schultz records one stand of Vouacapoua americana in Surinam producing an estimated annual crop of 20,000 seeds, yet over a 3 years period 20 seedlings per year were the maximum ever observed and most of these fell victim to rodents and deer. An interesting point made by Schultz is that field germination in this and other similar species was greatly stimulated by pressing the seed into the soil or covering it with litter or soil, and Schultz suggests that this increased germination may be a response to complete shading.

Distribution of Regeneration

These classes of germination behaviour are by no means rigid, and probably in any rainforest region a list could be prepared showing a gradient from the species with seed of short viability and with highly intolerant seedlings, through those where the persistence of the seedlings is greater, to those with a relatively long period of seed viability and tolerant seedlings. The broad classes described above are nonetheless very useful in understanding the regeneration present within any area of rainforest, since it is apparent that different conditions of disturbance and canopy opening within a single stand will favour the germination and initial survival of different groups of species. The seedling species present in the regeneration will of course be determined by other factors also: the prevalence of seed trees of the various species, the efficiency of their seed dissemination mechanisms, the frequency and regularity of their seed production, the season of the year, and so on.

In some rainforest areas, particularly where the climate tends to be seasonal, the amount of regeneration present on the ground varies greatly with the season of the year: in such areas most of the seed tends to fall during the wet season when conditions are most favourable for germination, and during this season the ground may be covered with young seedlings, most of which will die during the succeeding dry season. This condition applies with such species as Mansonia altissima in the semi-evergreen rainforests of Nigeria (J. Redhead, pers. comm.), Cynometra alexandri in Uganda (Eggeling, 1947) and Araucaria cunninghamii in the "araucarian vine woodlands" of southern Queensland (Cameron, 1958), and has been observed with Cedrela odorata in the evergreen seasonal rainforest at Curuá, Brazil. With the Araucaria, Cameron states that after a heavy seed year from 4 to 17 million seeds per acre may fall, subsequently producing in the order of 1/3 million seedlings per acre, yet few of these survive the following dry spring season and the browsing of wallabies. The ensuring that a reasonable stocking of seedlings such as these survives is a major silvicultural problem in many rainforest regions; with Cedrela odorata the most successful treatment appeared to result where the undergrowth was removed shortly before seedfall, while maintaining a shelterwood of the upper storey trees (see Chapter 10).

A dense ground layer or vegetation may preclude the germination of most seed and the survival of any seedlings which do happen to germinate. The dense blanketing growth of the scrambling Gleichenia spp. in Malaya and Puerto Rico produces conditions in which seedlings are quite unable to survive, and other fern or herbaceous growth may similarly prevent seedling establishment. Browsing will also affect the survival of regeneration: when consistent heavy browsing occurs in areas with a herbaceous undergrowth, as happens in Nigeria when elephants are attracted to open patches with Palisota and Aframomum, a vicious circle may be set up, preventing the establishment of useful regeneration for lengthy periods.

There is also some evidence that the presence of one species may prevent the establishment of certain other species in its vicinity. Cannon and others (1961) found in laboratory tests that litter from Backhousia angustifolia significantly decreased the germination of Araucaria cunninghamii, though field tests failed to indicate that this "antibiotic effect" had any practical significance. In Puerto Rico the heavy-seeded Manilkara nitida usually regenerates close to the parent seed trees, but a detailed examination of regeneration, in areas where M. nitida is moderately common, provided only one instance of a seedling of this species actually growing beneath the crown of its parent tree. This seedling was most unhealthy and it is suggested that M. nitida may produce from its leaf litter or from root secretions some substance lethal to its own young.

These various factors all suggest that the composition of young regeneration in any managed rainforest area is very largely a matter of chance. Certain site conditions will favour some species over others, but within the group of species most suited to a particular site there are many chance factors which will determine which species actually occur and in what quantity and proportion.

Development of Regeneration

Once the seedlings, be they of trees, climbers, shrubs or herbs, have become initially established, chance factors again play a large role in determining their subsequent survival and growth.

Sites that have been the subject of severe disturbance, as by fire or cyclone, regenerate rapidly with species characteristic of secondary succession. These will include both species whose seed has been lying dormant in the soil and species whose seedlings are unable to survive beyond the cotyledon state, save in the presence of copious light. Many of these are species which feature prominently in secondary succession (e.g. the invasion of land after farming) or in certain imposed successions (e.g. when the frequency of fire in communities adjoining rainforest is reduced), though some of the species regenerating in recently disturbed rainforest are not found in the secondary succession on land which has been under farming for a lengthy period (.e.g. Musanga cecropiodies in West Africa). Although this type of regeneration bears so close a resemblance to secondary succession, it should not be classed as such, since it is a characteristic, if spasmodic, feature of the life cycle of most virgin rainforests.

The species found in these large gaps are of mixed botanical relationships, though in tropical rainforest the families Euphorbiaceae (Macaranga, Mallotus) and Moraceae (Musanga, Cecropia) often are prominent. Climbers are extremely well represented, and many of the species are protected by spines and thorns (many of the climbers), stinging hairs (Laportea), or myrmecophily (Barteria, certain Cecropia and Macaranga spp.). In addition, where fire has not been involved, there may be a high seedling stocking of intolerant but persistent species (the light hardwood Shorea spp. and other dipterocarps); many climbers, including such serious weeds as the Nigerian Acacia ataxacantha and climbing palms (Calamus, Anistrophyllum), also come into this category (Redhead, 1960a). Unburnt disturbed sites will also produce coppice growth from many of the smaller saplings smashed during the disturbance.

These plants all grow with great rapidity, so that in a very short time the disturbed area is covered by a sapling thicket bound together by climbers The fastest growth is shown usually by those species which possess intolerant, non-persistent seedlings. Whilst usually these occur mixed together in the developing regeneration, a single species may dominate some sites: this is shown by Cecropia spp. in tropical America, by Musanga in Africa and by Laportea spp. in Australia, and is seen more markedly on the less optimal rainforest sites, e.g. by Acacia dealbata in the cool temperate rainforests of Tasmania (Gilbert, 1959) and by Macaranga maingayi in the Malayan swampy rainforests on peat (Wyatt-Smith, 1959d). Some indication of the rate of growth of these thickets is given by Musanga, which commonly reaches a height of 6-8 ft. in its first year and has been recorded with a height of 65ft. and a D.B.H. of up to 16 inches in 9 years (Taylor, 1960).

For the first few years the thicket may be almost impenetrable, but soon the lower branches die and the stand thins out beneath, allowing entry into the young regrowth stand. In the Malayan uniform system, which aims at creating these conditions by heavy logging and poisoning, the first follow-up treatment to release the more desirable species in the thicket is scheduled when the regeneration starts to become more open beneath (Chapter 10).

Most of the extreme light-demanders which dominate this phase of the regeneration are relatively small, short-lived trees (some only shrubs), usually producing soft, light timber. Few such species survive much longer than 20 years. Most species of this type are of little economic value though a few produce desirable timbers, e.g. Ochroma lagopus, the source of balsawood, and Didymopanax morototoni, which is a favoured species for match production in Trinidad. A few of these light-demanders are much longer lived and may grow to very large size. Into this class come Goupia glabra in South America and Laportea gigas in eastern Australia. The former, which yields a valuable timber, grows more slowly than some of its associates and is often suppressed seriously by such competitors as Cecropia spp. and Palicourea guianensis, or is malformed by climbers; in silvicultural treatment some tending to release the Goupia is necessary to ensure its survival (Schultz, p. 240).

More persistent seedlings, present when the disturbance occurs, also respond to the increased light and make rapid growth, though they seldom grow as fast as the extreme light-demanders. These develop with the thicket conditions, and although many must be lost by the severe competition in the mass of regeneration, a proportion survive and tend to take over dominance of the thicket as the short-lived, but initially faster-growing, species die. As a group these are among the most silviculturally valuable species found in rainforest and they form the basis of rainforest management in many areas (Beard, 1947). They include the light hardwood Shorea spp. of Malaya, Dacryodes excelsa and Tabebuia pallida in Puerto Rico; Byrsonima spicata, Hieronyma caribaea and Tabebuia serratifolia in Trinidad; Entandrophragma spp., Khaya ivorensis, Terminalia spp., Triplochiton scleroxylon and Chlorophora excelsa in West Africa; and Flindersia spp. in north Queensland. Some of these species, e.g. Tabebuia spp., Triplochiton and Chlorophora, barely qualify as persistent, the seedlings being unable to survive if the shade is at all heavy, but their subsequent growth is similar to that of the more persistent species. These species show a rapid response to increased light and, although they may have existed as small seedlings for a number of years in the undergrowth, they retain the capacity to commence height growth almost immediately conditions become favourable, some Shorea spp. even keeping pace with the most aggressive secondary species. Triplochiton suffers serious malformation if its terminal shoots do not get sufficient light and "this, no doubt is the cause of some of the monstrosities seen in the forest, which have had a struggle to get to the light" (Taylor, 1960). By comparison Chlorophora, though a strong light-demander, requires some shading till it reaches a height of about 12 ft if it is not to be retarded and malformed by the attack of the gall-forming Phytolyma lata.

The persistent species, including many climbers, typically have seedlings which can survive in the undergrowth between successive seed crops. With many of the species (e.g. Terminalia ivorensis) the seedlings need not survive longer than a year, but with some species, including most dipterocarps, the seedlings must be able to persist for up to 10 years. Richards (p.45) notes that with the Shorea spp. very few seedlings survive longer than 2 years. This may be correct in absolute terms of the viable seed produced during a seed year, but there is ample evidence that a very large number of seedlings do persist to produce a constant reservoir of regeneration on the ground.

Nicholson (1958a), in North Borneo, found that there was a minimum stocking of 4000 recent dipterocarp seedlings per acre in virgin forest, and that the stocking of such dormant seedlings averaged about 10,000 per acre over a long period. Barnard (1956) has studied the stocking, survival and growth of seedlings of economic species over a 5 years period in virgin equatorial rainforest in Malaya. On a transect of 27 milliacre quadrats, with 10 seed-producing trees within 33 ft of the transect, the density of economic seedlings was never below 2300 per acre and reached a peak of 29,800 per acre immediately after a heavy seed fall towards the end of the observation period. During the whole period there were never more than 5 quadrats bare of economic seedlings at any observation, and 60% of the milliacres which carried seedlings as a result of a seedfall at the start of the study were still stocked with regeneration from this initial seedfall 5 years later. The growth of these seedlings was, however, very slow, only one Shorea spp. exceeding 12 inches in height. Some other Malayan figures of the small regeneration in untreated rainforest are given by Wyatt-Smith (1960b). (See Chapter 10 also).

The southeast Asian rainforests with their dominance of dipterocarps may give a somewhat exaggerated picture of this reservoir of dormant regeneration in climax rainforest, but figures from other regions give not dissimilar results. E. Volck (pers. comm.), in north Queensland, found 38% of milliacre quadrats contained seedlings of economic species under 1 ft in height, and a further 30% contained seedlings between 1 ft and 10 ft high, while Redhead (1960a) in Nigeria, found that 42% of milliacre quadrats contained economic species from seedlings size up to 20 inches D.B.H., but mostly under 3 ft. in height. These figures include not only persistent seedlings but also seedlings of other classes.

The seedlings of the persistent class differ considerably in their degree of persistence and in their tolerance to shade. Some, such, as Triplochiton and Chlorophora, are not very different in their behaviour from the secondary species discussed earlier, while others, e.g. Dryobalanops aromatica (and possibly all species of this genus), fall almost into the class of truly tolerant species, being able to make slow growth under very shaded conditions. They can, however, usually survive in some quantity between successive seedfalls and, if in the meantime light conditions are suddenly increased, they are able to respond rapidly to the improved growing conditions. This response can occur in openings much smaller than is required by the secondary species, and the extent of the response varies with both the size of the opening and the degree of the increase in light. Most species respond well to complete opening, but tend to lag behind the secondary species which appear in such openings; their potential growth is depressed by the competition, but their persistence enables many to survive in the thicket and to assume dominance as the short-lived secondary species die. Some Shorea spp. can in fact compete successfully with the secondary growth, leading Barnard (1954) to conclude that this ability "appears to be an important part of the biological equipment of many top storey rainforest trees". Species so equipped are however relatively rare outside southeast Asia. On the other hand, some persistent species cannot tolerate sudden exposure to full light, a feature shown by Dryobalanops aromatica in Malaya and of considerable importance to its silviculture (Chapter 10). Nicholson (1960), in shade house experiments, found that 5 species of dipterocarps, including the apparently strong light-demander Shorea leprosula, showed better survival and initial growth under partial shade than in complete light, though after the first year plants in the open were growing at a faster rate than the shaded plants. As Nicholson stresses, however, in the field the increased root competition associated with shading depresses the growth of the seedlings to the advantage of those in the open.

Species with truly shade-tolerant seedlings differ only in degree from the less tolerant, persistent species. Whereas the persistent seedlings belong largely to upper storey trees and climbers, the tolerant seedlings include also lower storey trees and understorey shrubs, but exclude climbers. As shown previously these species often suffer heavy seed wastage, but the seedlings which become established, usually in shady conditions, may survive for very long periods making only slight growth. Schultz (p. 238) observes that in Surinam these species also respond to improved light conditions, but the response is usually less vigorous than with the classes of seedlings discussed earlier. Some may indeed be at least temporarily checked in their growth if they suddenly face strong daylight, as shown by Ocotea rodiaei in British Guiana where, particularly outside the optimum sites for this species, plants less than 6 ft high die if exposed suddenly to full light (Fanshawe, 1952b). However, if the light conditions above the Ocotea seedlings are gradually increased they can soon tolerate full daylight and make rapid growth. Dryobalanops also behaves in this fashion.

Some idea of the tolerance of species in this class and of their ability to respond after long suppression is given by Kirkland (1961), who records a pole stand of Nothofagus fusca in New Zealand resulting from the logging of a virgin stand. Ring counts showed that one stem in the new crop had been over 100 years old at the time of logging; it then had a diameter of 3.2 inches at the stump and had averaged 62 rings per inch while growing in the understorey. In the 12 years immediately following logging its growth rate increased to 4.4 rings per inch. This ability to persist for long periods with very little growth, and then to respond rapidly to improved environmental conditions, is one of the most important physiological characteristics of rainforests plants, and it appears to be shared to a greater or lesser extent by the majority of trees and vines other than those which behave as species in a secondary succession.

Size Class Distribution

As discussed in earlier chapters the stocking of virgin rainforest communities varies considerably in the different sub-formations. Basal area, for example, may average less than 100 sq ft per acre in some semi-evergreen and montane rainforest stands, and it may exceed 300 sq ft per acre in some cool temperate rain-forests. One 8 acre plot of cool temperate rainforest in northern New South Wales averaged 370 sq ft per acre, and one two-acre sub-plot within this carried 840 sq ft (420 sq ft per acre), an exceptionally high value for any community (I.P. Burgess, pers. comm.).

Within these communities the trees typically show a J-shaped size class distribution, the smaller size classes being represented by increasing numbers of stems (see Table 5). This type of distribution is shown not only by all stems, but also by the majority of species. Trees of the lower storeys very characteristic-ally have this logarithmic type of size-class distribution, and it is also shown by many of the overstorey trees (Schultz, p.218); indeed in the Mapane region of Surinam the only important species not exhibiting this type of distribution was Goupia glabra.

In West Africa, however, a number of the more important overstorey species show different types of stem-class distributions and in Nigeria Jones (1955-56) has recognised three categories of these trees based on their size-class distribution:

1. Those where the smaller size classes are almost or completely absent, the trees present being mostly large trees in the overstorey.

2. Those where the number of small girth trees still in the under-storey is considerable and usually exceeds that in the overstorey, but where there are few or no intermediate sizes present.

3. Those where the numbers of trees in the middle size classes are intermediate between the numbers of the large trees in the overstorey and of the small trees in the understorey, or at least not much less than the number in the uppermost storey.

Category 1 are the strong light demanders which only regenerate after exceptional disturbance. From Jones's figures they include Alstonia boonei and Ricinodendron africanum, and Jones suggests that such species as Ceiba pentandra and Triplochiton scleroxylon also belong in this category; these latter two are poorly represented in the plot studied by Jones. In Category 3 are the more shade tolerant species, such as Lovoa klaineana and Guarea cedrata; these are approaching the J-shaped type of distribution, though even here there is a tendency for fewer middle sized trees than might be expected. Category 2, which takes in such important species as Khaya ivorensis, Terminalia superba and probably the Entandrophragma* spp., appears to represent species which are relatively light-demanding, but capable of tolerating some shading in

*The figures given by Jones place Entandrophragma spp. in category 3, but Jones believes that this may be due to past commercial cutting of a selective nature removing most of the larger size classes.

their younger sizes. These three categories clearly are similar to the three main classes recognised from their regeneration behaviour.

Apart from the first of these categories, which have rather specific requirements for regeneration and which have been recorded by Aubreville (1938) as the trees "ne font jamais des petits", Jones considers that there are enough seedlings of most overstorey species to maintain the present number of mature trees, provided sufficient numbers of these escape out of the lower storeys of the forest. The deficiency in the middle size classes suggests that this escape may not be occurring in category 2, and Jones advances two possible explanations for this deficiency. The stems of these species may represent two populations, "a population of young which are constantly being recruited but which rarely contribute to the older population and an old population of mature individuals in which the wastage is not being replaced continuously but only occasionally when specially favourable conditions permit some of the many saplings to grow up". Alternatively recruitment to the middle size classes (say 12 inches to 24 inches D.B.H.) may be occurring, but accompanied by a sudden increase in growth rate which carries the stems rapidly through these size classes so that the number of stems present in them at any time is low. A study of growth rates indicates that the second alternative is only partially applicable, so Jones concludes that in many cases discontinuous recruitment must be occurring. Nicholson (1957) has suggested a third possibility which he favours, and that is that only a small number of recruits are necessary to maintain the canopy of virgin forest, and these grow rapidly when released. On the other hand, Gilbert (1959) records a large gap in the middle size classes (8 inches to 24 inches D.B.H.) of Nothofagus cunninghamii in Tasmanian temperate rainforest. He believes this to be part of a cycle of varying success in regeneration establishment, the gap in the size classes representing (by ring count) a gap of 200 years in successful regeneration.

Growth in the Climax Forest

G.G.K. Setten (pers. comm.) has aptly described the growth of climax rainforest as a study of "dynamic stagnation". The very definition of climax forest indicates that this must, in broad terms, be so. The environmentalconditions of any site are only capable of supporting so much growth from the native species present (though a greater total growth may be produced by some exotics on the same site). Possibly the best expression of this growth is basal area (B.A.) production, which bears a fairly direct relationship to the amount of cellulose produced on the area over any given time. This B.A. production also shows a variable relationship with the B.A. already standing on the site, since the latter value reflects rather closely the extent of root and light competition in the area. When the standing B.A. is low, for example during the early stages of invasion into a recently cleared site, B.A. increment tends to increase linearly with the B.A. already produced: the individual trees are unable to utilise fully the site. However as competition becomes greater the B.A. increment levels off, and for what is usually quite a wide range of standing B.A., the rate of increment shows little variation. Finally, at some upper level of standing B.A., the increment decreases until, in a fully stocked virgin stand, the nett B.A. increment averaged over a number of years is nil. This last condition is the one which can be expected to prevail over the greatest part of any virgin stand, and as shown previously, the B.A. corresponding to this fully stocked condition may vary from less than 100 square ft per acre to over 400 square ft per acre in different types of rainforest.

Although in the fully stocked stands there may be no nett increment over a period of years, growth plots established in virgin stands show that with few exceptions the individual trees are increasing in diameter (and hence in B.A.) each year, albeit very slowly in most cases. This leads to a slow increase in total B.A., which is negated by the death of trees within the plot. In favourable years there may be little mortality and the total B.A. will rise, but inevitably there comes the year that is drier than usual or when the winds are slightly stronger than usual, causing death and a reduction in B.A.: thus the upper limit of B.A. in rainforest fluctuates, but barring some wholesale calamity such as fire or cyclone, the fluctuations are relatively limited.

This constant balance between growth and death is shown well by a plot (TS3) in the submontane rainforest of the Luquillo Mountains, Puerto Rico, established and maintained by the Institute of Tropical Forestry. When established in 1946 this one acre plot contained 366 stems greater than 4 inches D.B.H. Ten years later the stocking was still 366 stems per acre, but in the meantime 48 of the original stems had died and had been replaced by an equal number of recruits growing to above 4 inches D.B.H. The plot had thus averaged 1.3% mortality in stems over 4 inches each year, a figure similar to that suggested by Jones (1955-56) in the Nigerian evergreen seasonal rainforest. B.A. increments from the Puerto Rican plot are not available, but from this and other similar plots Wadsworth (1957) records a gross volume increment of from 35 cubic ft to 60 cubic ft per acre per annum, and a nett volume increment of 24 cubic ft to 50 cubic ft per acre, over a short period of years. Wadsworth considers that these nett values are probably typical of the increment obtained in this forest between cyclones, which appear to be the major cause of tree mortality in the area.

Individual trees in a rainforest stand show great differences in their rate of growth. Baur (1959), studying the results of 12 years' measurements in a lightly logged stand of Ceratopetalum apetalum, found that the average diameter increment over the full 12 years was 0.81 inches (periodic annual increment of less than 0.07 inches). Because of its previous logging it might be expected that the growth differences between trees would be evened out in this plot, yet at one extreme one stem had made no diameter growth over the 12 years and 17 stems (out of 175) had grown less than 0.1 inch in diameter, while at the other extreme 8 stems had grown more than 2 inches with the fastest having increased in diameter by 2.75 inches (P.A.I. 0.23 inches). Over the whole plot there was a tendency for the larger trees to show faster diameter growth than the smaller ones: the average P.A.I. for trees of 2 inches D.B.H. (determined by a modification of the method described by Osmaston (1956)) was less than 0.03 inches, whereas 12 inch trees had an average diameter P.A.I. of 0.10 inches. However in any size class there was great variation in the rates of individual trees, e.g. the 17 trees in the 10 inches to 12 inches D.B.H. class at the start of the period showed the following range of P.A.I.:

P.A.I.				Number of Stems
0" -0.03"	..	..	..	1
.03"- .07"	..	..	..	3
.07"- .10"	..	..	..	4
.10"- .13"	..	..	..	4
.13"- .17"	..	..	..	1
.17"- .20"	..	..	..	3
.20"- .23"	..	..	..	1

This variation in the rate of growth of trees of similar size in rainforest is now widely recognised (Dawkins, 1956; Keay, 1961). Various explanations have been advanced to explain the cause of the variation and the problem is currently receiving intensive study (H.C. Dawkins, pers. comm.*). In the plot of Ceratopetalum the faster growing stems were mostly trees with well developed crowns growing under good light conditions. R.W.J. Keay (pers. comm.) has noted a strong correlation between crown conditions and diameter increment for Sterculia rhinopetala in Nigeria, the P.A.I. for trees of different crown types being of the following order:

Crown				Diameter P.A.I.
Broken	..	..	..	0.003"
Poor	..	..	..	0.03"
Fair	..	..	..	0.08"
Good	..	..	..	0.16"
Excellent	..	..	..	0.32"

Keay has also found that climbers in the crowns of trees have a depressing effect on growth rate. In Puerto Rico Wadsworth (1947a, 1952b) has shown that crown position significantly affects the growth rate, but that following logging the diameter increment accelerates. From these observations certain factors can be suggested as influencing the growth rate of individual trees: size class, crown condition, crown position, crown impedence and forest stocking. These are probably only a few of the factors causing the variability in growth rate.

As well as this individual variation between trees, there may be appreciable variations in growth rate within a tree during the course of a year. In the temperate rainforest of Tasmania and New Zealand this results in the trees producing clear annual growth rings from which stem analyses can be made (Gilbert, 1959; Kirkland, 1961). Lowe (1961), using an iodine staining technique which may have considerable application for determining increments in trees from a tropical seasonal climate, has shown that Triplochiton scleroxylon in Nigeria grows actively for only about 5 months of the year, with trees from the drier areas growing more slowly than those from the wetter forests. Dawkins (1956), working in Uganda with Lovoa brownii and Entandrophragma angolense, has found that diameter

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* See also recent paper by this author: H.C. Dawkins (1963) "Crown Diameters: Their Relation to Bole Diameter in Tropical Forest Trees". Comm. For. Rev. 42(4), 318-333.

growth is strongly correlated with rainfall, provided the tree is in full leaf and not flowering. He has also noted that during dry periods the trees can shrink appreciably, by as much as 0.03 inches in a week and 0.13 inches in 10 weeks. Dawkins obtained these results by using his 10-ring method of obtaining diameter measurements which are accurate to within 0.01 inch. Very similar results have been obtained by Schultz (p.234) in Surinam, where diurnal shrinkage was also encountered.

The average annual diameter growth in virgin rainforest tends to be slow*. Baur calculated that over 200 years were required for Ceratopetalum to increase from 2 to 20 inches D.B.H. on the average, while Wadsworth (1951) gives 160 years as the average period for a tree to reach 12 inches D.B.H. in the submontane rainforest of Puerto Rico, and 230 years in the montane rainforest. Faster rates are given by Keay (1961) from Nigeria, where the period for a tree to grow to 30 inches D.B.H. (8 ft girth) varies from about 180 years for Lophira alata down to about 40 years for Triplochiton. The immense variation in the growth rate of individual trees of the one species and of similar size however means that, if the faster individuals can maintain their rapid growth throughout their life, the period to reach a given size is considerably decreased. On this basis Baur (1959) states that the faster individuals of Ceratopetalum could grow from seed to 20 inches D.B.H. in 130 years, and in odd cases in 100 years, compared with the average 220 years to reach this size from a sapling. Similarly Keay notes that the faster individuals of Guarea cedrata are capable of growing to 30 inches D.B.H. in 79 years, instead of the average period of 149 years. In practice it must be doubted whether trees, other than some with the characteristics of secondary growth, would ever be able to show such rapid growth consistently through their life in climax forest; more likely is it that after a period of rapid growth they are checked by crown competition or some other cause and revert to a slower rate until some chance circumstance relieves them of the impedence. Under these circumstances the growth of the trees which are most likely ultimately to become part of the upper canopy lies somewhere between the theoretical maximum and the stand average. Against this, in properly managed rainforest where liberation treatments and thinning are regularly carried out, there is every reason to expect that the final crop trees should show growth rates in the order of the maximum throughout their life; the average growth rate of any species in virgin forest is scarcely comparable with its growth in managed forest, and evidence to support this is provided from such areas as the New Zealand Nothofagus stand discussed by Kirkland (1961) and the Trinidad series of thinning plots summarised in Table 39 (Chapter 10).

Despite the considerable variation in growth shown by individuals of one species, most species show a strong tendency for the average diameter growth to vary also with size. These growth trend curves for Ceratopetalum in New South Wales (Baur, 1959), and for 10 species in Nigeria (Keay, 1961, Table 1) are shown in Fig. 28, and similar curves from Surinam are given by Schultz

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*There is a popular misconception that this is not so, doubtlessly based on the undoubtedly very fast growth of a few species under ideal conditions. Dr F.H. Wadsworth (pers. comm.) recalls that when the first results from virgin growth plots in Puerto Rico were obtained, instructions were received to check all measurements since such slow growth could obviously not be correct in tropical rainforest!

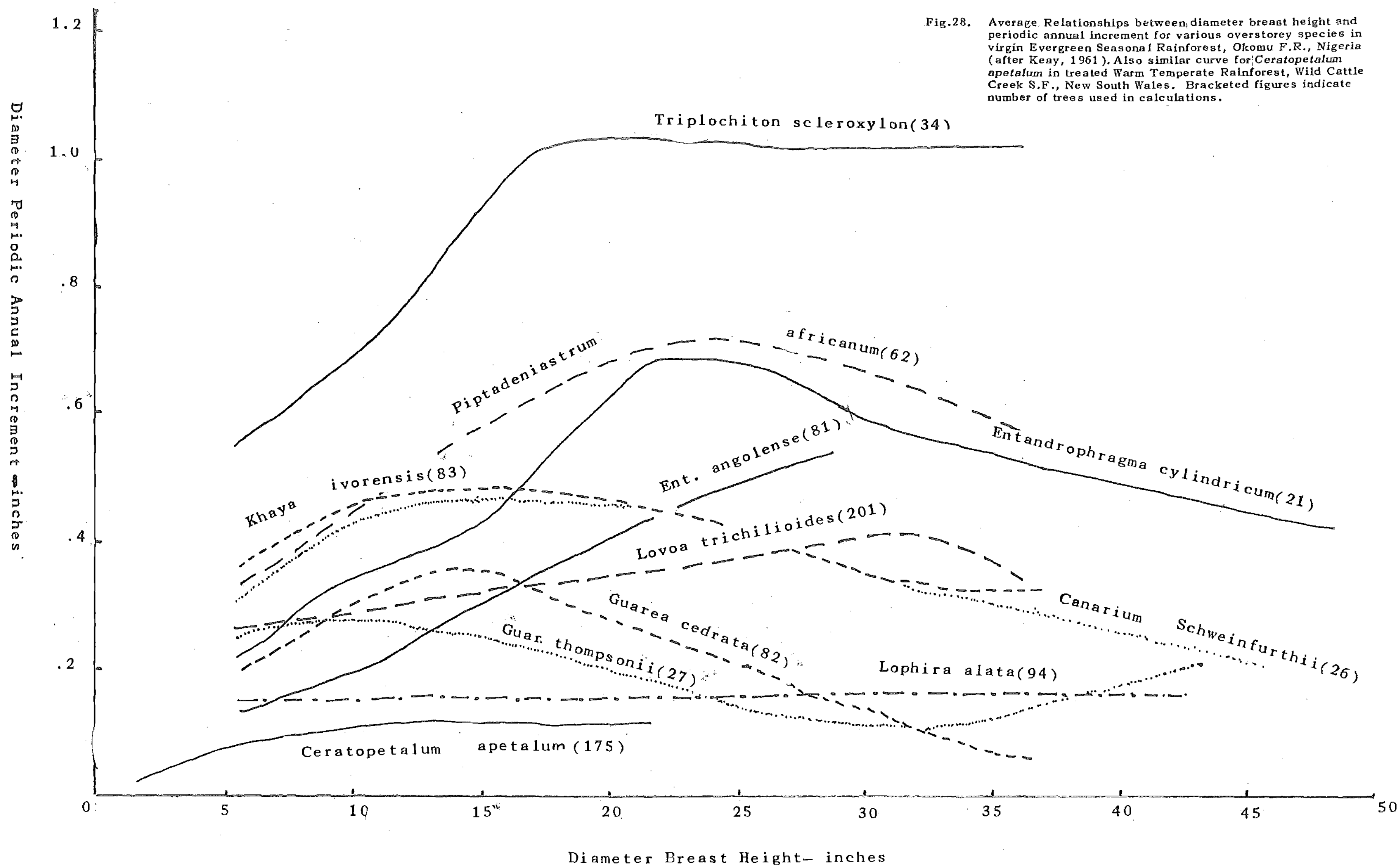

Fig.28. Average Relationships between diameter breast height and periodic annual increment for various overstorey species in virgin Evergreen Seasonal Rainforest, Okomu F.R., Nigeria (after Keay, 1961). Also similar curve for *Ceratopetalum apetalum* in treated Warm Temperate Rainforest, Wild Cattle Creek S.F., New South Wales. Bracketed figures indicate number of trees used in calculations.

(Figs. 66 and 67). Keay notes that "these varying growth rates appear to be real and it would seem most misleading to lump all girth classes and give a single P.M.A.I. for each species, or even groups of species". As shown by Schultz (Fig. 67) the growth rates will also vary on different sites, and may even show a different trend (e.g. Dicorynia guianesis) on different sites. The typical pattern of growth is for a slow initial diameter increment, increasing as the trees become larger until a maximum value is attained, and then decreasing in the still larger trees. The individual species however show great variation within this general pattern, and even away from it. In some the maximum value occurs only at a very large diameter, so that in the range of diameters normally encountered the P.A.I. curve shows a gradual increase with size (e.g. Entandrophragua angolense in Nigeria, Ocotea rubra in Surinam). Others attain the maximum value but then show little decrease, so that the larger stems, over a wide range of diameters, are growing at a fairly even rate (e.g. Triplochiton and Lophira in Nigeria, Dicorynia guianensis in the Upper Coesewijne forest of Surinam). Many show the more general pattern of rise and then fall, with the peak increment spread over quite a wide range of diameters (e.g. Khaya ivorensis), but in some the peak increment is maintained over a very limited diameter range, with a sharp rise on the one side and fall on the other (e.g. Entandrophrogma cylindricum and Guarea cedrata in Nigeria, Simaruba amara and Dicornynia in the Mapane forest of Surinam). Jones (1955-56, Fig. 5)) shows that with Lovoa klaineana the faster growing trees show this sharp peak of maximum increment, though averaged over all stems the peak is maintained over a wide range of diameters at a much lower value.

This general pattern of diameter growth goes part way to answering the problem of the missing middle size classes, though as Jones stresses it is insufficient to account entirely for the deficiency in the middle size classes found commonly with many of the more important species in West Africa. However where continuous recruitment of a species is occurring it is to be expected that there will be a build up of stocking in those size classes where increment is low, since it will take an appreciable period for any stem to pass through these classes, and conversely relatively few stems will be found at any time in the size classes where growth is rapid since they pass quickly through these classes. With continuous recruitment a regular series of age classes should occur (diminishing in number of stems with age as mortality takes its toll), but because of the differential growth rates the age classes are not synonymous with size classes. For example Keay's figures for Entandrophragma cylindricum (Keay, 1961, appendix A) show that an average stem takes about 18 years to pass from 1 ft to 2 ft girth (4-8 inches D.B.H.), or from 6 ft to 9 ft girth (23-34 inches D.B.H.), or from 12 ft to 14 ft girth (46-53 inches D.B.H.). Excluding mortality one would therefore expect to find for every 2 stems in a central 12 inch girth class (say 7-8 ft.), 6 stems in the 1 ft to 2 ft class and 3 stems in, say, the 12 ft to 13 ft class; allowing for mortality one would expect even more stems in the smaller size class and fewer in the larger.

The discussion on growth has been largely confined to the diameter growth of the economically important upper storey trees. Virtually no data is available on the growth of understorey trees, *

*Brown (1919) records the growth of two understorey species from rainforest in the Philippines, and this is discussed by Richards (p.47). As might be expected these tend to show slower growth than overstorey species.

and relatively little on other growth criteria, such as height, basal area or volume. Where a species shows a reliable diameter-height relationship (and this is commonly the case until a tree reaches its usual canopy layer and makes little further height growth), it is possible to use the rate of diameter increase to indicate height increment. Baur (1959) has used this approach for Ceratopetalum and found that, in contradistinction to the diameter increment (see Fig. 28), height increment was at maximum during the early growth of the tree: the greatest height P.A.I. with this slow growing species (0.43 ft.) was attained on stems between 8 inches to 10 inches D.B.H. though stems of 2 inches D.B.H. showed only slightly slower height growth. Above 10 inches D.B.H., when the trees averaged 78 ft in height, height growth fell off rapidly. This picture of fast early growth, reaching its peak well before the maximum diameter increment is attained, is probably characteristic of most upper storey rainforest trees.

Basal area increment can be calculated from the diameters, but despite B.A. growth probably being of greater theoretical significance in understanding growth patterns, and despite its almost linear relationship to total wood volume growth, the cumbersome calculations involved appear to lead to a general neglect of this growth attribute. Baur has touched on it with Ceratopetalum and found, surprisingly, that the percentage increase in B.A. was greater in the smaller size classes: over a 12 year period the B.A. of trees initially in the 2 inch to 4 inch D.B.H. class increased by 43%, while at the other extreme the B.A. of trees in the 16 inch to 21 inch class increased by only 13%.

Merchantable volume increase is very much dependent on local standards of utilisation. Keay (1961) states that under present methods of working in Nigeria no merchantable timber is produced until the D.B.H. reaches 24 inches, and thereafter the volume increment shows a rise up to at least 48 inches on virtually all species: a falling diameter increment is therefore not necessarily associated with diminishing volume increment.

Mortality

All trees must ultimately die, and the mortality in virgin forest is an important phase of the rainforest life cycle. This mortality is a continuous affair. Much of the viable seed produced is eaten or rots before it can germinate; the young seedlings suffer heavy loss until such time as conditions are suitable for them to assume height growth; saplings may be browsed until they die, or a falling limb or tree from above may smash them: competition for light and moisture and nutrients takes its toll in the developing trees; mechanical damage, such as the tusking of an elephant or the bruising of a falling tree, allows entry by fungi and insects which weaken the tree until it can no longer compete with its associates; fire or strong wind may cause wholesale destruction over areas of varying extent; and to the minute proportion of trees which survive all these and other hazards there is apparently, as with all organisms, some physiological limit which finally causes death through old age.

Death from old age determines the longevity of any species. With some secondary species the longevity may be very short: Taylor (1960) suggests that 10 years is the normal maximum life for Trema guineesis in Ghana and 15-20 years for Musanga cecropioides though favoured plants may survive possibly twice this long. For longer lived trees it is almost impossible to give reliable values except in those occasional species (mostly from temperate rainforest) which form annual rings. Gilbert (1959) in Tasmania gives the maximum age of Nothofagus cunninghamii at about 500 years and of Atherosperma moschata at about 250 years, though occasional individuals probably exceed these life spans. With trees in the tropical rainforest, estimates of maximum age are usually based on extrapolation from growth studies such as those discussed in the previous section, and these extrapolations may be far from the truth, particularly if the successful overstorey trees in any stand have in fact shown well above average growth for most of their lives. In the case of very large trees, such as the 34 ft girth (11 ft D.B.H.) tree of Entandrophragma cylindricum recorded by Obaseki (1960), radio-carbon dating may be able to provide at least some idea of the order of the age.

The heaviest mortality doubtlessly occurs during the seedling stage, but once a plant assumes active height growth it still faces heavy odds against reaching maturity. Figures from Nigeria and Puerto Rico suggest that for stems larger than 4 inches D.B.H. the average mortality is about 1% of stems each year, with the greater proportion of these coming not from trees in the overstorey but from the smaller and immature trees. For trees which do reach the overstorey it seems that strong winds are the major cause of tree destruction in most areas, destroying not only trees weakened by disease and old age, but frequently also sound trees. Winds are stated to be the main cause of trees falling in parts of British Guiana (Whitton, 1962) and are undoubtedly a major cause in such cyclone belts as the Caribbean, North Queensland and Mauritius. Dead trees, often blown out by the roots, are a feature of the ground layer in most rainforest areas, and the root mounds which remain long after the tree has rotted contribute to the uneven microrelief which is characteristic of many rainforest sites. The incidence of dead stems on the ground in one stand is shown in Fig. 10.

Even where the tree dies standing from some other cause, it will normally blow over in time as the trunk is weakened by rot, borers and termites. Such trees may lose most of their limbs before they finally fall, so that the falling stem itself causes relatively little damage. However, the limbs, which contrary to common belief do not fall with noticeable gentleness from a dead tree, may cause considerable damage to plants beneath: in Nigeria large, standing, dead trees are commonly surrounded by a circle of smashed and broken vegetation which is very favourable to the development of climber tangles. Even quite large trees growing beneath a dead or dying giant may have their crowns seriously damaged by falling branches, and as a result their growth rate is decreased and they in turn are liable to be further weakened by fungal and insect attack (evidence from 13 year's progress of Nigerian P.S.P. 81 on Gambari F.R.; R.W. J. Keay, pers. comm.). Smaller trees, in falling or dying, cause proportionately less damage than do large ones.

Where a mature living tree blows over the damage may be very great over an area of up to an acre. Not only does the falling tree smash down most of the vegetation in the path of its crown, which may be very large in some cases, but smaller trees in its line of fall will also break off or push over, extending the area of damage as they repeat the process on a smaller scale, while vines interlaced in the crowns of neighbouring trees will pull and tear, bringing down still more trees and destroying all or part of the crown of others. During severe cyclones, particularly in areas where such storms are rare and the vegetation not resistent to them, such damage may extend over much larger areas: a tropical cyclone of unusual severity in 1954 virtually clear-felled 200 acres of subtropical rain-forest on Yabbra State Forest, in northern New South Wales, (Baur, 1957); similar storms long past appear to account for some of the grassland clearings found surrounded by rainforest at high altitudes in New South Wales and also for some of the extensive areas dominated by large, overmature trees of Laportea gigas elsewhere in eastern Australia; while the very severe Kelantan storm of about 1883 caused similar havoc over an even larger area of northeastern Malaya (Browne, 1949).

Once on the ground the time taken for a stem to decay and disappear varies with a number of factors. Whitton (1962) comments on the greater number of logs on the ground in temperate rainforest compared with tropical rainforest, but this is surely accounted for by the much slower decay under the cool, temperate conditions rather than by a manifestation of higher mortality in temperate rainforest. Within tropical rainforest some of the more durable species remain intact for long periods while very soft, non-durable species such as Terminalia superba may disappear in a couple of years. Whitton notes that initial decay, which is mainly due to fungi, is relatively slow but that as termites and the roots of other trees penetrate the log its final destruction is rapid. Some species, if blown over while still alive, can produce a line of coppice shoots along the trunk and these may ultimately produce a line of independent trees: Whitton records this for Dimorphandra davisii in British Guiana, while the field notes on the Nigerian Etemi Inviolate Plot (SNR1) contain observations on this same phenomenon by the late A.P.D. Jones, who records Triplochiton scleroxylon and Cordia platythyrsa as producing such "tree lines". Probably more commonly the later stages of decay in a log provide a rather favourable seed bed from which a row of even-aged trees may finally result.

Trees isolated by the destruction of forest around them are particularly prone to early death. Ceratopetalum apetalum is so vulnerable to exposure that the only possible form of silviculture, if immature stems are not to be wasted, is a selection system (Baur, 1962b). Wyatt-Smith (1954b, 1960d) has traced the mortality of trees left standing in a Malayan area that was cleared for farming and then allowed to revert to forest. Excluding 11 trees that were subsequently illegally felled, 63 trees remained after the initial clearing and 14 years later these had been reduced to 24; 14 of the others had blown over and 25 had died from other causes, mostly in the first few years after clearing. Some species however seem quite immune to sudden exposure: in Nigeria Chlorophora excelsa is commonly left in areas cleared for bush fallow agriculture, either for religious or potential utilitarian purposes, and appears to thrive upon such treatment.

The Pattern of Growth in Rainforest

Previous sections have considered the processes of regeneration, growth and mortality in rainforest, and these can now be woven together to describe the general pattern of growth in an area of virgin rainforest. This broad pattern of the rainforest's life cycle varies to some extent in different areas and may be considerably upset by unusual biotic disturbance, such as the relatively recent arrival or evolution of a particularly aggressive species (e.g. Mora excelsa in Trinidad) or the introduction of destructive animals into a previously protected forest region (e.g. deer and possums in New Zealand). However, in most areas the trends to be described can be recognised.

If a smallish area of rainforest which has not suffered any extensive disturbance for a long period is selected, we can expect to find an overstorey of large trees, most of which tend to be light demanders through most of their life. Beneath these are one or more lower storeys which contain both smaller individuals of overstorey trees and mature trees of lesser stature. Large climbers are present in the upper canopy; epiphytes occur on the trunks and branches; shrub layers and in places a herb layer are found in the undergrowth; while on the ground are seedlings from these various life forms, some from the more tolerant species growing slowly in the gloom. In addition some viable but ungerminated seed can also be expected in or on the soil.

Competition is severe and mortality among the seedlings is high, but seedlings or viable seed of most species in the vicinity, and even from some distance away, can usually be found on the ground, although the quantity will vary seasonally and with the length of time since the last seed year.

Mortality is also occurring in the higher layers. In the lower tree storeys competition for light and moisture and nutrients and, for the smaller sized species, old age are causing deaths. These trees die gradually: the crowns become sparse and die branch by branch, while fungi and insects enter the dead limbs, further weakening the tree and promoting the decay of the dead wood already present. The dead branches, rarely of any size, fall to the ground without causing appreciable disturbance and in time the dead trunk collapses, again causing little disturbance. Because the process is gradual neighbouring trees of about the same size benefit equally gradually and their growth rate increases until they again come into full competition with each other and the process is repeated, often stimulated by the drier than average year when competition for moisture is at its greatest.

In the uppermost storey different influences are acting. Here the trees are large and their crown spread is often considerable. Competition applies here too, but it is not as critical as at lower levels in the community, though it doubtlessly contributes to the aging of the trees. The trees are frequently already suffering some attack by fungi and insects, and the trees in this layer are clearly headed for death by old age. Three different things can now occur.

Firstly one of the trees may die gradually of old age: trees in this condition are shown in the profile diagrams of Fig. 9 (Shorea macroptera) and Fig. 10 (S. leprosula). The stages of death are similar to those in the smaller trees, but with two important differences: neighbouring trees of similar size are rarely so vigorous that they can benefit fully from the death of the tree, and the trunk and limbs of the dying tree are sufficiently large that when they fall, as ultimately they must, the damage in their path will be more than slight. Trees beneath the dying veteran, particularly species which reach maturity in the overstorey, could be expected to benefit most by its death, but these are likely to be in the way of the falling branches: their crowns will be severely damaged and as shown this will greatly reduce their capacity for growth and may weaken them sufficiently to cause their own death in the fairly near future. Smaller stems will also be severely damaged by the falling limbs and ultimately falling trunk, though some of the smaller stems will survive with little or no damage. Thus the death of the veteran, even when it occurs gradually, leads to the creation of a small gap. This is usually not large enough for true secondary species to appear, nor for the more shade tolerant species to be at a disadvantage due to excessive opening, but it is large enough that most of the light demanding but relatively persistent seedlings can respond immediately, along with climbers whose seedlings have also been persisting in the undergrowth. A thicket of regeneration develops, overtopped in places by those larger stems which survived the disintegration of the veteran, but usually over much of its extent dominated by the faster growing seedlings and saplings and with the slower and more tolerant species coming on beneath these: the single overstorey tree has been replaced by a small, even-aged group of regeneration whose species composition is probably rather similar to that of the older stand whose place it takes.

The second happening, probably no less common than the first, is that the dying veteran, weakened by stem rot or a senile root system, blows down during a storm. This results in much more severe destruction over a larger area and produces a gap of appreciable extent. Into the centre of this, where light is strongest, true secondary species may appear; at the edges the more tolerant species can survive; while over most of the gap the light demanding but persistent species are able to respond. Again an even-aged thicket of regeneration replaces the veteran and those smaller trees which, in falling, the veteran has destroyed, but the composition of this regeneration over much of the opening will be different from that where the big tree dies gradually: short-lived, and occasionally long-lived, secondary species are now present.

The third possibility is that some extraordinary calamity, such as a severe cyclone, will flatten an extensive area of rainforest. This will normally regenerate with typical secondary species, including numerous climbers, while again the more persistent seedlings will also respond and grow with or between the faster secondary species, taking over from them as they complete their usually short life cycle and die.

Not always is the regeneration obtained as easily as might be inferred above. Some areas of apparent cyclone destruction in New South Wales have reverted not to rainforest, but to grassland. Fire in the debris of the destroyed stand probably contributed to initial entry of the grass, but the subsequent invasion of the grassland by rainforest has been greatly hindered by the incidence of frost in these large clearings (see Fig. 3): in smaller clearings frost is less of a hazard. In Nigeria the picture is complicated by the past history of agriculture, which has resulted in most of the high forest being late stages in a secondary succession on to the formerly cleared land, and by the presence in places of elephants. The old secondary forest is probably richer in the economically more desirable species than would be truly climax forest, and furthermore is frequently dominated by rather scattered trees with immense crowns, possibly the result of subsequent farming accompanied by only partial clearing. Where elephants are at all numerous these may destroy much of the reservoir of regeneration present on the floor in undisturbed patches, and when a gap does occur the large beasts tend to congregate in it causing much damage, delaying the growth of the regeneration and contributing to the temporary dominance of climbers. An interpretation of the influence of elephants in the Nigerian rainforest life cycle is shown in Fig. 29, based on records left by the late A.P.D. Jones for the Etemi Inviolate Plot on Omo F.R.: Fig. 29 should be examined in conjunction with Fig. 8, which refers to the same area. A rather similar interpretation is given by E.W. Jones (1955-56, Fig. 8).

These exceptional cases however do nothing to upset the basic theory, which is that virgin rainforest consists essentially of a patchwork of even-aged stands which result from the death of one or more overstorey trees. The patches are of varying extent: they may be quite small particularly where the overstorey trees have only small crowns and have died gradually; they may be very large where some catastrophe has occurred; or they may be of some intermediate size. Their composition will vary to some extent with the initial size of the gap, large gaps favouring the more intolerant species and small gaps the more tolerant. In mixed rainforest the actual composition is however largely a matter of chance, depending not only on the size of opening, but upon the species present as seedlings or saplings when the opening is formed; upon the nature of the microsite where each seedling is established; upon the proximity of each seedling to more aggressive plants; and upon other factors of a similarly fortuitous nature. The development of the plants in the opening is likewise strongly determined by chance. In the thicket which initially results, mortality is high as the saplings and vines compete with each other. Some plants, in particularly favourable sites, can show rapid growth from the start and in some cases may maintain this well above average rate throughout their lives. Others face competition which may greatly reduce their growth rate without causing sufficient suppression to kill them; under these circumstances the sapling may, in some species, become grossly malformed yet when finally the competition is reduced, as by the natural death of the more short-lived species, the plant is able to resume active growth at a faster rate. Still others may face such competition that active growth is impossible; early death progressively removes many of these, but some may exist for years making virtually no growth at all. Climbers, often extremely numerous in the early burst of growth in the gap, tend to thin out greatly as the trees in the gap become older, but a few individuals will hold on, growing upwards with, and supported by, the developing trees, till ultimately they reach the uppermost canopy of the forest.

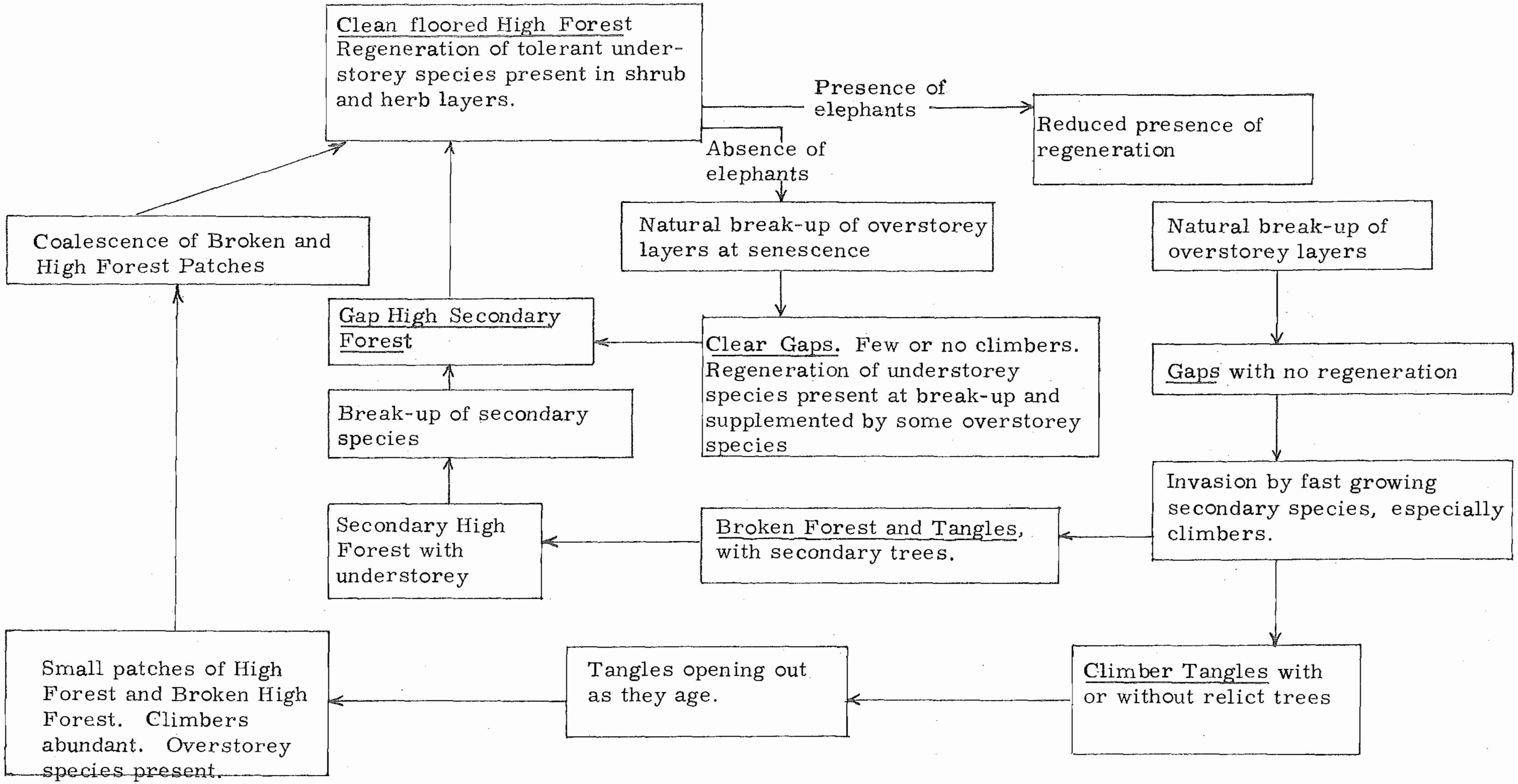

FIG. 29: Diagram showing postulated sequence of structural development in rainforest on Omo F. R., Nigeria, and indicating significance of elephants. (Based on records of the late A. P. D. Jones).

Apart from a few tolerant species which regenerate at a later stage and are able to maintain weak growth through the lower storeys, the trees and vines filling any gap are essentially even-aged (though some of the stems develop from seedlings or saplings which may have persisted for many years in the undergrowth). The very great differences in growth rate shown by a single species, however, soon result in the trees in the gap being far from even-sized, and it is probably not exceptional for a gap to contain trees of the same age yet with one having a diameter up to ten times as great as another. These size differences result in the boundaries of a gap becoming indistinct: the larger stems in a recent patch soon are larger than the less active stems of the same species in an adjoining but older patch.

This whole process can be seen in Figs. 6 and 9, which are taken from the same Malayan stand. In Fig. 6 a very recently wind-blown tree is shown: this has created a moderate gap which is starting to regenerate with an even-aged stand of light demanders. To its left is a larger gap containing a number of dead trees which were possibly killed by lightning: here the undergrowth was less disturbed and the effect has mainly been to promote the faster development of these lower storeys and in particular of the more light demanding trees present in them. A third gap occurs towards the centre of the profile (Fig. 9): this is an older gap occupied by what are already quite large trees, and it probably was created by the gradual death of a veteran since the most vigorous species occupying it, Shorea maxwelliana, appears to be more tolerant than many of its genus. Finally, at the left of the profile, is a senescent Shorea macroptera whose death or collapse will create another gap.

These even-aged patches together appear to form the "mosaic" recognised by Aubreville (1938). However it is impossible to agree with Aubreville that any unit in the mosaic cannot be succeeded by the same combination of species, but rather must be followed by other species in cyclic procession. Often this does indeed happen, but observation in all major areas of rainforest occurrence suggests that the reverse frequently happens also. As Hewetson (1956) points out, the composition of the forest at any time and place is largely a matter of chance: this certainly is the case in the regeneration of the even-aged patches and, as shown, these patches in aggregate make up the climax rainforest.

The patches are not, of course, permanent units of the mosaic. When a new gap is created it is unlikely to coincide in space with a former gap, but rather will take in parts of several previous patches and replace these parts by a new even-aged stand while the remainder of the previous patches continue to grow. The significance of the patch structure of rainforest lies particularly in its effect on regeneration, and in this regard this aspect of rainforest ecology is of the utmost significance to rainforest silviculture.

CHAPTER 7

UTILISATION OF RAINFOREST SITES

> "A plan for the development and use of land and natural resources is ....a document of temporary value, but .... should provide for the protection of environmental conditions necessary for desirable uses which may be unimportant at present, but for which demand can be expected to increase. It must make provision for research to enhance resource values by making possible more use with less conflict. It must be essentially flexible to meet the changing demands and the greater intensity of use which may be expected in the future."
>
> Wadsworth (1952a)

Use of Land

Any area of land which supports forest can be used in two essentially different ways. It can be used on the one hand as a source of various products obtained from the forest itself, or on the other hand the forest can be destroyed to enable its site to be used for a variety of other purposes. To primitive man the first purpose was paramount: the forest provided shelter from his enemies, the source of game and plant products for his food, timber for his boats and rudimentary structures, and so on. Some tribes in this stage of development still exist in some of the world's rainforests.

With the change in man from a food gatherer to a food raiser with agricultural knowledge, however, the forests took on a new significance: they occupied sites which were required for the growing of crops for food, and subsequently for cash, and as such the forest had to be destroyed. At the same time the use of agriculture enabled man to live a more settled existence, resulting in new uses being found for products from the forest, particularly for the increased use of timber as a construction material and a source of fuel. There thus arose the realisation, that whilst agriculture supplied the staple ingredients of man's existence, forests also were necessary if man were to maintain an anyway civilised standard of living. This realisation became more acute as population increased and more and more forest was destroyed. In most rainforest areas, at least in the tropics, this growth of population is a relatively recent affair largely due to the bad disease histories of the tropical rainforest environment, the diseases causing a short life expectancy in the inhabitants and a consequently slow rate of natural increase in the human population. With the control of many of these diseases during the past century, and with the introduction of more stable government, population is tending to increase rapidly and questions of proper land utilisation and of the desirable proportion of land to be retained as forest become matters of very great internal political significance.

The rising levels of civilisation have resulted in further appreciation of the need for retaining certain areas under forest, not only for their direct value in supplying the obvious products derived from the plants which constitute the forests, but also for the more indirect, but in some cases even more important, benefits which forests provide: the protection of watersheds and the regulation of stream flow; the conservation of unique plants and animals as part of the nation's heritage; the provision of recreation and scenic areas; and the retention of areas which can be used to study the ecological processes occurring in forest undisturbed by man.

Thus, at the present time one can distinguish three major uses of sites occupied by rainforest, though it must be stressed that these uses are not necessarily mutually exclusive:

1. the management of the area under forest for the direct benefits which it provides in the way of major and minor plant products.

2. the retention of the area under forest for its various indirect benefits.

3. the conversion of the area away from forest to some other type of land use, usually, though not invariably, associated with the growing of plants for food or cash.

These alternatives will now be considered in somewhat greater detail.

Major Forest Products

The so-called major forest products are those derived directly from wood: timber in the form of sawlogs or poles or hewn products, or intended for conversion to veneer or pulp or charcoal. In most areas of the world where rainforest is under some form of management these are indeed the products which the forester aims primarily to produce from his charge.

Rainforest timbers show a very great range in qualities and characteristics, as would be expected from stands with such diverse botanical composition. For example the commercial timbers possessing the extreme values for density come from the rainforest, Guiacum spp. (lignum vitae) having an average density (15% moisture content) of about 78 lbs per cubic ft., and Ochroma lagopus (balsa) a density of about 10 lbs per cubic ft. Similarly colours range from black (certain Diospyros spp.) through shades of red, brown, yellow, pink and purple to white, and almost all degrees of durability, figure, strength, toughness and other working qualities can be found among rainforest species. With such variety present, species suitable for almost any timber use can be obtained from the rainforest, though the quantity of certain otherwise suitable species may be insufficient to warrant their exploitation.

Because the world's major timber-using industries developed in the conifer-rich regions of the northern temperate zone, while in the tropical regions the use of timber for purposes other than fuel was generally very late in developing (see Chapter 1), the utilisation of rainforest timbers has for centuries been concentrated upon the export of relatively few species with outstanding characteristics not found among temperate species, such as are supplied by the mahoganies, cedars and ebonies. These species have primarily been specialty cabinet woods, and it is really only in the last few decades that more general purpose species have been utilised on any scale from the rainforests. This recent development has been sparked both by a worldwide shortage of such timbers, enabling tropical exports to compete with more traditional species on the world's markets, and by a growing demand within the rainforest countries themselves as living standards rise and as impregnation treatments enable the lighter and softer species to receive increased durability.

Gallant (1960) notes that the production of fuelwood still makes up the largest proportion of the timber production from tropical forests, though if tropical rainforests only were considered this proportion would be greatly reduced. The supply of fuel, mainly as charcoal, has played an important role in the development of silvicultural techniques in rainforest in many parts of the world, and examples can be quoted from Trinidad, Puerto Rico, Reunion and even from Nigeria and Malaya (see Chapter 10). However, with the increasing availability of alternate fuels (electricity and kerosene) the demand for fuelwood from the rainforest has greatly diminished, so that today this market is unimportant in most rainforest areas which are under proper management: although 22% of the total timber production from Malayan forests in 1959 is recorded as being for fuel or charcoal, most of this came not from rainforests, but from the coastal mangrove forests.

The main market from managed rainforest is for log timber, mostly for sawing into lumber, though veneer manufacture takes an increasingly important proportion of the better quality logs of suitable species and in some cases (e.g. Eastern New Guinea), may dominate the local timber industry in importance, if not in quantity. Strictly comparable figures on the production of log timber from various rainforest countries are difficult to come by, but the following figures give some indication: Malaya (1959), 58.9 million cubic ft.; Trinidad (1958), 3.5 million cubic ft.; North Queensland (average over several years), 6 million cubic ft., approximately. In the case of Malaya this log production was supplemented by 18.6 million cubic ft of poles and fuelwood to give a total timber production of 77.5 million cubic ft.: about half of this was obtained from forest reserves and provided the Malayan forest services with 94% of their total annual revenue of $M14.2 million (= about £st.1,653,000).

Where there is an important export market for the timber produced from rainforest, there is still a tendency in many areas for this timber to be shipped as logs rather than as converted lumber or veneer. Thus the 1959 timber exports from Sarawak consisted of 9.6 million cubic ft of logs and only 6.2 million cubic ft of sawn timber; similarly Western Nigeria in 1958/59 exported 2.66 million cubic ft of sawn timber and veneer, and 10.1 million cubic ft of logs. However increasing quantities of timber for export are being converted before shipment, thus providing local industries and opportunities for employment, and some countries have placed embargoes on the export of unconverted logs: for example Malaya, which in 1959 exported over 9 million cubic feet of sawn timber, prohibits the export of logs except in the case of a few species which are very refractory to handle.

Poles and hewn timber (sleepers, girders, etc.) provide a small but useful outlet for certain classes of trees from the rainforest, and the wider use of these products has been greatly aided by recent developments in the field of timber preservation which ensures their long service life. Fostering the increased use of these products, particularly poles, should be an important aspect of the work of the various forest services, since from managed forests there will always be a large supply of these from the smaller trees which should be removed on silvicultural grounds. In most rainforest countries there is still great room for improvement in this regard, though Trinidad with its departmentally-operated Brickfield Forest Industries indicates what can be achieved with effort (Lamb and others, 1960).

The production of pulp from rainforest trees has to date reached little further than the discussion stage. Most rainforest species can be satisfactorily used for the production of hardboard (e.g. see Packman, 1957; Natural Resources Committee, 1952-53), but this offers only limited scope for expansion although there are a few small plants operating in rainforest areas to serve local markets. Paper production appears potentially to offer much greater opportunity for the use of rainforest trees as pulp, but the difficulties in producing paper from the mixed rainforests are great: the mixed composition results in large volumes of a single species rarely being available; each species is likely to require a different type of treatment before it will produce a pulp suitable for paper making; the cost of such treatment (e.g. to remove extractives) can be high; only the sulphate process has so far given generally satisfactory results, yet the market for this type of pulp is more limited than for other types; the grades of paper produced compare not very favourably with those from long-fibred temperate conifers; the competition with temperate pulps means that rainforest paper plants must aim essentially at serving local markets, yet for economic operation the plants should be large and these will produce greater quantities of paper, at least of any particular type, than most local markets appear able to absorb (Natural Resources Committee, 1952-53; Rys, 1961; Swabey and Chittenden, 1961; L.H. Bryant, pers. comm.). In addition to these difficulties, which have so far prevented any large scale development of paper pulp production from rainforests, must be added the local competition from certain readily available and uniform agricultural wastes, such as bagasse which is being utilised as a source of pulp in Puerto Rico. The exceptions to this generally discouraging picture do not give rise to great hope for an early increase in the utilisation of rainforest for paper manufacture. A pilot plant was for some years operating in the Ivory Coast and produced an apparently satisfactory product from mixed species by segregating these into three grades (Natural Resources Committee, 1952-53). This plant however finally closed, though it is believed that the reasons for this were of an administrative, rather than technical, nature. In Surinam large scale Pinus caribaea planting is under way to provide basic raw material for a proposed paper plant which, it is hoped, will also supplement its supplies with a proportion of mixed rainforest species (C.B. Briscoe, pers. comm.): here however the main source of material will come from plantations of an introduced species, not from the mixed native rainforests. Similarly in Malaya it appears that any paper-making projects will be based on the extensive rubber plantations, not on the native rainforests (Wyatt-Smith 1962). In Peru plans have been made for a paper plant using timber from the rainforests, but only one species (Cecropia sp.) is envisaged as raw material, again scarcely contributing to the more thorough utilisation of the mixed rainforests (Rys, 1961; Gallant, 1960).

The general picture of the utilisation of major forest products from rainforest is thus based primarily on an increasing demand for saw and veneer logs, supplemented by a diminishing demand for fuelwood and by a limited but potentially useful demand for poles and other preservatised wood products. Pulp manufacture, which in temperate forest regions has provided the major recent impetus to timber demand, does not appear able to provide any early solution to the more complete utilisation of the world's mixed rainforests.

Minor Forest Products

By minor forest products are understood the various items of commercial value, other than timber, which are obtained from trees and other plants in the forest. Many of these products lie on the indeterminate borderland between forestry and agriculture; where they are obtained by selective working in natural forests, or even as a subsidiary operation to the production of timber in pure forests, the items are known as minor forest products, but where crops are raised specifically to produce these materials they may become indeed major agricultural products. Probably the outstanding example of this occurs with *Hevea brasiliensis*, the Para rubber tree, which provides an important but still minor forest product in its native Brazil, but which in Malaya, and in other southeast Asian countries, provides an agricultural crop of unequalled importance.

The utilisation of minor products is probably carried out most intensively by the more primitive native tribes who live in the rainforests and rely on these products to provide many of their daily needs, and the amazing scope of uses to which different plants are put can be readily appreciated by consulting one of the catalogues of useful plants which have been prepared for many rainforest regions, e.g. Dalziel (1937) for West Africa. However, even with higher living standards, there remains a demand for certain of these products, which continue to supply a usually small but nonetheless significant output from managed and unmanaged rainforests alike. Figures are not available for the area, but it is probable that in Brazilian Amazonia the cash value of "minor" products from the rainforest is in fact considerably greater than that of the timber products: a handy summary of the minor products from this region is given by Williams (1960).

These minor products serve a host of needs and are probably best classified by the type of product which they yield. Among these can be recognised:

Elastomers: A number of rainforest plants produce latex in their stems, and this is used to provide a variety of elastomers. Clearly predominant among these elastomers is rubber, which must rank as one of the world's two or three top, non-food, plant products. The major source of natural rubber is from *Hevea brasiliensis*, which occurs naturally in Brazil (chiefly in swampy rainforest) but which has been extensively planted in Malaya, Indonesia, Ceylon, parts of West Africa and elsewhere, and which now forms the basis of the prosperity of a number of these countries. Other rainforest plants have also been used on a smaller scale to provide rubber, these including Castilla elastica from Central America and Ficus elastica from India. Among other elastomers which are usually obtained by the selective working of trees within the rainforest are chicle, used in the manufacture of chewing gum and obtained from such trees as the Central American Achras sapota, the Brazilian Manilkara huberi and the Malayan Dyera costulata; balata, used in golf balls and telegraphic cables and obtained from Manilkara bidentata in the Guianas; and gutta percha, with similar uses to balata, from the Malayan Palaquium gutta.

Resins: Resins, used in such products as varnish, certain medicines and ointments, and as incense, come from a number of rainforest trees including many species of Burseraceae and Dipterocarpaceae and from Agathis spp. These resins are normally obtained by selective working.

Edible Oils: Edible oils are found in the fruit of many plants and in some the quantities are sufficiently great to warrant commercial exploitation. Outstanding in this regard is the common West African palm Elaeis guineensis, whose oil-rich fruits provide Nigeria with its most valuable export items as well as receiving much local use. Much of the Nigerian production, which is used mainly in the manufacture of soap and margarine, comes from trees growing wild in the forests but owned by individual Nigerians or by family groups. In addition Elaeis is grown extensively in plantations both in West Africa and in other rainforest regions.

Drugs and Medicinal Products: Drugs and similar products are obtained from many rainforest plants. Hyoscine, used in the treatment of mental illness and travel sickness, is obtained from the leaves of the common secondary species, Duboisia myoporoides, in eastern Australia; strychnine comes from certain Strychnos spp. and is used in treating paralysis as well as a poison. (e.g. curare); medicinal camphor comes from the east Asian temperate rainforest Cinnamomum camphora; Cinchona officinalis, from the Andean foothills, is the original source of quinine; another Andean species, Erythroxylum coca, is the source of cocaine; the roots of the widespread tropical leguminous vines, Derris spp. and Lonchocarpus spp., provide an important insecticide; and so on.

Essential Oils: The distillation of essential oils is not widely practised in rainforest areas, but an exception is the Amazonian Aniba roseodora (pau rosa), the wood of which is distilled to provide rosewood oil, much valued in perfumery.

Fruit and Other Foodstuffs: The fruits of many rainforest plants are edible and provide a valuable source of food to the local inhabitants. Many of these receive only local use, though the trees of these may be well cared for and even planted in the vicinity of settlements: in Malaya the rather open forest remaining in and around the villages is usually found to consist almost entirely of trees providing edible fruit, such as Artocarpus (bread fruit, jack fruit), Durio (durian), Garcinia (mangosteen), and the interesting gymnosperm, Gnetum gnemon. Many rainforest fruit bearers are raised commercially in plantations around the world: Musa (banana and plantain), Carica (pawpaw), Passiflora (passionfruit, granadillo), Annona (custard apple), Macadamia (Queensland nut), etc. The fruits of some, though not providing a direct foodstuff, are used in the manufacture of edible products, e.g. Theobroma cacao (cacao, used in chocolates and beverages), Caffea spp. (coffee). Others provide spices and condiments from their fruit, e.g. Piper and Capsicum (peppers). Mostly commercial supplies of these products are now obtained from plantations, but one important fruitbearer, the Brazilian Bertholletia excelsa, still provides its Brazil nuts primarily from trees growing in the natural rainforests, where they are protected by government decree. Other rainforest food stuffs come from other parts of the plants, including the buds e.g. Eugenia caryophyllata (cloves); roots or tubers, e.g. Zingiber officinale (ginger), Colocasia esculentum (taro or coco-yam), Dioscorea spp. (yams); bark, e.g. Cinnamom zeylanicum (cinnamon); and stem, e.g. Metroxylon sagu (sago), various other Palmaceae (palm wine and toddy).

Other Minor Products: Rainforest plants provide many other types of products. The majority of these are of local importance to the more primitive inhabitants only, but some of present or past commercial significance include dyes, e.g. Baphia nitida, the Nigerian cam-wood; fibres, e.g. Raphia spp. (raffia); Ceiba pentandra and other Bombacaceae (kapok); and canes, e.g. Calamus spp. and other climbing palms (rattans, Malacca cane).

Indirect Benefits from Rainforest

Because of the generally late development of forestry in the regions where rainforest occurs, and because of the initially large areas of rainforest - in these regions compared with the human population, an appreciation of the indirect benefits derived from rainforest has been late in developing in most rainforest countries and indeed in many countries to this day this appreciation is maintained only by a small, far sighted minority. The indirect benefits are those which result for keeping the ecosystem in a relatively undisturbed state: for some purposes it is essential that the environment should remain completely undisturbed by man, but for many purposes limited disturbance, for example logging, can be countenanced.

The indirect benefits of rainforest fall into four broad classes. These are not mutually exclusive, nor are they all necessarily exclusive of the need to manage rainforest for its direct benefits in the way of timber and minor products: the aim of forest management in any area should always be to balance the various purposes against each other so as to achieve "the greatest good for the greatest number in the long run". This is the principle of multiple use management, and whilst in various areas one or other of these uses will predominate and exclude some of the others, in most cases it is possible to achieve a balanced management which serves most purposes.

The four classes of indirect benefits are the preservation of undisturbed forest for scientific study; the protection of watersheds and the maintenance of stream flow; the protection (and in some cases, production) of native wildlife; and the maintenance of recreation areas.

Of these the most restrictive in scope is the first, the preservation of virgin areas for future scientific study. Such virgin reserves, which should be clearly marked and reserved in perpetuity, serve two purposes. One is to provide areas of natural forest in which the growth of the world's most complex and luxuriant vegetation can be studied and observed in generations hence by future scientists with their increasingly refined techniques and methods. The second is to provide the raw material for future evolution and to provide the source of material for study by phytochemists, wood technologists and others with a view to determining further uses of these plants to the benefit of man. The necessity of providing reserves of this nature has been stressed by such eminent rainforest botanists as Richards (pp. 404-407) and van Steenis (1961), and their warnings have been heeded in a number of countries. In Malaya the Forest Department has a policy of setting aside "Jungle Reserves" representative of typical types of vegetation in the country, with an average area of about 200 acres but ranging from a few acres up to 4500 acres in area, with compact, natural boundaries and, as far as possible, relatively accessible sites. Up to 1959 some 36 Jungle Reserves had been established (Wyatt-Smith, 1959a). In Nigeria similar areas known as Strict Natural Reserves are being established: the first of these has been described in some detail by Jones (1949). In Puerto Rico Wadsworth (1952a) has recommended the setting aside of over 2000 acres covering all vegetation types as a permanent virgin reserve in the Luquillo Mountains. In New South Wales a policy similar to that of the Malayan Forest Department aims at preserving typical areas of forest as "flora reserves". On an increasing scale in many other countries national parks, although usually primarily intended as recreation areas, will serve a similar purpose.

Watershed protection, to maintain regular streamflow and to avoid excessive soil loss with its consequent siltation of rivers and dams, has long been recognised as an extremely important function of forests generally, and it is of particular importance in rainforest areas where rainfall is heavy and the river catchments are frequently in very rugged, mountainous terrain. This excludes from consideration the still controversial effect of forest cover itself actually increasing rainfall. In the Luquillo Mountains of Puerto Rico the importance of the forest as a catchment area overshadows all other activities and was a major consideration in adopting a selection system of silviculture for the commercial rainforests; in addition over 2600 acres of critical areas with steep slopes and shallow soils have been set aside purely to protect the catchment area values (Wadsworth, 1952a and b). In Malaya about one third of the total area of forest reserves in the Federation (equivalent to over 8% of the total land area) is regarded as essentially protection forests in the mountainous central areas of the country (Federation of Malaya, 1961). Logging in these forests is not envisaged, though it should be pointed out that provided care is exercised (particularly in snigging the logs) logging need not run counter to the objects of catchment protection: this is particularly the case in areas of tropical rainforest where land seldom lies bare of vegetation for any but a very short period. In an effort to effect a compromise between protecting the catchments and obtaining major forest products, F.A.O. (1960b) notes that Burma, Ceylon, India and the Philippines have all gone in for some type of selection working in their rainforests.

The objects of wildlife protection run parallel to the reasons for establishing virgin reserves, though provided the habitat is not too drastically altered, wildlife protection can frequently be attained whilst still managing the forest to provide major products. The value of maintaining viable populations of native animals in all countries is not restricted to their scientific interest in understanding the part played by each organism in the complex ecosystem of the rainforest. Larger animals, often dependent in turn upon smaller ones, can be valuable tourist assets (estimated to be worth £5,000,000 annually in Kenya; Worthington, 1961), while in a commercial sense they may provide by-products such as hides and ivory and at the same time be a rich source of protein for local inhabitants. The management of areas to provide protein (the "bush beef" of West Africa) involves more than mere protection, important though this may be over limited areas: it involves positive management with the maintenance of habitat and controlled hunting. This is usually quite compatible with the management of rainforest for other purposes. At the same time strict protection of certain animals in special reserves may be necessary in some instances if the beasts are to escape extinction or until more is known of their habits: this is the case with gorillas in Eastern Nigeria, and with the rare and endemic Puerto Rican parrot in the Luquillo Mountains where Wadsworth (1952a) has urged the reservation of some 3000 acres as a strict sanctuary for these and other birds. Fortunately most governments are today aware of the desirability of preserving examples of all native animals in their natural habitat, but in many cases much greater effort and expenditure is needed if this ideal is to become a certain fact.

Recreation forms the fourth indirect benefit of rainforest, and apart from the often high scenic value of the landscape, few plant communities offer such facilities for recreation development as does rainforest: the equable microclimate of the rainforest, its usual richness of plant life and life forms, the variety of its fauna, its sheltered, shaded streams, all these offer attractions which become of increasing value and importance as the population becomes more and more urbanised. The popularity of such areas as the recreation reserve within the Luquillo National Forest, Templer Park near Kuala Lumpur, the more accessible national parks in Queensland, or the Bruxner Park Flora Reserve and Minnamurra Falls Reserve in New South Wales illustrate the demand for recreation reserves of this type. These areas have aims different from the strict flora and fauna reserves with which they are frequently confused. The latter aim to preserve the native vegetation and wildlife with as little disturbance as possible, and consequently should not be readily accessible to the general public, whereas recreation areas should aim to attract the public and provide for their relaxation and education. To do this limited development should be carried out over part of the area by the provision of such facilities as scenic roads and walking tracks, camping sites and rest houses, "nature trails" pointing out the various items of interest in the vegetation, vantage points from which to observe the scenery, swimming pools in the natural streams, and so on. Forest managed primarily for its major products can frequently serve many of these needs, but in most areas serious consideration should be given to reserving suitable areas in their natural condition as recreation reserves, particularly in localities accessible to the larger centres of population. Besides their value as places of rest, these can serve a most useful purpose in making the population aware of the need for sound conservation practices.

Because forest services have to operate on a budget there is a tendency for them to regard their revenue-making operations from the sale of timber and other products as their prime responsibility. However, in the long range view, the value of the indirect benefits of rainforest may well far outweigh the immediate gain obtained by exploitation. Some of the indirect benefits can well be obtained from forest managed also for major production, but in certain areas the indirect benefits - flora, fauna, water and recreation - will need more restrictive management practices if they are to be attained, and it is of the utmost importance that forest services should be kept ever mindful of their responsibilities in this regard.

Alternative Land Use

Preceeding sections have dealt with the utilisation of rainforest sites whilst maintained under forest cover, but in most rainforest countries the natural rainforest is being destroyed with increasing rapidity to make way for other forms of land use, usually agriculture. Thus Foggie and others (1952) state that in the Gold Coast (now Ghana) the rainforest was being destroyed at the rate of about 270 sq miles a year for conversion to agriculture. This demand for land for purposes other than forestry is one of the most vital issues facing most tropical countries at the present time.

The alternative uses for rainforest land are numerous, and range from sites for houses and towns, road and transmission line clearings and areas for mining, to such purposes as sites for television transmitters, microwave repeater stations and even artificial satellite tracking stations. However, the major competition with forest services for rainforest comes from the field of agriculture.

The types of agriculture practised on rainforest land are extremely varied. The most primitive is shifting cultivation, still practised by some peoples in many tropical countries, e.g. certain aboriginal tribes in Malaya (Wyatt-Smith, 1958). Here temporary settlements are made, patches of forest are cleared and burnt, and crops raised on the site for one or two years till the fertility from the original vegetation is lost. New patches are then cleared, and when suitable land in the vicinity is exhausted or some other reason forces a change*, the tribes move on to a new settlement, letting the land formerly farmed revert to forest, which in time restores the fertility of the soil (Chapter 2).

Akin to shifting cultivation is the bush fallow system of agriculture. As the name suggests this also relies upon the rainforest regrowth restoring, in part at least, the natural soil fertility, but in this case the farming activities are carried out from permanent settlements. While such settlements are small and the "fallow" period is long, there is a reasonable chance of maintaining soil fertility. However as population increases the fallow period inevitably decreases and the soil becomes steadily less fertile at each rotation on all except relatively small areas of unusually good soil. This type of

*Some primitive tribes will not remain in an area once a member of their clan has died.

agriculture is very characteristic of southern Nigeria, where the crops raised include cassava, yams, coco-yams, maize, beans, plantains and sweet potatoes (Keay, 1959a). Where land shortage is sufficiently great, agriculture of this type can be utilised by forest services to establish forest plantations under the taungya system, the plantation crop forming the highly profitable "fallow" (see Chapter 9).

In an agricultural sense farming practices such as these are inefficient, since the land is out of production for most of the time. More permanent agriculture requires one of several alternatives, namely the restriction of farming to particularly rich soils, usually in areas where the fertility is to some extent replenished by periodic inundation and siltation, or the regular use of manure or artificial fertilisers, or the growing of a crop which maintains the soil fertility itself. Examples of the first can be seen in the alluvial "wet paddy" fields used for rice growing in Malaya and in the sugar cane fields of Queensland. Regular fertilising is becoming more widely used in rainforest sites; it is for example the rule in the dairy farms established on former rainforest sites in New Zealand and Australia. Crops which maintain fertility are typically ones which to some extent resemble the natural forest, particularly by being made up of trees, and one of the features of humid tropical agriculture is the prominance of tree crops, such as rubber, cacao and oil palms. For the best results these crops usually benefit from fertilising also, but in contradistinction to the normal food crops they are able to maintain productivity on the typically poor rainforest soils for long periods without fertilising being essential. As explained previously, such crops are mostly of rainforest plants, and they play a vital role in the economy of many rainforest countries.

Balanced Land Use

In rainforest countries the forest services are therefore faced with dual problems in land use. One problem is to ensure that adequate areas of forest are retained, in the face of increasing agricultural and other pressure, to provide for all future needs from the forest itself. The other is to maintain a wise balance within its forest estate for the sometimes compatible, sometimes conflicting, needs of timber and minor products supply, streamflow, preservation of flora and fauna, and recreation. Of these the former is the more pressing, since unless it is satisfactorily resolved, the latter problem no longer remains. At the same time the latter needs must be taken into account when developing the arguments in favour of reserving an adequate, permanent, forest estate.

The needs in this regard appear to be in approximate order of significance:

1. The preservation of representative and undisturbed examples of all the natural types of forest.

2. The protection of all critical catchment areas.

3. The preservation of habitat to maintain viable populations of native wildlife.

4. The retention of sufficient area to provide the future population of the country or region with all its needs of forest products, taking into account the worldwide consumption trends for these various products.

5. The provision of adequate areas of forest for recreation needs.

The item which is most open to argument here is the retention of areas for timber supplies. Provided populations ultimately reach stability, an estimate can be made of the likely annual requirements of forest products in the future. Because timber products are bulky, freight charges contribute a large proportion of the final cost of these, and for this reason it is desirable that individual countries or geographic groups of countries should aim as far as possible to be self-sufficient in timber. The amount of land needed to produce this volume will vary with the intensity of forest management applied: with conversion to plantations of species such as certain pines or eucalypts, merchantable volume increments well in excess of 200 cubic feet per acre per annum can be expected over large areas, whereas the most intensively managed areas of natural rainforest (e.g. areas regenerated under the pre-war regeneration improvement felling system in Malaya, see Chapter 10) appear incapable of producing more than 75 cubic ft per acre per annum, with probably less than half this production being the average over extensive areas. Thus within a rainforest region the area of forest estate needed to produce a given volume of merchantable timber may vary by as much as ten times, depending upon the intensity of silviculture. A forest service therefore has two levels which it can set as the minimum area necessary for permanent dedication as production forest, over and above the area needed for more restricted indirect benefits.

In the long run it seems inevitable that the area finally left to the forest services will be towards the lower level, necessitating more and more emphasis by the services on very intensive management. If the areas to safeguard the indirect benefits are adequate, and if sufficient area of production forest is reserved to provide all anticipated future needs of the local population, it is difficult for a forest service to argue for the permanent retention of larger forest areas to provide, for example, timber for export, when the land is equally suited to producing more food for the local inhabitants or to providing other export crops, such as cacao or rubber, which make more efficient and economic use of the land. Possibly of all rainforest countries, this pattern of land use being tied to the needs of the future, with silviculture becoming increasingly intensive and concentrating upon the production of highly efficient cellulose-producing species whose timber is suitable for impregnation and pulping, can be seen to its best effect in Trinidad, and this serves as a pointer to the likely developments in other countries in due course.

CHAPTER 8

PROBLEMS OF RAINFOREST MANAGEMENT

> "The basic problem for the Silviculturist, therefore, is to change the forest from such a heterogeneous mixture of all ages and many species, a large proportion of which are useless, and in which only some stems of the economics are of value, to a forest with a large number of valuable stems of about the same age and of only a few well or reasonably well known species." Pitt (1961).

Introduction of Management

As indicated in the previous chapter, proper management of any area of rainforest will normally have as its aim the utilisation of the forest site for one or more of the purposes which have been already discussed. Of these purposes, the production of timber in its various forms is not necessarily the most important: the protection of watersheds and the preservation of characteristic ecosystems are undoubtedly of greater long range significance. However, the use of rainforest sites for the production of timber is the purpose which has in the past engaged the greatest attention of forest services, and this appears likely to remain the case in the future.

The reasons for this are not difficult to find. Other aims of forest management rely essentially on the retention of the natural vegetation with as little disturbance as possible, so that the managing authority has as its prime responsibility merely the protection of such areas. Against this the management, as opposed to pure exploitation, of rainforest for the production of timber requires definite and sustained activity by the forest authority. From the exploitation of the standing timber in the production forests comes the bulk of the revenue of the forest service, and the continuance of the service's policy, as well as the welfare of the country, depends in no small measure upon the ability of the forest service to maintain and even increase this production of timber and other products. Production and management indeed go hand in hand: from the first comes the financial returns needed to carry out management practices and so to ensure future production, while in addition, this revenue is also necessary to maintain other forest areas for the important, but usually unremunerative, indirect benefits which they provide. In the remainder of this report consideration will be given to the various phases of managing rainforest for the production of timber, and the other possible aims of rainforest management will only be mentioned where they impinge on or affect in any way the objects of production management.

Forest management in any area is beset by problems, but it is doubtful whether any other type of forest vegetation offers such a multitude of problems as does rainforest. These problems differ in extent and in emphasis in different countries, though many are common to all or most rainforest areas, but it is important that they should be fully recognised by the foresters whose responsibility it is to introduce or continue management in rainforest stands. Those problems which are essentially of a silvicultural nature are dealt with in chapters 9, 10 and 11, but there is a range of more general difficulties which shall be discussed briefly in this chapter.

"Economic" Species and Unmerchantable Species

It has already been shown that a very common feature of rainforest is the complexity of its floristic composition (see Chapter 4). Stands containing more than 100 different species of trees on a single acre are common in some areas (e.g. southeast Asia), and even in rainforest types with relatively few species entering into their composition (e.g. swampy rainforest, temperate rainforest) it is not unusual to have 20 species occurring in intimate mixture on an acre.

From a management viewpoint, these species can be broadly classified as those which are "economic" and those which are unmerchantable. Economic species are species which, when of suitable size and form, can be sold by the forest owner to some timber user for one or other of the purposes already discussed. Individual stems of economic species may not always be merchantable: poor form; faulty or defective stems; small or occasionally excessively large size are among the factors which may render any given stem unmerchantable, even though the species itself is highly sought after. However, in the early stages of forest management in any rainforest country it is usually found that many species are unmerchantable: the economic species are few, and the vast bulk of the trees are unsaleable, posing the silviculturist with his first and, possibly, greatest problem.

Gordon (1957) has considered this problem in some detail. He recognises four reasons for a species to be unmerchantable:

1. It is inherently worthless.
2. Its properties are unknown to potential purchasers.
3. Its stocking is too low to permit the collection of commercial consignments.
4. It is situated too far from the centres of timber consumption to allow the sale price to cover the costs of extraction.

Inherently worthless species are rare: indeed, if the market for fuelwood is large enough, probably no tree species is definitely without value, even though some species are preferred to others. However in the case of a relatively small number of species the potential value can always be expected to be low due to invariable bad form (e.g. the South American Aspidosperma spp.) or small size without any compensating features in the timber quality. With such species there is little real problem to the silviculturist since it is clearly desirable to eradicate these from forests which are being managed for timber production.

In rainforest areas being opened up to controlled exploitation for the first time it is usual for the properties of many species to be completely unknown. This is still the case in most of the areas of tropical rainforest to this day, and it can only be overcome by the forest services and the timbermen combining to study each species in turn, determine its properties, and then market the timber so that its most desirable properties can be utilised. To this end the forest products laboratories which are now established in most regions are of inestimable value. Often the lesser known species are first marketed as substitutes for species already well established on world markets. Thus the West African export market has seen the phenomenon of Chlorophora being introduced to world markets as a substitute for teak (Tectona), then being established in its own right, and finally of Piptadeniastrum being placed upon the market as a substitute for Chlorophora (Pollard, 1955). In Australia the plethora of adopted common names among the rainforest trees bears testimony to this same procedure among the early European settlers: probably the majority of species to this day are marketed as "elm", "beech", "sycamore", "maple", "oak", "ash", etc., without having any botanical relationship to the northern hemisphere trees bearing these names.

Low quantities of an individual species are a serious drawback to the development of export markets. As Gallant (1960) says: "It will be found to be more or less a general rule that the tropical timbers commanding most attention in world trade are among those of commonest occurrence in the forests, which seems logical enough an outcome of the marked preference of the trade for substantial and regular parcels of a single species". Herein lies one of the greatest difficulties in the utilisation of rainforest, compared with the floristically impoverished forests of the northern temperate zone. The problem is partially overcome as local markets absorb more and more of the forest production, but even in local markets there is a preference to handle large volumes of a few species rather than small volumes of many. In the development of export markets the problem is frequently nigh on insurmountable, though there are notable exceptions as when a rare species of particular quality attracts premium rates by virtue of its rarity (e.g. the silverballis (various Lauraceae) of British Guiana), or when a number of individually infrequent species can be marketed together: the outstanding example of this can be seen with the various grades of meranti (Shorea spp.) and keruing (Dipterocarpus spp.) marketed from Malaya. This problem of inadequate volumes, serious though it is, at least provides the silviculturist with a valuable object lesson: it is usually better to grow large quantities of a useful, though not necessarily highly valued, species, than to aim at a scattered and low representation of what is intrinsically a more desirable species.

Inaccessibility is possibly the commonest cause of a species being unmerchantable. This comes about both by the cost of transporting the logs from remote forests to the markets, and by the risk of degrade from insects and fungi when the extraction and transport period is long. The latter cause of unmerchantability has been reduced in recent years with improved methods of protecting timber from degrade, and with more rapid means of transport, but the costs associated with remoteness remain. In such cases only the more valuable species can be utilised, often with a low return to the forest service, while the silviculturist is left with a large number of species which, in that locality, are unwanted. In silvicultural treatment these unwanted stems are often destroyed, leaving the forester with the constant fear that the species so destroyed, at expense to the forest service, will be desirable when the area is more accessible and populated: "any species that grows to useful dimensions and is of good form is likely to prove useful" (Jones, 1950). Gordon believes that, where a large proportion of potentially useful species in any forest is rendered unmerchantable because of remoteness and inaccessibility, there is a fair indication that exploitation from the forest is premature, and he queries "is it not possible that we are rather too ready to use the advantages of mechanisation to work remote forests too soon, before circumstances favouring more complete utilisation are favourable?" This is a strong argument, though one that cannot invariably be answered in the affirmative: a country's need for foreign exchange may, for example, necessitate opening up distant forests to produce export timbers even though most species in the forest cannot be marketed. Such actions are however usually unsound when the long range silvicultural implications are studied, no matter how attractive they appear as a basis for a policy of expediency, and Gordon's plea to reserve the less accessible forests for the future, but to work those which are already well accessible and from which most species can be marketed, is normally sound managerial policy.

Gordon also observes that unmerchantable species are usually most plentiful where the logging is carried out along waterways and other routes not paid for by the timberman, and where the forest product is intended for export as unmanufactured material. Where the timberman has to construct roads to extract his timber, and where costly manufacturing plant is installed by the timberman, then the timberman has to be less fastidious to pay for his investments, taking a larger volume which inevitably must contain more and more of the less favoured species. This is the general pattern of forest exploitation in the world's rainforests, and examples can be taken from eastern Australia, starting with the very early selective logging for Toona australia, and from Malaya, with the early emphasis of Balanocarpus heimii and Palaquium gutta, till today in both countries complete utilisation is at least in sight, if not yet quite an accomplished fact. In areas such as Amazonia, however, with its small local markets and seemingly endless areas of virgin forest, the problem of the unmerchantable species seems likely to plague silviculture for many years yet, and the various actions mentioned above are all necessary if an improvement in the standards of forest utilisation is to be achieved.

As indicated, economic species and unmerchantable species are essentially determined by economic factors. Improved logging methods and other technological advances will, with time, result in more species being "economics" and fewer unmerchantable: statements on the poverty of timber trees in rainforest must always be interpreted with this knowledge. Thus Smith (1959) estimates that an acre of virgin Malayan rainforest carries some 5000 cubic feet of stemwood, yet at the start of this century only 100 cubic ft per acre were being extracted, this value rising to about 500 cubic ft at the present time*.

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* Vincent (1960a) however shows that recent logging in Malaya yields an average of 860 cubic ft per acre from 17 trees per acre.

In Nigeria, Gray (1952) has recorded that from 3 sq miles in the Omo F.R. an average yield of only 134 cubic ft per acre was obtained, from an average stocking of only 2 merchantable trees per 3 acres, though Rosevear (1952) notes that from 1 sq mile in the Sapoba F.R. 440 cubic ft per acre of merchantable timber were obtained. This leaves an immense volume which even now is not being used. However in the virgin forest much of this residue is in stems which are overmature, rotten or of such poor form that economic handling is impracticable, while more is in immature stems which appear better left till a later felling cycle. In the relatively evenaged stands being produced by silvicultural treatment the volumes per acre are likely to be much higher: in the intensively treated, 50 years old stand of Dryobalanops regeneration on Kanching F.R. in Malaya, the writer measured a plot with an estimated 3,000cubic ft per acre of potential merchantable timber, while Cousens (1957) estimates the average volume of regenerated Shorea rainforests in Perak (Malaya) at age 40 years at about 1,300 cubic ft per acre, with considerably higher volumes in selected stands. Rosevear (1952), in Nigeria, estimates that up to 6,000 cubic ft per acre (including thinnings) may be obtained from treated rainforest at the end of the first 100 years rotation. A high proportion of unmerchantable trees (as opposed to unmerchantable species) is characteristic of many of the world's virgin forests, not just rainforest, and treated rainforests are capable of yielding much greater volumes. Nonetheless the depressed merchantable volumes available from virgin rainforest do put a distinct damper on utilisation, as well as creating a costly problem for the silviculturist who has to remove the remaining useless stems.

Agencies of Damage

Rainforests, particularly in the tropics, are subject to many agencies which severely damage or destroy the trees and forest products. Some of those which affect the growing trees are mentioned elsewhere, and the importance of these to the silviculturist should never be underestimated: the effects of periodic cyclones on pure, even-aged plantations; the ravages of high populations of native or introduced animals; the significance of specific insect pests such as Phytolyma lata on Chlorophora or of Hypsipyla spp. on various Meliaceae; these are but a few of the problems which are concerned with damage to growing trees and which can profoundly influence silvicultural thinking on the management of rainforest areas.

Trees which have passed maturity in the rainforest commonly show considerable timber degrade due to the attacks of insects, fungi and other as yet unexplained pathogens. Damage of this type also occurs on immature trees, especially where these have been previously damaged at some time in their life by large animals, by fire (which on rare occasions can enter most types of rainforest), or by falling trees and limbs. The defect to the stems from such causes renders many of the trees economically worthless and is a major reason for the relatively low yields obtained from virgin rainforest.

Logging is a major cause of damage to the remaining stems in rainforest, as has been shown in the studies of Nicholson (1958b) in North Borneo and of Redhead (1960b) in Nigeria. Nicholson found that the removal of slightly under five trees per acre, to yield 1,300 cubic ft of timber per acre, caused some damage to 53% of the remaining trees, while Redhead found that the removal of 2.3 trees per acre, yielding 577 cubic ft per acre, damaged 32% of the remaining trees. Largely because of this intensity of damage, Dawkins (1958) recommends that tropical rainforest should be managed by some type of uniform system. In some areas of temperate rainforest, including New Zealand (Kirkland, 1961) and New South Wales (Baur, 1962b), undamaged stems remaining after heavy logging are subject to crown deterioration which may, in severe cases, lead to the death of the trees.

Weed growth, on a scale not encountered in any other type of forest, provides another type of damage to the growing trees in rainforest. Fast growing, useless trees develop rapidly after rainforest is opened up and, with the prolific vine growth which occurs under similar conditions in most rain forest areas, suppresses, deforms and frequently kills much of the useful regeneration occurring with it. Vines, stranglers and probably to some extent mistletoes, continue to damage potentially valuable stems throughout their life, confronting the silviculturist with further problems.

Logs taken from the rainforest are also liable to heavy damage from insects and fungi. While some species show a high resistence to this type of damage, the majority of species, and particularly the faster growing light timbers, are highly susceptible. The naturally durable timbers, such as Chlorophora in West Africa and Balanocarpus in Malaya, are those which in the past have been most sought after for local use. Susceptible species, which are usually the silviculturally more desirable, have until relatively recently been little used in most areas because of the very real risk of degrade between the time the trees are felled and the logs are finally processed or exported. The recent change in utilisation patterns from the rainforest is in no small measure due to the introduction of rapid mechanised extraction and haulage, thus lessening the chances of deterioration, coupled with improved measures both to protect logs and to increase the durability of the timber in service. However, as Gallant (1960) points out, much still remains to be done in this field. These problems of susceptibility to insect and fungal attack are to some extent aggravated by the rainforest climate; to maintain timber supplies during excessively wet periods, when bush operations may be virtually impossible, the timbermen must create reserves of logs in their mills or timber yards, and these reserves, often in store for lengthy periods, are particularly prone to damge unless special measures are taken to protect them at additional cost to the timberman.

Difficulties of Mensuration

Forest management for the purpose of producing a sustained yield of timber, is largely dependent upon a knowledge of the amount of standing timber in the forest and of its rate of growth. Other factors are of no less importance, e.g. the introduction of silvicultural systems suited to the species of the forest, assured markets for the produce, protection from uncontrolled fire and logging, the provision of adequate access, and so on, but where the main object of management is to bring the forest to the state where it can provide a high and constant yield of timber and other products in perpetuity, these other factors are of little value in the absence of reliable data on stocking and growth.

The forester dealing with the management of rainforest is faced with very great problems when it comes to obtaining this essential information, and Dawkins (1958) is not overstating the case when he asserts that "progress in sound management of natural tropical high-forest is chiefly dependent on the development of sampling methods .... In terms of academic forestry, the limiting factor is our ignorance of mensuration, rather than of silviculture". These mensurational difficulties arise in a number of ways.

The first problem, encountered particularly when new forest areas are being opened for management, is botanical rather than mensurational, and it comes from the difficulty in identifying many of the species present. This of course is related to the problem already mentioned of many rainforest timbers having completely unknown qualities, and the timberman can scarcely be expected to develop markets for thse when the forest manager is unable to identify them. Well established timber species are usually adequately known by forest assessors, but in many areas hosts of species, often including large and common trees, are unknown, and the problem becomes more acute when the regeneration is considered. Recognition of seedlings and saplings of the important species is becoming increasingly important as a guide to the type of silvicultural treatment needed in any area (e.g. Wyatt-Smith, 1961a and 1962), and these frequently differ greatly from the mature trees. To aid in overcoming this problem, botanical sections are an important part of any forest service working in rainforest areas, and studies such as those of Taylor (1960) and Pitt (1961) on the characteristics of seedlings are an essential part of the service's research programme.

The form of the trees themselves frequently creates difficulty in mensuration. Highly fluted stems or tall buttresses are common in many rainforest trees (see Chapter 3) and make the measurement of stem diameter awkward at best and sometimes almost impossible. Studies such as that of Vincent (1960b) on the buttress dimensions of Shorea leprosula in Malaya have aimed at providing solutions to this problem, but much further work is required before any simple answer is available. Height measurements too are difficult and time consuming in rainforest, where the dense growth of understorey trees and vines obscures vision and causes appreciable errors in the estimation and even measurement of both merchantable and total tree height.

Probably the most important development in relatively recent years in forest management has been the introduction of aerial photography as an aid to forest mapping and assessment, but again the rainforest proves a refractory subject for such techniques. Where there is little topographic relief the density of the vegetation is often sufficient to obscure all but the largest drainage patterns, whilst the mixed composition and the dense, closed canopy make the use of photographs appear at first sight almost useless for purposes such as distinguishing species'types, tree heights or crown diameters as guides to estimating the volume of growing stock present. These difficulties are very real, but the work of Heinsdijk (1957-58, 1960) in Brazil, and of Swellengrebel (1959) in British Guiana, and the useful reviews of the subject by de Rosayro (1959, 1960), with their emphasis on southeast Asian experience, indicate that aerial photography can in fact prove a most useful tool in rainforest management.

Even without the aid of aerial photographs, assessment can be carried out by the older ground sampling techniques, modified where necessary to suit modern statistical design (e.g. Dawkins, 1958). These methods are in fact those still most widely used in assessing the growing stock present in rainforest, and are likely always to remain the basis for the more intensive types of assessment, such as those regularly carried out ahead of logging in Malaya and elsewhere (Chapter 10). However for extensive areas of rainforest, such as still exist in many tropical regions, their utility is greatly limited. Ground assessment encounters the problems of measuring diameter and height. They also face in virgin rainforest the problem of unmerchantability. As discussed previously this has two phases, one concerned with unmerchantable species, and the second with useless stems of merchantable species. In the assessment, economic species for the time and locality should be known, but in view of the ever-growing range of "economics" it is obviously desirable to assess all stems of good form and suitable size: even though many of these are currently unmerchantable this position is likely to be constantly changing.

Individual unmerchantable stems pose a different and more difficult problem to the forest assessor, and subsequently to the exploiter. Some are clearly useless due to poor form or obvious signes of severe internal decay, but invariably in virgin forest (and not merely in rainforest) there are many stems which, on appearance, may or may not be worth the cost of felling and extraction. Rot and the results of insect damage inevitably occur in a proportion of the larger trees in virgin forest, but the extent of the damage is rarely visible in the standing tree. Various methods of estimating the soundness of individual stems exist, based on the assessors' knowledge of the behaviour of the species, on the ringing sound made when the stem is hit, and on other similar devices, but none are precise and the errors which they bring into the assessment results can invalidate subsequent attempts at maintaining sustained yield, and can also lead the loggers into unnecessary expense when useless stems are felled or potentially useful stems are left standing. . In New South Wales the logging problems are largely overcome when the Forestry Commission staff marks all stems to be felled, the fallers being given an allowance if any marked stems prove useless and the timberman being given the option to extract any marginal logs at a nominal royalty. These measures, however, do not overcome the other problem which arises when the unmerchantable volume differs appreciably from that which was assessed.

The growth rate of trees in rainforest, the other basic piece of information needed in introducing sustained yield, is still far from certain in most areas. The problems here have already been discussed in Chapter 6: the absence of reliable growth rings from most rainforests, the great variations in diameter growth of individual trees of similar size and species, the flaking of bark to give apparent diameter shrinkage, and so on. Much of what increment data are available comes from virgin forest (e.g. Keay, 1961), where the growth phenomena are probably very different from those in treated forests. Efforts are now being made to overcome some of these problems by dynamic sampling. (Dawkins, 1958, Chapter 4), but much more work is necessary before it will be possible to relate increment to yield in most of the world's rainforests.

Policy Problems

The forester managing rainforests has to cope not only with these technical and economic problems, but also with some involving governmental policy. In this he is of course not alone: all governments with a forest estate must have some policy concerning its management, be it declared or undeclared, be it one of immediate expediency or one based on long range land use planning, and the forester, who is most frequently a government servant, must work within the bounds set by this policy. Nonetheless rainforest areas appear for various reasons to provide more problems arising from these policies than do most other forest areas. These problems are many and varied, and only a few examples can be quoted here to indicate the type of situations which the forest manager may face.

Land tenure is a common problem. In many tropical countries the present political units are amalgams of various tribes which, until quite recently, were locally autonomous, and often at war with their neighbours. Land within each tribal area was frequently vested in the local chief, so that governmentsof a wider nature do not possess land which can be dedicated readily to forestry: dedications in such cases involve purchasing the land from the tribe or else persuading the tribe itself to reserve forest areas, usually with the forest's management being left largely to the government forest service. Such problems of land tenure have resulted in very slow progress in the dedication of a permanent forest estate in Eastern New Guinea. In the former Gold Coast Colony (now Ghana), Foggie and others (1952) note that only one rainforest reserve was owned by the Government, on all others the ownership resting with the local "Stool" though managed by the government: as a result the tribal owners, not the manager, decided to whom the timber should be sold and at what price, while the government met all costs of protection and administration with the Stool meeting the development costs from current revenues. Very similar positions prevail in Nigeria, though a larger proportion of the forest reserves is vested in the government: these are mostly areas which in earlier times were disputed territory between tribal groups (Keay, 1959a). The very valuable forests in the Benin area of Nigeria are, for example, owned by the Benin Divisional Council, and an agreement with the Regional forest service provides for the setting up of a £40,000 forest regeneration reserve fund, for the paying of most administrative expenses from the revenue, for 40% of the remaining nett revenue being used for silvicultural treatment in accordance with the approved working plans, and for the remaining nett revenue to go to the Council. This scheme appears to function well, though it clearly introduces problems which are absent when the Government has sole ownership rights.

Similar problems, which may affect government-owned forests, arise from long established local rights on the forest for such purposes as hunting, the collection of minor products and even the obtaining of major products for local use, if not for sale. Another practice still exercised in many areas, though seldom with the approval of the forest service, is that of shifting cultivation by more primitive tribes. Some areas have been able to channel this and similar agricultural systems into highly successful taungya plantation schemes (see Chapter 9), but even such a well developed country as Malaya still experiences shifting cultivation in some of its less accessible forests (Wyatt-Smity, 1958).

Countries still possessing relatively large areas of rainforest may face quite appreciable problems to organised forest management when extensive areas of forest are suddenly opened for closer settlement. When such development threatens forest reserves, strong action is needed by all interested parties to ensure that adequate areas of forest remain for all future needs (see Chapter 7). However, even when the reserves are not threatened, the increase in timber supplies from the land being cleared can lead to a decline in production from the actual permanent forest estate, with consequent disruption to planned management. This position is currently occurring with the land development schemes in Malaya.

Other major policy problems of a different type exist also. Taking a long range view it seems inevitable that more and more of the production forests in rainforest regions will ultimately be managed as plantations rather than by the use of natural regeneration: pressure for land for agriculture and the apparent greater efficiency of certain species normally grown in plantations will in time force this change. The question then arises as to the timetable for changing the emphasis in rainforest management from natural regeneration to planting. Natural regeneration treatments can in many cases be comfortably financed from the revenue obtained from logging the original forest: the process is financially painless, still providing profit for the forest owner. Planting involves a deliberate outlay of money for the future, and immediately becomes subject to the dictatorship of compound interest. On such fallacious economic reckoning money is frequently spent on treating natural forests with little thought of the likely return, while plantation schemes languish unless they can be established by such low cost methods as taungya. Certainly in any rainforest country with existing large reserves of forest, the natural forests must be expected to provide the bulk of the forest produce for many years to come, and there can be little argument, that these require treatment to maintain and increase their productive capacity. However, there does seem a need for carefully weighing the costs and expected returns both from treated natural forest and from plantations, and for considering the result in the light of anticipated population growth, demand for timber and likely ultimate area of production forest. It is felt that this examination will more often than not point to the need for greater immediate emphasis on plantations. Eggeling (1952) has made this type of study in East Africa, and concludes that "work must wherever possible be concentrated and except where natural regeneration can be obtained easily, the emphasis .....should be on compensatory planting".

This switch to plantation establishment is likely to be speeded up when the natural forests take longer than 100 years to produce mature trees, as happens in many temperate rainforests. Governments generally realise that trees take long to grow, and rotations up to 100 years can be tolerated, but there appears to be definite mental block against rotations lasting longer than a century, particularly where exotics or certain native species are known to be capable of producing mature trees in half this time or less from plantations.

These matters, whilst confronting the forester with real problems, still concede the necessity of managing forests for the future. Unfortunately some rainforest areas exist to this day where the forests are regarded as mines, to be exploited for present benefit but not to be managed for the benefit of future generations. In such areas attempts at management on any but a token scale are futile: here the emphasis of the forest authorities must essentially be on reasoned be on reasoned propaganda, on publicity and on local demonstrations of what can and must be ultimately done.

Other Problems and Their Lessons

Preceding sections have dealt in passing with a number of problems facing the rainforest manager. In addition to these, there are many others of a more purely silvicultural nature and these will be considered in the next few chapters.

There is considerable importance in recognising all these difficulties at an early stage. In total they form a formidable list which at sight may deter any but the most stouthearted from venturing into the management of rainforest. Yet the fact remains that around the world forest services are actively engaged in managing rainforest, often with striking success. In all of these countries many of the problems mentioned have been present and have, with the effluxion of time and with experience, been overcome. Undoubtedly the solutions to the problems, economic, silvicultural, technical and political, have often added to the cost of producing timber from the managed rainforest areas, yet even so the produce is being obtained and is contributing to the countries' development and export earnings. Probably in no land are the problems of the rainforest manager unique, though their scale may be greater in some countries than others. Appreciation that others have faced and overcome similar problems is an encouraging thought.

One of the main steps in overcoming these difficulties is taken when the forest service adopts a definite policy on its aims, and the methods to be used in achieving these aims. Some of the points to be considered in developing a suitable policy for rainforest areas will be discussed in Chapter 13.

CHAPTER 9

PLANTING IN RAINFOREST AREAS

> "That famous disease, 'planting measles', is contracted through deficiency of the ecological vitamin."
> Beard (1947)

> ".... as population and demands for land and forest products grow and as other types of agriculture progress, intensive plantation culture may prove to be the only economical source of timber in the tropics."
> Wadsworth (1960)

Introduction

This report is concerned primarily with the management of natural rainforestcommunities, and a discussion of plantation management in rainforest areas may seem out of place. However there are a number of reasons why it should be considered. In the first place, in practically all areas where forest management in its broadest sense has been introduced to rainforests, one of the earliest developments has been to attempt to convert the normally mixed, all-aged, natural forests to even-aged stands of one or a few species by planting. The apparent simplicity of this approach has obvious attractions, but many forest services in their early years have learnt to their cost that there are also difficulties, both technical and managerial, to be overcome. The choice of species, seed supply, nursery and planting techniques, weed control, insect and fungal attack, damage by larger game, and by no means least the cost of the operations, are some of the difficulties that have had to be faced. Depending upon the severity of these problems and the success with which they have been tackled the forest services either persevere with planting or finally abandon it as an apparently overwhelming task and revert to managing the natural community. It is this initial effort at plantation establishment, all too frequently of dubious success, that Beard has termed "planting measles". Another problem, of a different type, arises from the fact that in most countries the area of rainforest originally available is large, but the funds for planting are limited, so that only a relatively small proportion of the forest can be converted to plantation.

On the other hand techniques involving natural regeneration are not everywhere practicable in rainforest countries. In some places large areas of forest have been devastated by destructive logging techniques or by temporary agriculture: long periods must elapse before natural succession will produce economic timber crops on such sites, and planting is a means of speeding up this succession - the so called "accelerated succession hypothesis" discussed by Tansley (1944). In other areas the most valuable species of the natural rainforest tend to be scantily represented both as mature trees and as regeneration, and artificial means of introducing these into the community by planting may be highly desirable. Such a process is clearly on the borderline between outright plantation establishment on the one hand, and the management of natural forests on the other.

Planting also deserves some examination on the grounds suggested by Wadsworth in the second chapter quotation. As population increases and more land is required for agriculture, it becomes increasingly important for forestry to make the maximum use of the land at its disposal. Where the forests are intended mainly for the production of timber it will be necessary to obtain the highest possible output of timber from the forest estate, and all indications are that, in terms of merchantable volume, much greater output can be expected from artificial plantations than from forests where the reliance is on natural regeneration. Plantations lend themselves to extremely intensive management, with the resulting benefits that this can bring: natural forests (or perhaps more aptly, unnatural forests) rarely are so amenable.

Finally it is perhaps worth mentioning that plantations, with relatively large areas of a few species growing in straight rows, are valuable politically. They give the public the impression that the forest service is really doing something, and they rarely fail to bring enthusiasm to ministers and members of parliament. By contrast, rainforest being managed by a clear cutting system tends to resemble an unsuccessful attempt at rural development to the uninitiated in its early stages, while in its later stages, or under a selection system, it looks like just more jungle.

The literature on planting practices with reference to rainforest areas is voluminous, and reference should be made for details to such publications as Troup (1932), Champion and Brasnett (1958), the papers on exotic forest trees presented by various Commonwealth countries to the 7th British Commonwealth Forestry Conference (1957), and the F.A.O. series on tree planting practices in various regions of the world. Wadsworth (1960) has given an excellent summary of trends in planting in tropical areas. In this chapter it is proposed only to discuss the main developments in the rainforest areas and to examine briefly a few examples of planting practices.

Reasons for Planting

The early attempts at planting in the rainforest areas usually aimed at establishing highly valued local species of relatively scattered occurrence in the natural stands. Examples are Toona australis (red cedar) in eastern Australia, Balanocarpus heimii (chengal) in Malaya, Khaya spp. and Entandrophragma spp. (African mahoganies) in Nigeria, and Swietenia spp. (true mahoganies) in parts of tropical America. Where exotic species were introduced at an early stage they were usually again species of high commercial value in their areas of origin, such as Tectona grandis (teak), which is rarely itself a rainforest species, and Swietenia. This continues to be a developing process to the present: as more species become known on the world's timber markets, so is more attention paid to the planting of these species, both in their native lands and elsewhere as exotics. As examples one can mention the African Chlorophora excelsa (iroko), now successfully established in Trinidad, and Flindersia brayleyana (Queensland maple) which appears promising in Malaya. Some valuable species that have been widely planted in rainforest areas occur in relatively high volume stands, but have proved refractory to regenerate naturally. Such species are usually not present in climax rainforest: the Araucaria spp. (hoop, bunya, and klinki pines) of eastern Australia and New Guinea and Aucoumea klaineana (okoume) in Gabon are examples.

However, as explained in Chapter 1, while the rainforests were first valued for only a few specialty timbers such as those mentioned above, there has been a general increase in the markets for a much wider range of species from the rainforests. Particularly does this apply to those species with lighter, general purpose timbers, usually moderately common in the natural rainforests, usually also of faster growth rates and frequently less difficult to regenerate, naturally or artificially, than the more highly valued species. Into this group come Triplochiton scleroxylon (obeche) and the Terminalia spp. of West Africa. These species have been extensively planted in their native areas and have also been introduced to tropical America. Such species appear to have assured export markets and, with the use of impregnation techniques to increase their durability, seem destined to provide much of the rising local demand for timber in their native lands for many years.

A further development of this trend towards greater emphasis on the planting of general purpose timbers comes with the introduction of even faster growing species from outside the rainforest, such as Pinus spp. and Eucalyptus spp. To date, most of the rainforest planting with this group has occurred in the sub-tropical and temperate rainforest zones and in the tropical mountains. This is probably in part due to the pines and eucalypts suitable for such sites (southern Brazil, New Zealand, Central African highlands) being better known for a longer period than those adapted to truly tropical conditions. Other reasons for the longer planting of these genera in the cooler rainforest regions are that the native species tend to be very slow growing, thus forcing attention towards faster growing species at an earlier stage; that, in the case of southern Brazil and New Zealand, the demand for cheap, easily produced, industrial wood for a technological society occurred sooner than in the tropics; and that the extraordinary increments obtained from some of these species (e.g. Pinus radiata, P. patula, Eucalyptus grandis) made them appear a good planting proposition, sometimes without thought for what was to be the market for the end product. In some areas, where much of the original rainforest had been destroyed, eucalypts have been extensively planted as a source of fuel. With the trend away from wood fuel the future of these plantations frequently poses a real problem, as fast-grown eucalypts on a short rotation tend often to produce a very low grade of timber. Some countries have been able to utilise this material for pulp production, but in general the current trend is to reduce the area under eucalypts and to increase the area under pines. Except in those areas where pines and eucalypts occur naturally adjacent to rainforest, usually as a result of fire (e.g. Pinus caribaea in Central America, P. merkusii in Sumatra, Eucalyptus deglupta in New Britain), this group of species for planting has until very recently received relatively little attention in the lowland tropics, but they are now being tried in many areas and are being planted on a commercial scale for particular purposes in some: examples are the P. caribaea plantations being established in Surinam as the basic source of long-fibred pulp for a proposed paper plant that will also utilise species from the natural rainforest, and the use of the same species in Malaya to reforest the larger patches dominated by Imperata cylindrica (lalang; a rhizomatous grass) as a result of war-time agriculture and subsequent burning on forest reserves.

The reforestation of areas out of timber production has had to be faced in many countries, and a wide range of species has been employed. Pinus spp. generally have proved most successful in overcoming, and ultimately suppressing, the heavy early competition of grasses, though in such grass-dominated sites effective fire control until the pines are well established becomes essential and, in some rainforest areas, has had to be faced for the first time by forest services engaging in such reforestation. Queensland, with a long history of planting Araucaria cunninghamii, is using this species to replace forest cover on some 4,000 acres of former farmland that has reverted to forest reserve after being isolated by the construction of the Tinaroo Dam: P. caribaea competes with the heavy grass cover more successfully, but the slower growing araucarias are preferred because of their greater ultimate value. In Puerto Rico the absence of a suitable mycorrhiza has until recently prevented the successful growth of pines on the island, and the native Tabebuia pallida has given satisfactory results in producing forest cover on some of the badly eroded hills. In Malaya attention has been given to afforesting the spoil heaps that result from widespread tin-mining activities (Mitchell, 1957).

Planting has also been employed in areas of forest poor in economic species. Frequently such areas result from past farming, that has produced a secondary succession in which economic species are almost entirely lacking; at other times they may occur in a forest that is just naturally poor. Malaya provides examples of both in the tracts of secondary vegetation (belukar) that followed agricultural squatting on forest reserves during the Japanese occupation, and in what Wyatt-Smith (1961b) has termed the Kempas - Kedongdong (Koompassia malaccensis - Burseraceae) forest type. Similar poor forest stands may result from past selective logging having removed all the more valuable stems, as in some areas of subtropical rainforest in New South Wales.

Thus planting in rainforest areas has been carried out for a number of reasons:

1. Creating forests rich in the more valuable species and subsequently in the faster growing, general purpose species, both native and introduced.

2. Creating forests of very fast growing species suitable for general industrial timber.

3. Replacing slow growing, native species difficult to regenerate with forests of faster growing, more amenable species.

4. Establishing forests to provide local needs in areas where the original rainforest has been destroyed.

5. Re-establishing forest cover on areas that have been devastated by previous poor land use.

6. Improving the composition of forest poor in economic species.

Problems of Planting

The problems arising in planting schemes in rainforest areas are numerous and frequently more intense than in localities with less luxuriant native vegetation, though at least partial solutions to most of these have now been found in various parts of the world.

The first problem of course is whether to plant or not. In most rainforest countries one of the primary objects of the forest service must be to ensure that the local population does and will continue to receive from the forests the timber needed by the community. Where population is high and the available land for production forests is low, as in some islands of the West Indies, there can be little doubt that intensive forestry with emphasis on high yielding plantations must be the ultimate choice, and as population increases generally this approach will need be taken over wider and wider areas. Planting is also the obvious remedy for producing economic timber on currently unproductive sites and in areas where the original rainforest has been destroyed, as mentioned above. Elsewhere the choice may be more difficult, particularly in regions where the area of forest is large and the population is relatively low. Here the decision must be made between using the inevitably limited financial resources of the forest service to regenerate large areas by some extensive method or to apply a more intensive treatment to restricted areas, and the decision must be based on a study of current trends in population growth, the need for agricultural development in the future, the foreseeable pattern of timber requirements, and the nature of the existing forests and the main commercial species themselves. Where the choice is for intensive treatment by planting the plantations are termed compensatory. This approach has been used in many areas, and examples can be found in the *Pinus radiata* plantations of New Zealand, *Araucaria* in southern Queensland, and in the plantations in parts of Ghana, Nigeria, East Africa and in many Central American countries. In some cases (e.g. Ghana and Nigeria) compensatory plantations are still being established, though the residue of the forest estate is receiving extensive treatment. Eggeling (1952), in discussing the pros and cons of various types of regeneration treatment in East Africa, comes out strongly in favour of compensatory planting for that area. In the French-speaking parts of Africa the same problem has been faced in a different way: artificial regeneration has been employed, but on an extensive scale by enrichment planting, planting seedlings of economic species at relatively wide spacing in the forest after logging. On a large scale this has been practised in areas where it has been considered too difficult or risky to rely on natural regeneration (Aubreville, 1953a), though it is now well recognised that the amount of subsequent tending needed to establish the plants may be appreciable (Aubreville, 1953b: Brasnett, 1949). Enrichment planting has also been widely used to supplement natural regeneration.

Having decided to plant and having determined the type of planting to be used, the next problem is that of the choice of species. Obviously these must be species suited to the local conditions and capable of satisfying the reasons for the planting being undertaken. In certain specialised sites (e.g. severely eroded slopes, mine tailings), the choice may be very limited, as only a few species are able to form a forest cover on such sites. Sometimes, as in the case of the Queensland and New Guinea araucaria plantations, the planting scheme aims at maintaining a sustained yield of an important native species which is basic to much local industry. However, in most instances the choice of species able to grow is considerable, and ultimately, with the unavoidable entry of economics into such matters, the selection will depend on which species will give the greatest financial profit. Considerable literature is now available on the behaviour of individual species for planting in various regions (see Champion and Brasnett, 1958, for a selection of references), and much can be learnt from the experiences of other regions of similar environmental conditions. However, it must be stressed that the use of any species for planting schemes should only be undertaken after the species has received extensive trial, preferably extending over a long period of years, and at the same time forest research organisations throughout the rainforest zones should persevere with the trial of new species, both native and exotic. Despite the wealth of information already available there are many potentially valuable species which as yet have barely been tested for planting, at least outside their native lands. The dipterocarps of South-east Asia are probably the outstanding example, largely due to the difficulties of seed supply and storage. The examples of *Pinus radiata* and *Eucalyptus robusta*, both species, like the prophets of old, being of little honour in their own countries, should always be kept in mind by those responsible for the introduction and trial of new species. In dealing with exotic species it should also never be forgotten that distinct racial strains, or provenances, may exist, particularly with species that have a wide or discontinuous distribution. As far as possible, these also should receive trial.

The costs of establishing open plantations may be extremely high. Henry (1960) gives the direct costs of establishing plantations at Akilla, in Western Nigeria, by departmental labour as £38 per acre up to year 6, and estimates the overhead costs at an equivalent sum. Expenses of a similar order can be matched from most rainforest areas where departmental labour has converted natural high forest to plantation by clearing and planting. Such costs grow to frightening proportions under the grim hand of compound interest*, and provide a strong incentive to concentrate on fast growing species with short rotations in the plantations. These costs have been greatly reduced where it has been possible to use some form of taungya planting, in which the clearing, planting and early tending can be combined with the raising of agricultural crops. By comparison with the costs at Akilla, Redhead (1960c) quotes the costs of establishing species other than *Terminalia ivorensis* (which is cheaper) in the taungya plantations at Sapoba, in Western Nigeria, as £6/3/- per acre up to year 6, again excluding the overheads.

Other problems in rainforest planting are more directly technical, though where solutions are not readily forthcoming they can have a strong bearing on the matters just referred to. They fall into six main groups which are closely interrelated: seed supply and storage, nursery technique, site preparation, planting, tending, and damage agencies.

Seed Supply and Storage

Many rainforest species are irregular in their seeding habits. The Malayan mountain dipterocarp, *Shorea platyclados*, is

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* At 5% compound interest, one unit of cost at establishment increases to 4.3 units at 30 years, 18.7 units at 60 years, and 131.5 units at 100 years.

recorded as having gone 17 years between successive flowerings in the Tapah district of Perak (Malayan Forestry Department, 1961). Records of the fruiting of Triplochiton at Gambari F.R., in Western Nigeria, show the existence of only 7 mast years over a period of 32 years (Mackenzie, 1961). Araucaria cunninghamii in New South Wales has heavy seed years, when the seed tends to have a higher germinative capacity than in poorer years, at irregular intervals of about 5 to 7 years. While many other species are much less irregular, the fact remains that a large number of species, suitable otherwise for planting in rainforest areas, produce seed only erratically.

Another common characteristic of rainforest species is that the seed, once ripe, loses its viability very quickly. The figures for several Malayan species (from Barnard, 1954) given in Table 13 show the rapidity with which the germinative capacity falls off: in this case the seed had been stored in dry sawdust. Flindersia brayleyana in North Queensland loses its viability rapidly a month after ripening. In New Guinea Araucaria klinkii loses its viability at the rate of 10% per week (Anon. 1960). Of 23 important Amazonian species for which details of seed viability are given by Pitt (1961), 8 are listed as losing their viability very quickly and only 5 as having long viability. Aucoumea, with a germinative capacity of 80% at collection, has this fall to 15% in 2 weeks and to nil in 3 weeks (Becking, 1960). There are of course exceptions. Many of the hard-coated seeds of leguminous trees retain their viability well, and Pitt observes that Bertholletia excelsa, with good viability, takes "ages" to germinate: more detail about this species is given by Barnard who notes that seeds, placed 3 inches deep in sand and watered if no rain fell for 3 days, commenced to germinate after 3 months and were still doing so 4 years later. Similar results have been experienced with Gmelina leichardtii and Elaeocarpus grandis in New South Wales.

Irregular seed years and poor viability are not serious drawbacks to planting operations if the seed can be artificially stored. Araucaria cunninghamii will retain its viability well for at least 8 years when stored at a temperature of about 10°F, and A. klinkii can be successfully stored at about 38-42°F in airtight containers. Many Meliaceae can also be stored satisfactorily at temperatures slightly above freezing, as can many (and indeed probably all) of the Pinus spp. used for planting in rainforest sites. Eucalyptus grandis, used for reforesting certain rainforest sites in New South Wales, normally seeds annually, but occasional failures in the annual fruiting necessitate keeping a supply of seed in hand: the viability is retained for several years when stored at room temperature in closed containers with insecticide added. Unfortunately storage techniques for many species that might otherwise be of value for planting purposes are still not available: the list is lengthy and includes the dipterocarps and the African Triplochiton.

There are obvious advantages in using for planting trees that seed regularly, so that storage is unnecessary. Where storage is required there are still advantages if the seed will retain its viability at moderately high (near room) temperatures: near or below freezing storage chambers, larger than a household refrigerator, are usually difficult to come by in forest regions and, when available, the cost of hiring space to store bulky seed is usually high.

TABLE 13

Loss in Viability by Malayan Species
(after Barnard, 1954)

Germinative Capacity

Species	At Collection	Length of Storage (days)				
		7	14	21	28	35
Shorea leprosula	78%	71	58	28	nil	nil
S. acuminata	74%	58	28	8	nil	nil
S. parvifolia	84%	50	80	38	nil	nil
S. resinanigra	88%	92	nil	2	nil	nil
Koompassia malaccensis	50%	40	22	24	6	8

Species that seed irregularly and that cannot be stored are difficult to incorporate into a planned planting scheme, though there are some partial measures that can be taken to alleviate the problem. Where the species is a native one, wildings (natural seedlings in the forest) can often be obtained. As discussed previously, many such seedlings will exist for long periods on the forest floor without making appreciable growth; they can be lifted from the forest, usually hardened off for a period in a forest nursery, and then used for planting in lieu of normal nursery stock. This practice is used to some extent with Shorea spp. in Malaya and with Lovoa trichilioides in Nigeria, and was employed to give some of the oldest and most successful plantations of Araucaria cunninghamii in New South Wales. Because of the longevity of these seedlings in the forests, supplies of planting stock may be available for the entire period between successive seed years. A modified version of this approach is occasionally used following seed years when some of the nursery stock is deliberately kept suppressed by shading, topping and root wrenching, thus holding it back so that it can be planted the second year. By analogy to natural rainforest conditions there appears nothing fundamentally undesirable in this method, as opposed to the action, also sometimes employed, of using the cull plants from one year for planting the next: this may well have genetic disadvantages. In the Sapoba taungya plantations in Nigeria one fifth of the annual coupe is normally planted with Terminalia ivorensis and the remainder with a mixture of Nauclea diderrichii and various local Meliaceae in a 5:1 mixture. However when Triplochiton seedlings are available these are preferred to the Terminalia and are planted over one third of the coupe; the Triplochiton is thus brought into the crop whenever possible.

Nursery Technique

Except where artificial regeneration is brought about by direct sowing, or where wildings are used (and in the latter case the plants normally spend some time in a nursery before planting), the seedlings are raised in nurseries. Nursery technique in a general way covers all the operations between preparing the seeds for sowing and packaging the resultant seedlings for transport to the planting site. The actual details of nursery technique differ greatly with the species being used and also frequently with the same species in different areas.

The nurseries may be either temporary or permanent. Permanent nurseries are probably to be generally preferred: water supplies, shade frames, equipment sheds and so on can be constructed to last, without the recurring expense of erecting less substantial structures at short intervals. Where, as with most conifers, the soil needs to have a suitable mycorrhizal fungus present, this need only be introduced the once. Disadvantages in permanent nurseries may be the ultimate loss in soil fertility, the build up in pathogens and the distance to transport seedlings to the planting site. The first disadvantage can largely be overcome by manuring and crop rotation, the second can usually be controlled by the use of modern insecticides and fungicides, while distance ceases to be of much moment when lorries can be used to transport the planting stock.

The type of nursery depends largely on the species being raised. Most Pinus spp. are sown into open beds and bear the full force of the sun from the time they germinate, but the majority of rainforest species need to be raised in their early stages under some form of shade. In some nurseries (usually temporary) the shade is provided by forming the seed beds under existing trees. While this has advantages in terms of cost, the seedlings produced are usually uneven, and may be severely retarded, in development* through the root competition of the shade trees. More usually some form of shade frame is erected, ranging from the extensive high shade constructions (7 feet or more high) of the Queensland araucaria nurseries to small, low, temporary frames over individual beds. In many tropical areas the shade is provided by thatched palm leaves and can be varied according to the seedlings' needs by removing or adding fronds; other methods of providing shade come from the use of wooden or aluminium slats, which may be either fixed or movable, roll-up bamboo curtains, and sheets of hessian. Where fixed slats are used, normally to provide 50% shade (i.e. 3 inch slats alternating with 3 inch wide openings, as in the araucaria nurseries of eastern Australia), the slats should be oriented in a north-south direction to give a constant interchange of light and shade upon any point within the beds throughout the day. Wooden slats can prove undesirable in areas subject to heavy storms, particularly where small seeded plants are being raised, because of the regular pattern of heavy drops of drainage water causing severe wash in the beds beneath; aluminium slats (similar to the material often used in venetian blinds) may be preferable in such cases as their slightly concave face can be used to drain the bulk of the rain water away from the beds. Where it is not necessary to vary the amount of shade during the seedlings' term in the germination beds, high, fixed-shade frames probably require less maintenance and make for easier working conditions: this is the case with Araucaria cunninghamii and Flindersia brayleyana in Queensland. Where however shade manipulation during the plants' development is essential, as with A. klinkii in New Guinea (Anon., 1960), low shade frames are to be preferred. The provision of suitable shade is often essential to the production of satisfactory planting stock, and the necessary degree of shading can only be determined by experiment or (more frequently) by trial and error.

Since most rainforest species have no dormancy in their seeds, special pre-treatment is seldom necessary: with their usual rapid loss of viability the seeds should be sown as soon as possible after receipt at the nursery. However pre-treatment is desirable with some species. Certain Pinus spp. (e.g. P.taeda and P. elliottii) used in subtropical areas benefit from stratification (moist cold storage for several weeks) before sowing: the resultant germination occurs more rapidly than with unstratified seed, giving a more even crop of seedlings and reducing the danger of weed competition. Many hardcoated legume seeds require pre-treatment to promote rapid germination and this may be brought about by nicking the seed coat or soaking for a period in hot water. Tectona grandis, which has been successfully planted in many rainforest areas where there is a regular dry season, is a species whose seeds normally retain their viability for a long period and germinate irregularly over a period of years: alternate soaking and exposure to sunlight for a number of days has been found to promote regular germination. With some slow germinating spedies (e.g. Bertholletia, Gmelina leichhardtii) a means of speeding germination has still apparently to

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*This may not be a disadvantage to the seedlings physiologically, but it well may be a drawback where the aim is to produce even sized planting stock within a given time schedule.

to be found: these provide a case where the use of wildings if available, may well be preferred to raising stock from seed.

The soil of the nursery beds should normally be light, rather than heavy, in texture, and of moderate fertility. A very high level of fertility may be a disadvantage if the stock produced is too succulent or if the seedlings are to be planted in a site of low fertility The beds should be raised to produce good drainage. Symbiotic microorganisms may need to be introduced when certain species are being raised for the first time: this may apply with Casuarina spp. and some legumes, and certainly applies with the mycorrhizal fungi needed by most conifers. The microorganisms can usually be obtained by incorporating into the nursery top soil from beneath healthy trees of the species to be raised. However, where the species is an exotic not yet present in the country difficulties in initial supply may arise.

Sowing methods vary with the species being raised. Eucalypts and some other very small seeded species are commonly germinated in seed boxes and then pricked out at a very early stage directly into the planting containers (tubes, pots, etc.). Some species, particularly those that are large seeded or irregular in their germination, may be merely spread on theground and kept watered, and then as the individual seeds sprout the young plants are carefully moved into a nursery bed. Where the seedlings are to spend a relatively short time in the germination beds fairly close sowing, either broadcast or drill, is usually practiced, but where the seedlings are to be allowed to develop to some size in the germination beds the seeds should be adequately spaced to permit proper seedling development, the spacing theoretically being varied with the germinative capacity of the seed batch. Thus at Sapoba Terminalia and Nauclea are sown densely in the germination beds where they spend 6 months; the seedlings are then moved to unshaded transplant beds where they are spaced 12 inches by 18 inches and remain for 12 months. By contrast Entandrophragma spp., which are sown 6 months later, remain in the one bed until required for planting 2 years later: their seeds are spot sown at 9 inches by 12 inches spacing and the seedlings are shaded for 9 months, after which shade is removed.

Watering is usually necessary during dry spells when the plants are germinating or still small, but should be reduced as they develop in order to harden them off. Weeds should be kept under control, and in permanent nurseries should not be allowed to reach the fruiting stage. Temporary soil sterilants (e.g. methyl bromide, allyl alcohol) have given good weed control when applied to nursery beds shortly before sowing in pine nurseries and appear suitable for wider use. However, selective weedicides, applied to seedling crops in order to control weeds, should only be used after careful investigation, as many of these may destroy the seedlings also.

The time of sowing is beyond the control of the nurseryman when he is dealing with species whose seed cannot be stored: obviously such seed must be sown immediately if it is not to deteriorate. Other seed should be sown at the time necessary for it to produce optimum planting stock for the planting season. Since environmental conditions can be varied in the nursery far more readily than in the planting area, it is clearly desirable to organise the nursery technique so that the best type of stock is available at the time when planting can be most safely carried out: in tropical areas with definite wet and dry seasons this optimum planting season is early in the wet season, in temperate regions it will normally be during the winter, while in regions with no marked seasons (e.g. much of Malaya) the choice of the planting season may be determined by past weather records showing the reliability of the rainfall at different times of the year (see Barnard, 1954). The length of time required to produce such planting stock from seed varies with both species and locality. The extremes for species normally planted in rainforest sites are probably marked by certain eucalypts, which may be plantable in 2 or 3 months from seed, and by Araucaria cunninghamii in eastern Australia, where about 27 months are required. Dryobalanops aromatica in Malaya takes 3 months, Tectona grandis in New Guinea from 6 to 8 months, most temperate and subtropical pines about 10 months, Flindersia brayleyana in north Queensland and A. cunninghamii in New Guinea about a year, Terminalia ivorensis and Nauclea diderrichii in Nigeria 18 months, and Entandrophragma spp. in Nigeria 2 years. Sometimes the season of sowing may strongly affect the quality of the planting stock: because of seed shortage A. klinkii in New Guinea has been sown immediately after seed fall (about November), in the wettest part of the year, and planted 12 months later, but this wet season sowing has promoted much fungal attack. As soon as sufficient seed reserves can be built up it is proposed to delay sowing until the dry season and raise the plants for 18 months in the nursery (Anon. 1960).

Where there is a distinct winter season and the plants cease growth and form a resting bud (e.g. Pinus radiata, P. elliottii) the nursery stock can be planted open-rooted and no special attention in the nursery between sowing and lifting for planting is required. However, even in temperate regions this most simple form of planting is not always applicable, most eucalypts and some pines (e.g. P. patula, P. caribaea), among many other groups, being difficult to plant in this way. In tropical regions there is usually no evident resting phase in the seedlings growth or, if there is, it does not coincide with the desirable planting season. Consequently most rainforest species require some form of additional treatment to prepare them for planting: an apparent exception is Malayan dipterocarp, Dryobalanops aromatica, which is being successfully used for enrichment as normal, open-root stock in parts of Selangor. The forms of such treatment vary. One very simple treatment is to root wrench or root prune the seedlings, as recommended by Wyatt-Smith for Dryobalanops (Vincent, 1961). Another operation frequently used is to move the seedlings during their nursery stage from the germination beds to open transplant beds; here the plants have more room to develop, the process helps to harden them off and to weed out the weaker individuals, and at the same stage it permits the area of more costly shade beds to be reduced as the seed can be sown fairly densely. Such plants usually require further treatment before planting. The simplest form of treatment is to prepare stumps or striplings: in Nigeria, where stumps are the standard type of planting stock in the Sapoba taungya plantations, the seedlings are cut back to 4 inches of stem and 6 inches of taproot at the time of lifting and are then planted open-rooted; stems up to the thickness of one's thumb are acceptable. This method is commonly used with Tectona, but is not suitable for species which are unable to produce strong coppice growth from the stump. Striplings are commonly used for enrichment planting where tall plants have an advantage in avoiding both weed competition and animal damage. Tall plants are used (up to 8 ft high) and all leaves are stripped from the stem before lifting. A modification is in the use of "cut-backs", which are striplings cut back to the old stem wood shortly before planting (Brasnett, 1949).

Species which cannot be satisfactorily planted open-rooted, either as complete seedlings, striplings or stumps, must be prepared for planting with a soil ball still adhering to their roots. Various devices are in use. Eucalypts, which, with their rapid growth, can be planted while still small, are sometimes transferred from the germinating boxes to planting trays and these are subsequently taken to the planting site and the individual seedlings cut out from the tray with a cube of soil containing their roots. More usually the seedlings are transferred from the germination beds to individual containers of some sort. These may be metal tubes (commonly used in Australia), veneer rubes, bamboo tubes, tarred paper, soil blocks (used for eucalypt planting in southern Brazil), palm leaf baskets or, increasingly commonly, polythene plastic tubes along with many other types of container. Polythene tubes are now being used in many areas, being cheap, strong, light, easily handled and expendable: those used in Malaya are made from 200 gauge (0.005 mm.) clear plastic, and measure 9 inches by 6 inches, with 16 drainage holes stamped in their base; when filled they stand about 7 inches high and 4 inches in diameter, and in planting the plastic can easily be ripped away from the soil cylinder within. The seedlings are generally transplanted into the containers some months ahead of planting; eucalypts shortly after germination, when 2 or 3 pairs of leaves have appeared; P. caribaea normally at a similar stage of growth; A. cunninghamii in New South Wales after about 15 months in the germinating bed and 12 months before planting; Flindersia brayleyana in north Queensland after 5 months in the germinating bed and 6 to 7 months before planting. After tubing the seedlings should usually be shaded and well watered for some days, after which they can gradually be exposed to more open conditions.

In addition to insect and fungal diseases in the nursery, small mammals and birds may cause damage, the birds usually as the seed germinates. The most common mammal pests are rats and mice, and whenever they occur efforts should be made to control them by poisoning and trapping.

Nursery practice is one of the most important aspects of any planting scheme, and the above notes indicate some of the practices that have been developed to produce satisfactory planting stock in rainforest areas. The correct technique for any species and area is that which produces the best stock at the lowest cost. Absence of a suitable technique may upset an entire planting programme. As an example, for a number of years in New Guinea great difficulty was experienced in raising seedlings of A. klinkii; only after considerable research was a technique developed and this species now constitutes 50% of the annual planting rate of about 1,000 acres per year in the Bulolo-Wau areas (Anon., 1960).

Site Preparation

The type of site preparation carried out in rainforest planting schemes depends upon both the nature of the country to be planted and the type of planting, open or enrichment, envisaged. Broadly three main types can be recognised:

1. Enrichment planting within existing forest.

2. Open planting in areas carrying existing rainforest.

3. Open planting in areas where the original rainforest has been converted to grassland.

For enrichment planting two important facts should always be borne in mind: for satisfactory growth the seedlings need good light conditions, and the amount of subsequent tending if the plantings are to succeed should not be underestimated. The first point requires that openings be present in the forest when or soon after the seedlings are planted, and the second that these openings can be readily relocated when further treatment is to be given. Both are equally important, though the second can be disregarded if the enrichment is intended merely to supplement natural regeneration in unstocked areas and if the whole area, containing both natural and artificial regeneration, is to receive subsequent tending. This is the approach which is used in north Queensland (see Chapter 10) and in some of the Malayan enrichment plantings, and which has been suggested for certain Nigerian forests, and in the writer's opinion it is by far the highest development in enrichment planting within high forest of reasonable quality (as opposed to planting in second growth scrub or in forests intrinsically poor in commercial species).

With any enrichment work planting should be delayed until merchantable stems in the forest have been removed in logging. This both produces some degree of canopy opening and avoids the damage to planting stock that is inevitable if logging follows planting. Much early enrichment planting was confined to the openings created by logging, but the difficulty in refinding individual planting sites for tending has caused a trend away from this practice (except, as noted above, where it is proposed to tend the entire stand). By far the most usual practice nowadays is to open planting lines at regular distances apart through the forest. The distance between lines varies with the proposed intensity of the work: in some Malayan enrichment in secondary scrub the distance is as little as 15 feet, and in the very poor Kempas - Kedongdong forest type it is 25 ft.; in the former Belgian Congo and French African territories 1 chain (20 metres) is normally used (Forestry Service, Belgian Congo, 1958; Aubreville, 1951; de Fays and Huygen, 1957), though sometimes the distance may be extended to 2 chains (Aubreville, 1957); in Uganda it was 75 feet (Brasnett, 1949) and in the Omo F.R. in Nigeria, 2 chains. In tropical areas the lines should run east-west to take full advantage of the sun (Foury, 1956); by the same reasoning beyond the tropics north-south lines are probably preferable to enable the plants to receive at least some full lighteach day. The degree of opening carried out along the lines before planting varies considerably. In Malaya mere brushed access tracks are prepared before planting and the opening of the canopy occurs some months later, when the seedlings have become established under the shaded conditions. With the extreme light demanding Aucoumea klaineana in Gabon strips $1\frac{1}{2}$ chains wide, separated by uncleared strips of half a chain, are completely cleared, and the debris thrown into the uncleared strips: this is not strictly enrichment planting, as direct sowing, not planting, is employed to introduce the species after clearing (Aubreville, 1957). In enrichment planting on the Omo F.R. alternate 1 chain strips were poisoned and the seedlings planted in the centre of the treated strip, while in the former Belgian Congo planting was in strips opened to a width of 16 ft. It is generally agreed that the overhead opening should permit as much light as possible to reach the plants, though on account of the strong weed growth that this promotes Cooper (1961a) considers that a lesser degree of canopy opening should be employed (by leaving a single, upper canopy layer) wherever reliable labour for tending is not available or there is any question of not being able to follow up with regular clearing operations.

The main items in site preparation for extensive enrichment planting thus are ensuring that logging is completed and opening up planting lines while remembering that at some stage, before or after planting, the stems will need to receive considerable light.

The site preparation needed to establish intensive, open plantations in areas currently carrying forest is appreciably greater. Basically the problem is to destroy the existing vegetation,* and produce a clean, clear, open site on which planting can occur. The operations to be carried out can be simply stated: sell all merchantable timber off the proposed coupe; brush the undergrowth; fell all remaining trees; burn the debris after it has been permitted to dry out sufficiently; possibly fence and carry out a pre-planting weed control operation. Unfortunately, these operations can rarely be put into practice so simply.

The sale of merchantable timber before final clearing is an obvious action, and even more necessary than with enrichment, where it may at least be possible to salvage this at a later stage. Clearing the trees and undergrowth can be carried out in various ways: hand clearing, using axe, crosscut saw or power saw, is probably still most widely used, but where labour costs are high, and the machinery is available, bull-dozers can be profitably employed to push or pull the forest down. Very large trees are beyond the capacity of most 'dozers, so that some manual work is still required. In most areas such "stags" should not be left standing, however desirable this may at first sight seem: if living they will depress the growth of plants for a considerable distance around and are liable to wind throw, thereby causing much damage; if girdled or otherwise killed the breakage of the dead crown will cause much damage to the new crop below and may needlessly endanger human life, while in some areas at least the slowly decaying stem will provide ideal harbour for noxious, arboreal pests, such as brush-tailed possum (Trichosurus caninus) in the rainforest plantations of northern New South Wales. Where mechanical clearing is employed the temptation to heap all the debris into windrows should normally be avoided: the clear burn

*There are cases where intensive planting is carried out under existing vegetation, which is subsequently destroyed. While the ultimate result is similar to that by planting in the open, in this report this type of planting (e.g. Malayan planting in secondary growth) is regarded as a form of enrichment.

tends to be restricted to these heaps, and plant nutrients are concentrated in them, with the result that growth in the new crop is most irregular, strips of vigorous plants alternating with wider areas of poorer growth. This strip effect may last well into the rotation and, on sites that are poor in nutrients anyway, may extend to subsequent rotations. When hand clearing is employed the smaller undergrowth should also be slashed down, though with mechanical clearing the 'dozer will normally destroy this.

The clear burn to destroy the debris can pose great problems in timing, though these are minimised in cool temperate regions, where weed growth is less severe, and in tropical seasonal climates, where there is a reliable start to the wet season. The fundamental problem is that burning is best carried out during a dry season, planting normally during a wet period, but, except where taungya is practised, as little time as possible should elapse between burning and planting. The ideal, usually unattainable, is to burn at the very end of a dry spell and immediately plant in a period of regular rain; in practice burning is carried out when conditions are suitable, and the planting then delayed until good rain falls. Actually the timing is not always as critical as this may suggest. In temperate regions where winter planting is carried out the burn usually occurs in late summer or early autumn and the subsequent development of weeds may not be severe; where tubed stock is planted with a block of nursery soil around the roots planting can safely occur in anticipation of a wet period to follow shortly; while in most cases where labour costs are not extremely high manual weeding operations can be countenanced. In northern New South Wales, where labour costs are high, a different approach has recently been tried and from its early results appears promising. Here a shrubby composite, Helichrysum diosmifolium, is widespread in cut-over warm temperate rainforest intended for planting: it seeds profusely, produces sucker growth from cut stems and roots, grows initially as fast as or slightly faster than the pines being planted (P.taeda, P. elliottii), and can form thickets that will completely suppress the pines as well as harbour a variety of animal pests. Manual weeding is very costly, and the weeding method tried involves an early summer burn, the growth of Helichrysum throughout the summer and early autumn growing season, and the the spraying of the entire area with a 2, 4, 5-T solution which is effective in controlling this weed. The pine seedlings are then planted in late autumn (May) in a site comparatively free of weed growth, and less liable (through the death of the Helichrysum stems and roots) to reinfestation.

Fencing or netting may be required in some areas to protect the coupe against animal pests, and should be completed ahead of planting. This practice, however, does not seem widespread in rainforest plantations, partly because many of the pests are too small (e.g. rats), too big (e.g. elephants, buffalo), jump too high (e.g. certain deer, wallabies) or climb over the fence (e.g. monkeys, possums).

Site preparation for open plantations in areas carrying rainforest can be the most costly item in establishing such plantings, and attention should always be directed at means of reducing this expense. One of the greatest beauties of taungya is that these operations are carried out by the farmers as part of their agricultural methods,and so the forestry service is spared what can otherwise be and extremely high cost.

The final type of site preparation commonly encountered concerns areas that, under the incidence of fire and farming, have been converted to grassland. In reforesting such areas there is much to be gained by using those species that are able to compete actively with, and ultimately to suppress, the grass with little assistance by man, e.g. P. caribaea in tropical regions and P. elliottii in the subtropics. With these species little is needed in the way of site preparation other than to fence (usually against domestic grazing animals as much as more positive pests). Some form of soil treatment, such as ploughing or tilling the individual planting spots, may also be provided: this breaks the grass-root mat and gives the seedlings an initial period of freedom from competition. Where the species being used is less able to cope with the grass competition, more intensive site treatment may be required, but in general such species cannot be recommended for use in these sites.

Planting

The cost of actual planting depends a lot on the type of planting stock used, small, open-root stock being by far the cheapest (e.g. stump plants, pines in temperate regions, Dryobalanops in Malaya). Where large (e.g. striplings) or tubed stock has to be planted the cost and difficulty of carting the plants to the planting spots can be great; where containers have to be removed from the plants before placing in the ground, the costs becomes even greater. With any plant taken to the field in a container some form of pit sufficiently large to accommodate the soil around the roots must be prepared; with open-root stock a simple dibble, spade or planting bar is frequently sufficient to make the slit needed for planting. In taungya schemes the planting is carried out by the farmers.

Where it is intended to obtain a rapid tree cover on the site planted, close spacing is normally used; e.g. in planting in grass or on eroded sites. Close spacing is also employed where there is a market for small thinnings or where for some other reason (improved form of the planted stems, weed control) early canopy closure is required, though it should be remembered that, where the invading secondary species grow no faster than the planting stock, these can often be utilised to improve stem form and create a closed stand at much less cost and with a saving in seedlings, while at the same time reducing the need for later weedings. This use of wider espacements, coupled with a more lenient view of "weeds" that are not suppressing the crop stems, is commonly used in tropical plantings, e.g. in the Sapoba taungya farms (Nigeria), Terminalia ivorensis is planted 15 ft by 15 ft (194 stems per acre), and other species 12 ft by 12 ft (300 per acre). Even wider espacement has been used in the type of taungya practised in conjunction with commercial banana growing in the Mayumbe district of the former Belgian Congo ("plantation sylvo-bananieres" or "uniformisation par le bas"), where T. superba was spaced as widely as 33 ft by 33 ft (40 stems per acre; Donis, 1958), though 13 ft by 40 ft (85 per acre) was more usual (Dawkins, 1955a).

Replanting failed stems may be necessary, particularly if early mortality after planting has been high. This should be carried out at the earliest possible opportunity if the "refills" are not to form a permanent reservoir of suppressed stems in the stand.

With enrichment on an extensive scale very much wider spacings than these are commonly used; in French-speaking Africa a spacing of 16 ft along rows 1 chain apart (40 per acre) has been employed, and in Uganda 25 ft along rows 75 ft apart (23 per acre; Brasnett, 1949). As Foury (1956) stresses, in this type of planting there are advantages in spacing the plants relatively closely along more widely spaced lines, as a better choice of final crop trees is provided, and the cost of maintenance per stem is reduced. Other planting patterns have also been used, at least experimentally. The earlier "patch planting" in logging gaps has already been referred to; a development from this, in the planting of spaced groups as suggested by Anderson (1951), was tried in the Belgian Congo with promising results: areas of about 13 ft by 13 ft (4 x 4 meters), spaced 33 ft apart, were completely cleared of all growth and planted at a spacing of 3 x 3 ft (1 meter x 1 meter; 25 plants per group); a dense clump of artificial regeneration resulted and one of the central stems in each clump could be expected to make a satisfactory log with much reduced subsequent treatment (Dawkins 1955a). This type of planting suggests itself as of possible value in the planting of Meliaceae subject to twig-borer attack, the dense clumps forcing vertical growth despite damage to the leading shoots.

In the more intensive forms of enrichment planting, or where it is used to stock up isolated blanks in otherwise natural forest under treatment, the spacings used are more akin to those used in open plantations; the prescribed espacement to use in blanks is 12 ft by 8 ft in north Queensland (see appendix 3), while in recent enrichment plantings in Malaya spacings of 10 ft apart along lines 25 ft distant from each other (175 per acre) have been used in the Kempas-Kedongdong forest type, with less distance between lines in plantings in young secondary growth.

Tending

The operations grouped under the general heading of "tending" are those required to keep the planted stems in a healthy and vigorous condition capable of serving the purpose for which they were planted, be it to produce a tree cover on the ground, firewood, mill timber or a high quality veneer log. In the years immediately after planting the tendings most frequently given are various weed control operations, often coupled in the case of enrichment plantings with a gradual opening of the forest cover away from the planting lines: in both cases the ultimate aim is the same, to free the young plants from unwanted competitors likely to retard their development.

A weed is a plant that interferes with the objects of management. A plant that does not interfere with the objects of management, even though it contributes nothing to them, is by definition not a weed and, as mentioned above, such plants may indeed serve a moderately beneficial purpose in the young community. In fact too much weeding can at times be a disadvantage: in some of the earliest open plantings of Flindersia brayleyana in north Queensland a regular schedule of clean tendings, taken directly from the plantation practice with Araucaria cunninghamii, was adopted, and the resultant stands are noteworthy for their poor form and heavy branching; by comparison enrichment plantings of similar age, well tended, but with natural seedlings permitted to develop with them, to-day form as fine a plantation crop as one could wish to see.

However, weed control in the first years after planting is an essential part of plantation management in most rainforest areas, and the cost of the operation should never be under-estimated. One of the many advantages of taungya planting is that initial weed control remains the responsibility of the farmer while he tends his crops between the young trees for one or two years, after which the forest authority takes it over. As in most fields of forestry activity the final decision as to whether and when to weed is a matter of economics: if the plants are capable of ultimately getting ahead of the weed growth, even though their rate of growth is reduced in the meantime, the choice may justifiably be against a weed control treatment. For example, P. caribaea planted in heavy grass undoubtedly has its growth rate slowed by the grass competition, but nonetheless can usually come through and ultimately suppress the grass without aid; in such a case, the cost of periodically clearing the grass away from the pines needs to be carefully weighed against the financial return from the improved growth. The main danger from weeds lies with climbers and those fast growing woody species that can completely suppress the tree crop, and most weeding operations are concerned with these groups. The New Guinea schedule for weed control in the submontane araucaria plantations is probably fairly typical of many rainforest plantings: during the first year after planting 3 or 4 clean tendings are given, followed by an annual "grub" tend for a further 3 to 5 years when canopy closure occurs; subsequent weed control is restricted to climber cutting at periodic intervals (Anon., 1960). Where the aim is to restore a natural forest structure, particularly when planting has been at relatively wide espacement, less intensive weeding may be carried out: in the open plantations of Western Nigeria one or two clean weedings are given in the year after planting (in the case of taungya plantations at no expense to the forest service), and succeeding cleanings aim mainly at ensuring that the individual young plants are free from competition, though palms and vigorous woody species such as Musanga cecropioides and Trema sp. are uprooted or poisoned throughout the coupe on each occasion (Henry, 1960b).

Weed control is no less important in enrichment plantings, though when carried out on an extensive scale the intensive tendings given in open plantations can hardly be justified: for this reason Foury (1956) recommends that only very vigorous, light-demanding species should be used for planting, and this is also one reason why large planting stock is commonly used. Nonetheless considerable weed control is still essential if the plantings are to succeed, annual tendings for up to 6 years and thereafter less frequently being required (Brasnett, 1949). These are coupled with opening out the forest canopy, either along the rows in a fan-wise fashion from the top (Aubreville 1951), or in a general treatment of the entire forest, as is now more generally recommended (Foury). In the latter case the weeding of the plants also becomes part and parcel of a more widespread forest treatment, such as is carried out in north Queensland.

In the Malayan enrichment plantings, where the seedlings are established along narrow cut lines in fairly heavy shade, the lines are opened out 2 or 3 months after planting by poisoning all stems within 5 feet of the planting line and all relic stems (over 17 inches D.B.H.) throughout the stand.

In addition to weed control, the necessary early tending of planted stands can often profitably include form pruning, in which multiple leaders, malformed leaders, and other undesirable features in the plants are removed in order to promote the development of clear, straight stems. Pruning of the lower green crown may also be carried out as the trees develop. This is particularly so where the aim, as in the Queensland and New Guinea araucaria plantations, is to produce veneer logs with a premium on clear, knot-free timber. The New Guinea pruning prescriptions involve the pruning of all stems to a height of 7 ft, when 75% of the dominant stems exceed 20 ft in height (about age 4), followed by a high pruning to 25 ft when 75% of the stems exceed 45 ft in height. The high pruning stage (about age 6 or 7) is accompanied by a thinning in which the less desirable trees in the stand are removed, and only the remaining high quality stems are pruned. Queensland practice is broadly similar, though the pruning operations occur at a later age owing to less rapid growth in the subtropics, two individually less drastic high pruning operations are given, and thinning usually does not accompany these prunings, but the stems selected are chosen by what has become known as the "Queensland eclectic method", * are marked by a paint ring, and in subsequent thinning operations are favoured by the removal of any competing stems.

Thinning of course forms a whole subject by itself, and it is not intended to delve into it here. Suffice it to say that in closed stands thinning is at least desirable if the best stems are to attain their optimum increment: a given volume production of cellulose on an acre is of much greater value when concentrated on relatively few trees than when spread over many strongly competing stems. This is well recognised in most areas where intensive planting is carried out, and provision is usually made for periodic thinning based on the crop's needs, even non-merchantable thinnings being carried out when there is no sale for small produce.

Damage Agencies

Like any biological entities, plantations are subject to damage from various sources, and because of their usual high degree of homogeneity they may often be more subject to severe damage than other plant communities. Indeed out of all the problems that have to be faced when engaging on a planting scheme none (except possibly finance) exert greater influence on the choice of techniques, species and even on the ultimate likelihood of success or failure than do those concerning damage agencies. These agencies fall into a number of groups, of which the most important are fungi, insects, larger animals, fire and climate.

The species commonly planted in rainforest areas have so far avoided any widespread fungal outbreaks such as the

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*In its classical form, involving the selection of the best 160 well-spaced stems per acre in an unthinned stand of 550-600 stems per acre, this is carried out by selecting the best stem of each 4 trees along a row beyond the last selected tree. Thus along a row with trees numbered 1, 2, 3 ..., the first choice is made from trees 1, 2, 3, 4. If tree 2 is selected, the next choice will be made from trees 3, 4, 5, 6. If tree 6 is selected, the next group is trees 7, 8, 9, 10, and so on.

Chestnut Blight (Endothia parasitica) and the White Pine Blister Rust (Cronartium ribicolor) which have caused such devastation in North America. Two groups of diseases are however moderately widespread in rainforest plantings. One is the ubiquitous Armillaria mellea (Shoestring or Honey Fungus) which can occur wherever planting takes place amid the stumps of the former forest vegetation, and its significance is such as to lead to the suggestion that planting should be confined to grassed-over areas where Armillaria can be expected to be of little moment. The second group includes the various root-rot fungi which are individually probably more specific in host than is Armillaria, but which, once present, can persist for long periods attacking subsequent plantings. To these groups, which appear able to attack healthy and undamaged trees, should be added the various wood-destroying fungi that enter their host through damage to the stem and branches, and may ultimately kill the tree or at least greatly reduce its timber value. These can usually be controlled by reasonable care of the planted stems at all stages of growth.

Insect pests have caused the failure of many a planting scheme in rainforest areas. Virtually all parts of a tree can be subject to insect damage, from the roots to the flowers, and any form of damage, if widespread and severe enough, may cause the planting scheme to be abandoned. Some of the most serious pests have proved to be local insects attacking native trees when these are established in concentrated blocks in their country of origin. Under natural conditions, with host trees usually of scattered occurrence and growing in their younger stages with considerable shelter from the surrounding vegetation, the normal balance of nature tends to keep these insects at a low level of intensity, and damage to the host species is relatively slight. When, however, the species is raised under artificial conditions in pure stands, the damage may attain epidemic proportions, as witness past attempts at planting various Meliaceae (subject to flower, fruit and shoot borer attack by Hypsipyla spp. (Lepidoptera)) in many parts of the world, or Chlorophora excelsa (subject to the gall-forming psyllid, Phytolyma lata) in Africa, or as appears to be occurring with Nauclea diderrichii (subject to the cerambycid bark-borer, Hecphora testator) in Nigeria (Henry, 1960a). In other cases local insects have attacked introduced species, for example the leaf-stripping carried out by Atta spp. (ants) on many tree seedlings in parts of America, and the termite damage to eucalypt seedlings in West Africa.

Control measures against insect pests vary greatly. In some cases, where the pest is fairly specific in its host, it may be preferable to use some other species for planting or to restrict the susceptible one to scattered stems in a matrix of resistent trees (e.g. the mixed Meliaceae plantings in Africa); sometimes such species can also be introduced at a later stage by underplanting beneath the shelter of an established crop, thus making conditions more similar to those encountered naturally. Changes in cultural techniques may sometimes prove effective: early damage in South Queensland araucaria plantations by the bark weevil Aesiotes notabilis was overcome by restricting pruning in the plantations to the winter months, when egg-laying adults are absent and the pruning wounds can be covered by resin before a new generation appears in the spring. In New South Wales there is evidence that damage to Eucalyptus grandis by leaf-mining psyllids can be reduced by avoiding clean-weeding, and allowing the "weeds' to develop with the eucalypts. Insecticides have been successfully used in some cases, as in the soil treatment of eucalypt seedlings prior to planting in Nigeria, in order to avoid termite attack, and in protecting plants against Atta. However, the use of insecticides on a wide scale in plantation work should be approached with the utmost caution, as the long term effects of destroying the entire insect population over a large area may well be far more severe than the immediate gain warrants. On the other hand there is an insecticide approach that may prove of value in raising species subject to shoot damage, but where once a merchantable length of log is obtained, subsequent attack on the tree is of little economic significance: this is the use of systemic poisons, introduced into the stem of the tree and lethal to any insects actually attacking the tree. In the case of Meliaceae, such poisons would need only be effective till a height of perhaps 30 ft was obtained.

Mammals can cause severe damage to plantings, and indeed Foury (1956) considers that enrichment planting is futile where large game, such as elephants and buffaloes, is present. Such large game can be no less damaging in more intensive plantings, and can be extremely difficult to control by methods other than wholesale slaughter - a method which most foresters view with repugnance. More usually however the damage comes from less spectacular beasts such as deer, wallabies, rabbits, rats, possums, and monkeys. Where these are plentiful and liable to damage the trees* enrichment planting on an extensive scale may be just as impracticable as where large animals are present. With larger animals in enrichment areas the planting lines have an attraction as paths through the forest; with smaller creatures the attraction appears more often to lie with the fresh soil around the plantings and with the greater succulence of the planted stock, natural seedlings of the same species often being undamaged while those artificially introduced may be totally destroyed. In areas of more intensive planting, control operations can usually be introduced to protect the plants by such methods as netting the planting areas, trapping and poisoning, though very small animals (e.g. rats) and arboreal pests (monkeys, possums) may be difficult to control. In some areas thorough cleaning to remove all plant growth that provides harbour for the mammals has been found to help control animal damage in young plantations.

Fire is rarely of significance in natural rainforest except where this adjoins a more fire-prone type of vegetation (e.g. savanna), and while rainforest after logging, when much dry debris is on the ground, may be susceptible for a short period this rarely lasts more than a year or so. However pure plantations with their simpler structure are often very susceptible to damage from fire during dry periods, and the likelihood of damage is intensified when planting has occurred in heavy grass on a former rainforest site. Fire in rainforest areas is almost invariably man-caused: burning off adjacent grassland to obtain fresh growth or to drive out animals, escapes from clear-burning the next planting coupe, carelessness, and sometimes outright incendriarism. The usual precautions to

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*Many pests tend to be omnivorous, but some are more specific in their tastes. In New South Wales the native possum (Trichosurus) appears to damage only Pinus spp., while in one area of enrichment planting wallabies have severely damaged Araucaria while adjacent areas of apparently more succulent, and certainly less spiny, Cedrela have suffered no attack.

protect against fire should be taken wherever there is any risk of this type of damage, by such measures as guarding against the causes, provision of access through the plantation, supplying fire-fighting equipment, storage of water and breaking up the plantation into blocks surrounded by fire breaks. In many areas strips of natural rainforest are retained to provide these fire breaks.

Damage from climatic causes occurs in several forms. The most obvious is in the choice of a species unsuited to the regional climate, as for example in the use of P. radiata on the lowlands of northern New South Wales or Queensland, or in the use of an equatorial species in the sub-tropics or temperate zones. Less obvious often is the damage that may occur to a native species when the microclimate is altered by plantation clearing. Araucaria cunninghamii has been wiped out in some higher altitude plantings in eastern Australia by severe winter frosts which only develop in clearings, even though the conifer occurred naturally in the forests prior to clearing. In Queensland sites subject to such damage (the lower topographic positions) are now surveyed out after clearing and are planted with frost-resistant Pinus app. Similar to this is the isolation damage suffered by some rainforest species when planted in the open. Of a different nature is the damage that may occur from less frequent meteorological disaster, such as severe cyclones. Pure, even-aged stands are much more prone to damage by cyclones than mixed, all aged forest (see, for example, Wadsworth and Englerth, 1959). While some species tend to be more resistent to cyclonic storms than others, where there is a frequent, recurrent threat of such storms occurring in a restricted area (e.g. parts of the north Queensland lowlands and, one suspects, the island of Mauritius) it may well be unwise to consider establishing open plantations at all: if planting is to occur it should be as enrichment retaining the mixed, all-aged character of the natural forest. Where such storms are less common planting becomes a calculated risk in which the use of wind-firm species and of frequent light thinnings will do much to reduce the possibility of calamitous loss. Other rare climatic disasters, such as hailstorms and floods on lowland sites, should similarly be taken into consideration when any planting scheme is proposed.

A Breathing Spell

In the proceding sections many of the problems that have to be faced when a planting scheme is considered have been reviewed, and approaches used in overcoming the problems have been mentioned. Despite the magnitude of these problems and the failures that they have caused in probably every rainforest country where planting has been practised, the fact remains that throughout the world there are very large areas of artificially regenerated forests growing in rainforest areas and contributing appreciably to the wealth of their countries. In the next few sections some of these successful planting schemes will be briefly examined.

Artificial Regeneration by Direct Sowing

Direct sowing is strictly outside the scope of this chapter ("Planting"), but it is a form of artificial regeneration that is used in several areas as a direct substitute for planting, the general approach being the same in both instances. In direct sowing the nursery and planting operations are replaced by the operations of sowing the seed in situ. The method is used to supplement natural regeneration in Reunion (Miguet, 1955; see next Chapter), to establish Aucoumea klaineana in Gabon (Aubreville, 1957), and to convert certain rainforest areas in New South Wales to Eucalyptus grandis (Floyd, 1960; Baur, 1962b).

E. grandis occurs in imposed successions following storm, logging or fire damage in many rainforest localities of eastern Australia, but particularly in the narrow, gully bottom belts of rain-forest that are common in otherwise sclerophyll forest-dominated areas. It is initially a very fast growing species whose timber is locally valued in small sizes as case or pulp material, and in larger logs for mouldings and other interior purposes. When a market for the timber first developed regeneration was attempted by leaving scattered seed trees, clearing the remaining immature rainforest in the gullies and burning the debris. Many successes were obtained, but the method was only applicable where seed trees were present, and even then it was not always completely satisfactory. As a result artificial regeneration was attempted by planting. This produced many excellent stands, but the costs of planting the tubed seedlings were high and led to studies on the use of direct sowing.

The method now used involves logging out the regeneration coupe thoroughly; completely clearing the remaining stems during the early spring; burning the debris in December or January, immediately before the advent of the wet season; and spot sowing the seed within a week of the clear-burn. The normal sowing rate is 4 oz seed per acre (E. grandis has about 250,000 viable seeds per pound), but the rate is varied depending on local site conditions (Floyd, 1960). The spots are spaced at 8 ft by 8 ft., with some latitude permitted so that the seed may be deposited in the most favourable microsite in the vicinity. The seed is delivered from a modified "pepper-shaker", calibrated (by using apertures of a given size and number per shaker) to yield at each shake the equivalent of 4 oz seed per acre at a spacing of 8ft by 8 ft (i.e. 680 shakes should yield a quarter of a pound of seed). Germination follows the first rain after sowing, and the seedlings are able to keep ahead of the weed growth that comes in at the same time. When the seedlings are about 4 ft high (usually some 8 months after sowing) the spots are thinned to leave the best seedling only at each spot. Other plant growth is not controlled as the eucalypts can normally keep above it and its presence tends to restrict branching and, by apparently reducing the incidence of psyllid attack, actually to promote more rapid height growth in the eucalypts.

This method has achieved plantation - like stands at a cost very much below that when planting is used. Planting is now only employed on difficult sites (grassed areas, steep slopes, broad gullies liable to flooding). Growth is rapid: figures quoted by Baur (1962b, referring to both sown and planted stands) show at age $2\frac{1}{2}$ years a mean dominant height of 31 ft and a mean diameter of 2.70 inches, at $5\frac{1}{2}$ years 60 ft and 4.40 inches, and at $16\frac{1}{2}$ years 127 ft and 8.87 inches. The rotation is expected to be 40 years. The technique appears suited to species whose seed is cheap, which germinate rapidly after sowing, and whose early growth is sufficiently fast for them to compete successfully with the weeds. If the seeds are liable to be stolen by insects or small birds and mammals (which is not the case in most gully rainforest sites in eastern Australia) they should be treated before sowing with an insecticide or repellent.

Taungya Planting

Taungya is of Burmese origin and is one of the tropics' major contributions to world silviculture. The word "taungya" means hill cultivation of a temporary nature, or in other words shifting cultivation, and the basis of taungya planting is to utilise the shifting cultivators to establish young forest stands after the farmers have finished with the site. The classical account of taungya planting is given by Blanford (1925) who states that it was introduced in the Toungoo Division of Burma in 1866, the credit for its introduction lying with the then Conservatorof Forests, Col. Seaton. From the distance of nearly 100 years one can perhaps discern a little canny Scottish ancestory in the distinguished colonel.

The major use of taungya has been made in areas of tropical forest more seasonal than rainforest as interpreted here, but nonetheless it has been employed on no small scale in rainforest areas also, as for example in India (Krishnaswamy, 1952), Pakistan (Ghani, 1957), the former Belgian Congo (Forestry Service, Belgian Congo, 1958), and Nigeria (Redhead, 1960c). It is only practicable in its usual form in areas where a land hunger exists and where the subsistence farmers are willing to submit to certain restrictions in their activities, and to cooperate with the forest authorities. It should however be noted that in the Mayumbe district of the former Belgian Congo a system closely resembling taungya was employed with the commercial growing of bananas as a cash crop (Wilten, 1957). Because taungya is normally associated with a low standard of living and with a subsistence type of agriculture its social implications are sometimes criticised in a world paying lip service to raising living standards and providing freedom from hunger; on the other hand, in a world facing the no less real threat of a population explosion, it may ultimately prove the only way for much of the world's population to obtain the timber needed if it is to have any living whatsoever.

The taungya plantations in the Benin Division of Nigeria can probably be taken as fairly typical examples of taungya operations in the rainforest zone. These commenced on a small scale at Sapoba F.R. about 1927, though not as true taungya since most of the operations were carried out by paid labourers who also farmed the planting sites. In 1939 two genuine taungya series were commenced, and there are now 11 taungya series operating on Sapoba F.R., with annual coupes totalling 555 acres, while 11 other series on other forest reserves in the Division have coupes totalling 250 acres. All but one of these series (the Ona series, on an unlicensed section of Sapoba F.R.) are within the group of forests under license to African Timber and Plywood Limited, and the working plan for this group is divided into two working circles, a Taungya W.C. of 85 sq miles and a T.S.S. Working Circle of 1,000 sq miles (see next chapter).

The farmers live in villages located either on the edge of the reserve or in enclaves set aside as village sites within the reserve; in the latter case the enclave is large enough for some permanent crops (usually rubber) to be planted by the villagers. Redhead considers 3 miles to be the maximum distance farmers can be expected to travel to their farms, and that in laying out a taungya series in the district useful guide figures are 5 acres of permanent crop per family or 4 acres of permanent crop per one acre of annual coupe, and one acre of annual coupe per 1 adult male, 1.5 adult females and 4 children. In the Iguomokhua series, quoted by Redhead, the population consists of 137 adults and 240 children, and they have about one square mile of permanent crops and an annual planting area of 60 acres of taungya: the 55 men consists of 37 taungya farmers, 5 farmers in the enclave, 8 wine tappers, 4 teachers and one trader. New farmers are normally given one acre of taungya a year at the start, and 2 acres is the usual maximum area allowed to a family. Each year the taungya farms are inspected by the local forestry officer in company with the village headman. Poor farmers are warned on the spot, and if their unsatisfactory farming continues they are liable to have their area of taungya reduced or taken away, the area of good farmers being increased or a new farmer admitted to keep the annual coupe static.

During November and December the new annual coupe is selected and surveyed, and the land allocated to the individual farmers. These clear the land during January and February and burn the debris in April, following which the farm crops are planted: these consist of cassava, maize, rice, yams, coco-yams, various legumes, peppers, pineapples, plantains and sugar cane. In June the farmer stakes out his area for the tree seedlings, and these are then supplied by the forestry department and planted by the farmer: spacing is 18 ft by 18 ft for Terminalia ivorensis (planted on no more than 1/5 the total coupe), and 12 ft by 12 ft for other species, normally a 5:1 mixture of Nauclea diderrichii and various Meliaceae (Entandrophragma spp., Lovoa klaineana), but with up to 1/3 of the total coupe being planted with Triplochiton in years when stock is available. The seedlings are raised in temporary nurseries which serve several taungya series. The farmer tends the young trees while he raises his food crops, refilling any dead seedlings in August. Normally he only farms the area for a single year, though occasionally he may crop some maize and rice in the second year. Permanent crops are not permitted in the taungya farms, though up to 50 plantains per acre may be planted and brought to fruit. At the end of each year satisfactory farmers are paid a small annual bonus by way of recompense for staking and planting.

Subsequent work is carried out by the forest service to a prescribed schedule of two weedings in the second year, two line cleanings in the third year, further line cleanings in the fourth and sixth years, and the commencement of thinnings in the ninth year. The plantations aim at a rotation of 70 years to provide the final crop of 20 to 25 stems per acre. Some of the older experimental plantings at Sapoba F.R. indicate that this final crop should be readily attained; one planting of Terminalia ivorensis at 31 years carries 48 stems per acre with the 25 best all above 21 inches D.B.H., while more densely stocked stands of Triplochiton and Meliaceae, of similar age, have the 25 best stems per acre all in excess of 17 inches D.B.H.

Extensive Enrichment Planting

As pointed out previously, the term "enrichment planting" as understood here (following the interpretation of Brasnett, 1949) covers the planting of seedlings in forest which receives the least possible disturbance before the seedlings are established. It ranges in intensity from virtual true, close-spaced plantations in which clearing follows instead of precedes planting, to the widely spaced inoculation of seedlings into forest which is regarded as unsuited to natural regeneration operations, and to the planting up of isolated patches deficient in natural regeneration in forest otherwise treated for natural regeneration. Between these three extremes, situated as it were at the points of a triangle, practically all intermediate combinations of enrichment planting can be found in practice. Where one draws the line between them for terminological reasons is very much a matter for personal interpretation: as in all forest management, the terminology is of much less importance than the ability to adopt the most suitable method to the local needs. The third type, enrichment planting to supplement natural regeneration operations as is done in north Queensland, is here considered as part of the broader natural regeneration treatment and is dealt with in the following chapters. The other two types can conveniently be divided into intensive and extensive enrichment planting.

Extensive enrichment planting has been most widely used in the French-speaking areas of Africa. Foury (1956) has summarised the experiences with this type of enrichment and makes seven points needed for the technique to be successful:

1. Space closely along the lines to give a good choice of final crop trees and a low cost of maintenance per plant.

2. Use only vigorous, light-demanding species.

3. Orient the lines in an east-west direction to obtain maximum sunlight.

4. Exploit the forest fully before planting.

5. The method is useless if large game is present.

6. Never under estimate the effect of root competition and of overhead and lateral shade.

7. After planting treat the whole stand as if it were naturally regenerated.

Dawkins (1959) produces a similar list of conditions under which extensive enrichment may be practicable, and in addition stresses that the species used should be what he calls "gap species" which, while fast growing, are able to tolerate fairly intense root competition. Dawkins also considers that at least 10 trees should be planted for every one expected to be retained throughout the rotation, and that relatively tall striplings are normally the best type of planting stock to use, particularly if bucks are present and the species is palatable.

As described by Aubreville (1957), for the Ivory Coast and Camaroon, lines are opened through the forest at a distance of 33 ft to 66 ft apart and running as far as practicable in an east-west direction. Seedlings are planted at the start of the wet season and spaced at intervals of from 8 ft to 16 ft (sometimes more) along the lines. The trees overshading the seedlings are progressively removed by ringbarking and the forest conditions are altered only gradually, though Aubreville believes it preferable to open the lines too heavily rather than too lightly, despite the impetus that this gives to weeds. The young plants need to be given freeing treatment for at least 6 years after planting. Among the species successfully planted in this way have been Khaya ivorensis, Entandrophragma spp., Tarrietia utilis, Lovoa trichilioides and Triplochiton. Highly light-demanding species, such as Aucoumea, Terminalia spp. and Chlorophora, have been less successful. Growth figures for moderately well tended enrichment plantings in the Ivory Coast (quoted by Brasnett) at age 15 years are Khaya, mean height 37 ft., mean diameter 4.1 inches; Lovoa 33 ft and 3.8 inches; and Tarrietia, 36 ft and 3.3 inches. In discussing these particular plots (planted in 1931), Aubreville (1953b) observes that the growth has been poorer than was originally hoped, and that even after 20 years only about half the remaining trees can be considered safe, unless further tending is given. However, with sufficient care he feels that satisfactory results should be obtained.

In reviewing the results of extensive planting, Brasnett (1949) concluded that enrichment offers a method of partial regeneration or of increasing the proportion of valuable species where (1) natural regeneration is deficient and cannot be adequately induced, (2) so few trees can be sold that the care of the scattered natural regeneration is more costly than the forest can sustain, or (3) where no valuable tree species are present. For reasons (1) and (2) Roxburgh (1953) recommended that enrichment planting should be used in the Calabar forests of Eastern Nigeria, and enrichment is indeed widely used in the Eastern Region (Eastern Nigeria Forestry Division, 1961); for similar reasons it was employed in the Omo F.R. in the Western Region, a reserve very poor in the more valuable species, but because of the high costs and relatively poor results it has since been suspended and interest is now centred on more intensive planting methods.

Because of the necessity for frequent tending and the risks encumbent, extensive enrichment should be embarked upon with caution and not regarded as a sure, cheap method of regenerating large areas of rainforest. However, thanks to the ability of many rainforest species to survive long periods of suppression and then respond well to release, some areas have received a bonus when early, untended, enrichment plantings have been released in subsequent natural regeneration operations. Dawkins (1959) records this as happening in Uganda, and a similar occurrence in Oluwa F.R. (Western Nigeria) well illustrates the response to release by stagnant plants: Khaya ivorensis was planted in 1941, but received no further treatment till 1954 when T.S.S. operations started in the compartment. By then more than half the plants were dead and the mean height of the survivors was only 7.3 ft.; in the following 5 years after release there was no further mortality, average height increased to 14.7 ft., and the tallest stem grew 10 ft to reach a height of 28 ft.

Intensive Enrichment Planting

As opposed to extensive enrichment, where the desirability of tending the whole stand after planting is now widely acknowledged, but appears seldom to have been applied, intensive enrichment normally aims at establishing a fully stocked stand while at the same time making use of any desirable regeneration that may be present in the planting coupe, though enrichment planting is generally only employed where this natural regeneration is very deficient. It has been employed in many areas at various times, usually with very satisfactory results. In New South Wales, it was used to produce some of the oldest and most successful plantings of Araucaria cunninghamii in the state; it has been used in Ceylon (Holmes, 1956-57), India (Krishnaswamy, 1952), Puerto Rico and Malaya, and is being introduced experimentally to the Omo F.R in Nigeria in place of the more extensive methods used earlier. In Malaya, intensive enrichment is being used to regenerate both areas of secondary vegetation resulting from farming activities on forest reserves during the Japanese occupation (1942-45), and also certain forest types (notably the Kempas - Kedongdong type of Wyatt-Smith, 1961b) deficient in both economic stems and worthwhile regeneration.

In Malaya, areas of secondary vegetation (belukar) are still being planted up in the vicinity of Kuala Lumpur. On hilly country the species most favoured is Dryobalanops aromatica, while on lower sites and flat ground, less suited to Dryobalanops, various of the Red Meranti group of Shorea spp. (S. leprosula, S. acuminata, S. ovalis) are used in planting: unlike Dryobalanops these have to be planted as tubed or potted seedlings. Prior to planting narrow access traces are opened through the belukar in parallel lines 15 to 25 feet apart, and the seedlings then planted at a spacing of 10 ft along the lines. Two or three months after planting stems of unwanted species within 5 ft of the planting line are poisoned, as are relicts over 17 inches D.B.H. anywhere within the coupe. The plantings are assessed regularly for the first 5 years and liberation treatments are given when required, based on these assessments, so that the final result is a virtually closed plantation, standing above those unwanted stems that caused no interference with its development, and interspersed with any worthwhile natural stems that might have been present, though these are extremely rare in belukar. Practice in the poorer forest types is almost identical, the planting lines being 25 ft apart, and the likelihood that valuable natural regeneration is present being somewhat greater.

Open Plantations by Direct Labour

The final major type of artificial regeneration carried out in rainforest areas is the establishment of open plantations by direct labour, as opposed to their establishment under taungya. This practice is so widespread, using such a variety of species under such diverse conditions for such a range of purposes, that there is little point in selecting a few successful examples from the host available for detailed description. The choice is immense - P. radiata in New Zealand, Araucaria spp. in Queensland and New Guinea, Tectona and Pinus spp. in parts of Indonesia, Pinus spp. in Mauritius, Eucalyptus spp. and Pinus spp. in southern Brazil, Tectona and P. caribaea in Trinidad, P. caribaea in Surinam, and a great range of species in parts of West Africa: all these and many others provide excellent examples of this type of planting, and details of the techniques used can be found in the literature mentioned at the start of this chapter. They represent in sum the most intensive form of silviculture practised, and also the most costly in terms of capital outlay, though in soundly based schemes they can ultimately prove highly profitable.

The Future of Planting in Rainforest Areas

Throughout this chapter the attempt has been made to indicate the various ways that planting has, in the past, been used in rainforest areas, and it is obvious that many outstanding successes have been achieved with this type of regeneration work. Failures there certainly have been, but even these are useful in pinpointing the hazards that have to be faced, so that due precautions can be taken in future. The type of planting that appears generally of most doubtful success for the money and effort invested is the one that is most extensive - extensive enrichment. Even this, when the difficulties are realised, and when the whole forest and not just planted stems receive follow-up tending, will probably achieve the purpose for which it is carried out at a profit to the forest authorities. However, with the inevitable increase in demand for forest products as population and living standards rise, the chances of natural regeneration treatments being successful increase also in the more extensive tracts of rainforest: as more species are used, the chances of "economic" species occurring as regeneration automatically increase. This being so, extensive enrichment does not appear to be a permanent feature of rainforest silviculture. In those forests being managed by more extensive methods, the trend can be expected to lie towards more "natural" methods (see next Chapter) coupled with localised enrichment planting to stock isolated patches deficient in regeneration and to inoculate the forests with promising exotics. In the latter case the goal will be less towards obtaining a timber yield from the introduced stems at the end of one rotation, than towards making the species a permanent member of the forest for future rotations, so that Malayan *Flindersia* or Amazonian dipterocarps might ultimately establish their mark on the world's timber markets.

Excluding this specialised type of planting to supplement natural regeneration, the main interest in rainforest planting must lie in the more intensive forms. The disadvantages of these are well known - high initial capital outlay and the various risks that the plantations face, though these risks diminish steadily as more and more experience is gained in plantation management in the rainforests. Against these must be set the advantages of intensive plantation management: much higher yields (a volume mean annual increment under 100 cubic ft per acre is probably rare in successful rainforest plantations, and it may be four or five times this value, while an M.A.I. in excess of 50 cubic ft per acre is unusual in rainforests managed under natural regeneration, see Chapter 11); homogeneous crops more in keeping with current trends in timber demand; the prospects of improving the yield through applied genetics and the use of fertilisers; greater possibilities for mechanisation; and, in the long term view most important of all, from the product of these other advantages a more efficient use of the available land in competition with alternative forms of land use. Looking into the future, it is hard to disagree with Wadsworth's conclusion quoted at the start of this chapter, and indeed in some of the more densely populated rainforest countries it is unnecessary to look ahead at all; the present will suffice. The argument is sometimes advanced that plantations are wrong because they are unnatural and disturb the balance of nature; unfortunately the final choice is unlikely in many countries to be between planted forests and natural forests, but rather between some form of tree crop and intensive agriculture. Under these circumstances only the most efficient tree crops can be countenanced and, however artificial these may be, they will still be considerably more "natural" than vast areas of maize and cassava and potatoes.

CHAPTER 10

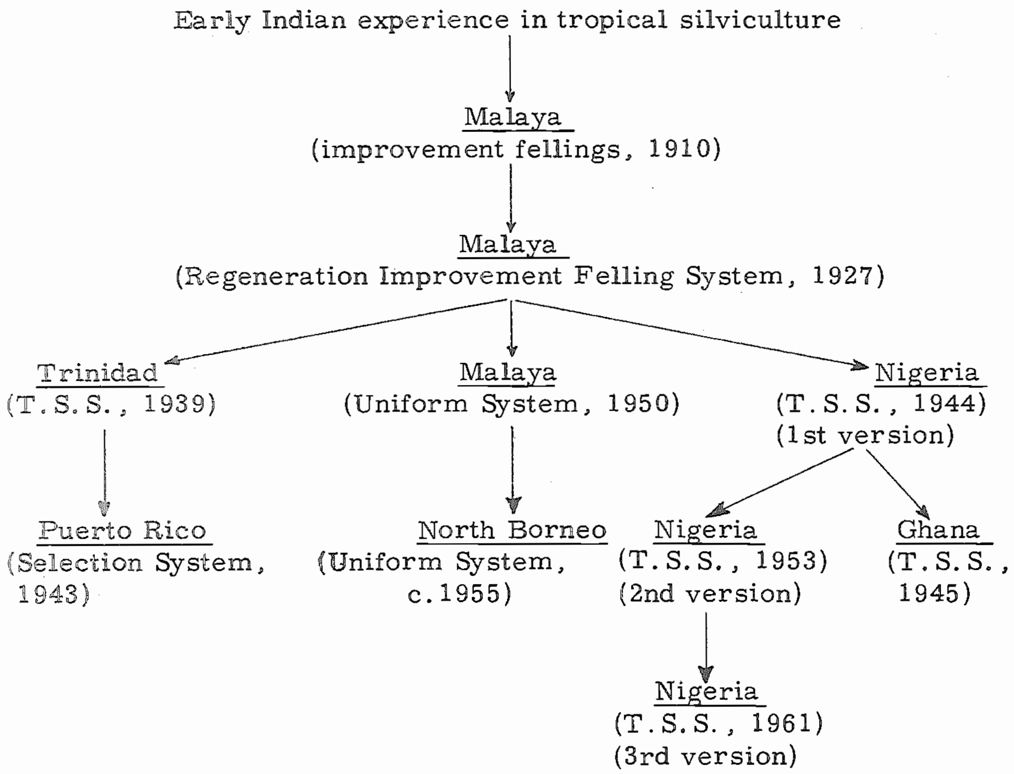
THE MANAGEMENT OF NATURAL RAINFOREST STANDS

> "It was formerly believed that under the warm, moist conditions of tropical forests productivity would take care of itself and that the main problem was merely to extract timbers - but it is now recognized that a program for maintaining and replenishing forests is indispensible to provide a satisfactory basis for their long term exploitation."
> Report of International Bank Mission to Nigeria, quoted by MacGregor (1959).

Introduction

In the consideration of rainforest silviculture being adopted here a sharp line has been drawn between techniques using artificial regeneration and those relying on natural regeneration. However in reality the boundary between the two is far less sharp than this approach would indicate. On the one hand, it is not impossible that some stands raised artificially in the past will, in future rotations, be managed with the use of natural regeneration; on the other, enrichment planting is used in a number of countries to supplement the regeneration present following the treatment of natural stands. Nonetheless the division is a practical one that separates those techniques where the emphasis is on establishing artificial regeneration in some form or another from those that concentrate on the treatment of natural communities, even though the use of artificial regeneration may sometimes be an important feature of such treatment. This report is concerned primarily with the latter, "natural" techniques.

The silvicultural treatment of rainforest is a relatively new phenomenon. India, which in so many fields of tropical silviculture has been the source and inspiration for current practices around the world, made comparatively little impression on the problem of managing these complex communities, although as early as 1906 improvement fellings were introduced to the Andaman Islands (Griffith, 1947). It fell to Malaya to tackle the problem of rainforest silviculture in earnest. Improvement fellings were commenced about 1910 and by 1920 had covered 49,000 acres, the operations differing in details in different parts of the country. These techniques were considered at a Silvicultural Conference in 1927, when a sequence of regeneration operations was prepared, and this outline provided the basis for treatment of the Malayan rainforests up to 1941 as the Malayan regeneration improvement felling system, to be replaced by Malayan uniform system after the war (Barnard, 1954), this now being applied also in North Borneo (Sabah) (Nicholson 1958a). During the 1939-45 war silvicultural operations were started in the Nigerian rainforests under the name of the tropical shelterwood system (T.S.S.). This was based upon the pre-war Malayan regeneration system, largely due to the influence of a Malayan forestry officer seconded to Nigeria during the Japanese occupation of southeast Asia. T.S.S. has subsequently undergone two major revisions within Nigeria and has also been introduced in a modified form to Ghana. Independently of these African developments a regeneration treatment also known as T.S.S. evolved in Trinidad, where it has been applied since 1939 (Ayliffe, 1952). This may have been a truly indigenous development, but in view of the fact that only 7 years before T. S. S. was introduced it had been concluded that work to assist natural regeneration in Trinidad "does not justify the addition of any definite regeneration proposals to the yield controls" (Swabey, 1932), it seems rational to assume that the Malayan successes had their repercussions in the western hemisphere also. The Trinidad experience in turn influenced work in Puerto Rico (Wadsworth, 1947b). The main stream of the development of rainforest silviculture can be represented as follows:



Although definitely the main stream in the treatment of natural rainforest, this has been by no means the only stream. However, in the interchange of ideas that has occurred on a worldwide scale it is probably correct to say that nowhere is there in operation a rainforest silvicultural treatment which has not been influenced by practices elsewhere - in other rainforest areas, in other forest formations, or in both.

Thus current treatment in north Queensland rainforests has been shaped by earlier developments in Australian eucalypt forests, particularly the Australian group selection silvicultural system and the timber stand improvement (T.S.I.) treatment, the latter having itself been modified from North American T.S.I. work which aimed at bringing previously unmanaged, overmature, but usually selectively logged, forest into a healthy silvicultural condition. The American T.S.I. appears also to have influenced the nature of rainforest treatment in Puerto Rico. In the former Belgian Congo the same aim of improving the condition of unmanaged forest led to the development of "l'uniformisation par le haut" (Donis and Maudoux, 1951), and a somewhat similar technique has been employed in recent work in the Ivory Coast (Foggie, 1960) and in Surinam (Schultz, 1960).

In this chapter the developments that have occurred in various countries will be examined, paying particular attention to the work in Malaya, Nigeria, Trinidad, Puerto Rico and north Queensland, but dealing also with practices in other parts of the world. In the following chapter these treatments will be compared, and the significance of the individual operations considered.

MALAYA

The Physical Environment

The Federation of Malaya* occupies the southern tip of the Kra Peninsula in southeast Asia, having a roughly elliptical outline with its long axis running from northwest to southeast for a distance of about 450 miles between latitude 6°30' N and 1° N; longitude 102° E passes more or less through the centre of the Federation. The greatest width of the ellipse is slightly under 200 miles and the total land area is 50,700 square miles. To the north Malaya has a common border with Thailand, on the east it faces the China Sea, on the west the Straits of Malacca separate it from the Indonesian island of Sumatra, and at the extreme south it is linked to the island State of Singapore by causeway.

Geologically Malaya is marked by a Mesozoic batholith of granite and related plutonic rocks, which have intruded earlier Mesozoic and Palaeozoic sedimentary deposits of shales, quartzites and limestone; late Palaeozoic volcanic series occur in parts of the country, particularly towards the east coast. The granite forms the backbone of the peninsula, providing most of the higher mountains and ranges (highest peak, Gunong Tahan, 7186 ft) and giving Malaya a very rugged topography. Recent alluvial and coastal deposits are found along the river valleys and both coasts, and include fairly extensive peat swamps in active formation.

The climate of Malaya is typically equatorial. On the lowlands mean temperatures average about 80°F, with barely any seasonal variation; in the higher country the means are lower and at Cameron Highlands (4,750 ft) the lowest temperature ever recorded in the Federation, 36°F, occurred. Rainfall is high throughout, the driest station (Jelebu in Negri Sembilan) having a mean annual rainfall of 65 inches. Over most of the Federation almost any month can be the wettest or driest in a particular year, but in the extreme northwest (Perlis and Kedah) there is a short but fairly definite dry season in January and February, associated with the northeast monsoon, while along the east coast this same monsoon, blowing off the China Sea, produces months that are even wetter than during the rest of the year. Humidity tends to be high throughout the year. Malaya lies outside the range of tropical cyclones, and strong winds are not a regular feature of the climate: the most noteworthy hurricane of recent history occurred about 1883 in the northeastern state of Kelantan, and was probably a by-product of the Krakatau explosion centred some 900 miles to the south.

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* The former Federation of Malaya ceased to exist in 1963, when it became part of the new Federation of Malaysia by merger with Singapore and the former British Borneo territories of Sarawak and North Borneo (now Sabah). However, the discussion here concerns only the earlier Federation on the mainland of Asia, and references to the Federation should be read in this context.

Some 72% of the country still carries natural forest (Federation of Malaya, 1961). Most rural development has occurred in the western states and in the valleys of the larger east coast rivers. Tin mining is extensively carried out in some areas, notably the states of Perak and Selangor. However, the most important industry in Malaya is the growing of rubber, and there are 3.5 million acres of rubber plantations in the Federation, divided roughly evenly between large estates and small holdings: in one belt rubber trees extend in an almost unbroken planting from central Perak south to Johore, a distance of about 300 miles, and this must have good claims to being considered the largest man-made forest in the world. Rice is cropped over nearly a million acres, mostly in the north, and coconuts and oil palms have also been widely planted. Shifting cultivation is still carried out by some small tribes of nomadic aborigines, though efforts are being made to induce these people to lead a more settled existence.

Historical and Social Background

For many centuries various Malay sultanates have existed in the peninsula, sometimes truly independent, and at other times owing overlordship to kingdoms in Siam, Sumatra and Java. In 1511 the Portugese captured the former rich trading sultanate of Malacca, on the west coast, and administered it as a trading post for 130 years when it was taken by the Dutch. Malacca was ceded in 1825 to Britain, who in the meantime had established its own trading posts at Singapore and on the island of Penang, further north along the west coast; these three colonies (including the mainland Province of Wellesley opposite Penang) formed the Straits Settlements. By this time 9 sultanates were firmly established in what is now Malaya: Perlis, Kedah, Perak, Selangor and Negri Sembilan proceeding south down the west coast; Kelantan, Trengganu and Pahang on the east coast; and Johore in the south. During the 19th century Chinese miners immigrated in quantity to the rich tin fields of Selangor and Perak, and the apparently inevitable disorders caused by large mining populations finally prompted the British to intervene in the affairs of the independent sultanates in 1873 in order to "rescue the fertile and productive countries from the ruin which must befall them". *

British residents or advisors were appointed to the sultans between 1874 and 1914, and the foundations for more stable government were established. In 1896 the states of Perak, Selangor, Negri Sembilan and Pahang formed a loose confederation for administrative purposes, with its capital at Kuala Lumpur; the remaining states retained their independent administrations till 1942 when Malaya was occupied by the Japanese Military Forces. Following the return of British administration in September, 1945 proposals were made in London for the establishment of a strongly centralized Malayan Union. This was highly unpopular with the Malay section of the population, and was dropped in favour of a federal form of government uniting the 9 states in 1948. Also in 1948 a campaign of violence, murder and terrorism was launched by a relatively small band of communists, mostly Chinese, who hoped to seize control of the country. A state of emergency was declared throughout the country, lasting from 1948 to 1960, and this period, virtually of civil war, is euphemistically

*Directive to the Governor of the Straits Settlements from the British Colonial Secretary, September, 1873.

referred to as the Emergency. Whilst the Emergency was still in force, arrangements were completed to transfer full self-government to the people of the Federation, and independence was achieved for the 9 states and the colonies of Penang and Malacca in 1957.

Malaya, as part of the Federation of Malaysia, thus now consists of 11 states, 9 of them constitutional sultanates, all enjoying full self-government, but united for matters affecting the country as a whole under a federal government. The population is about 7 million, made up racially of about 50% Malays, 37% Chinese, 11% Indians and 2% others; the Malay figure includes a small number (possibly 50,000) of aborigines, some of whom still lead a nomadic existence in the interior of the peninsula.

Vegetation

Malaya is essentially a rainforest country. Natural vegetation that is not rainforest occurs in some coastal and littoral sites (the mangrove forests of the west coast being the most important) and in certain areas of shallow soil or excessive exposure (e.g. limestone hills and high mountain peaks). However, over the great bulk of the country rainforest of some form or other constitutes the natural vegetation. The floristic richness of the forests is exceptional even by rainforest standards, there being an estimated 8,000 flowering plants, of which 2,000 are trees and 800 of these reach a D.B.H. of at least 12 inches (Wyatt-Smith 1959b).

Various attempts have been made to classify the vegetation of Malaya, the best known being that of Symington (1943)*, subsequently enlarged upon to some extent by Wyatt-Smith (1952-53).+ Symington's "formations" that can be referred to rainforest (and that are not unduly affected by man's activities) are tabulated in Table 14, giving the synonyms that relate them to the rainforest subformations recognized in this report.

From this it can be seen that 6 subformations can be recognized in the rainforests of Malaya. Swampy rainforest on peat still covers some 1920 square miles, mostly down the west coast and in Johore (Wyatt-Smith 1959d). Much of this is intended for agricultural development after the swamps have been drained, but there are extensive areas situated on very deep peat that are likely to be retained as forest. Important timber species occurring in these forests are Shorea rugosa var. uliginosa, S. teysmanniana, Gonystylus bancanus and Koompassia malaccensis, the last also being common in many dryland forests.

* This outstanding volume, "Foresters' Manual of Dipterocarps" was actually published during the Occupation by the foresight of an exceptional Japanese scientist, Prof. Tanakadate, seconded to the occupying forces. It was published in conformity with the earlier volumes of the Malayan Forest Records, of which it is No. 16, but bears the Japanese date 2603. The copy in the Forest Research Institute library at Kepong is bound with this date embossed upon the cover, giving its fellow volumes a somewhat medieval appearance.

+ A later and more detailed description and classification of the dry land forests of Malaya is given by R.G. Robbins and J. Wyatt-Smith (1964), "Dry Land Forest Formations and Forest types in the Malayan Peninsula", Mal. For. 27(3), 188-216.

TABLE 14

Rainforest Subformations in Malaya
(after Symington, 1943)

Symington's Name and Number	Site	Subformation
1. Lowland Dipterocarp Forest	Well-drained, to 1,000'	Equatorial; probably some Evergreen Seasonal in extreme N. W.
2. Hill Dipterocarp Forest	1,000-2,500', depressed on isolated mountains	Equatorial; occasionally merging towards submontane at upper limits.
3. Upper Dipterocarp Forest	2,500-4,000', depressed on isolated mountains	Submontane
4. Montane Oak Forest	3,500-5,000'	Montane
5. Montane Ericaceous	5,000'+; in cloud belt	Montane Thicket
8. Peat Swamp Forest	On peat swamps)	Swampy; also other types of swamp subformations (not rainforest) in places.
10. Other Swamp Forests	Flat land subject to periodic inundation)	
9. Riparian Fringe	Along rivers	Equatorial
11. Heath Forest	Podsolized coastal sands	Xeromorphic

Xeromorphic rainforest has a restricted occurrence on the east coast, on old coastal sand deposits which have become podsolized. Shorea materialis and, less commonly, S. collina are among the most prominent trees present. These sites on clearing lose their fertility with extreme rapidity and revert to poor grassland with scattered trees of Fagraea fragrans and bushes of Rhodomyrtus sp. and the introduced Anacardium occidentale (cashew nut). One occurrence, dominated by Shorea glauca, is also known from the west coast.

What should probably be classed as evergreen seasonal rainforest is found in Perlis and northern Kedah, where the distinctly seasonal climate occurs, and the vegetation is marked by a predominance of what Symington called the Burmese flora. Undisturbed forest shows a relative abundance of the White Meranti (Anthoshorea) group of Shorea spp., including S. assamica, S. globifera, S. hypochra, S. service-ifolia and S. tabura, and by Parashorea lucida. After cultivation these forests revert to Symington's Schima-bamboo formation.

The submontane and montane rainforests are of little importance commercially, but they form a large proportion of the 4,300 square miles of protection forests reserved in the Federation, and also cover extensive areas of higher altitude forest still unreserved. In both subformations various Lauraceae and Pasania (Quercus) spp. are well represented; a few dipterocarps are found in the submontane rainforest (notably Shorea platycladus), while podocarps (Podocarpus spp., Dacrydium spp.) are often common in the montane rainforest (see Fig. 22). Other species of the Antarctic floristic element also occur in these mountain forests, including Weinmannia blumei, while the Australian element is represented by Tristania spp. and, in the montane thickets, by Leptospermum flavescens and Baeckia fruticans.

The most important and extensive subformation, however, is equatorial rainforest, which covers or originally covered most of Malaya up to an elevation of 2,000 to 2,500 ft. Wyatt-Smith (1961b) has recently made an attempt to divide this extensive subformation into distinctive types, and his classification, admittedly tentative only, is summarized in Table 15. Swampy, evergreen seasonal and xero-morphic rainforest, also included by Wyatt-Smith in the classification, are excluded from the summary. The outstanding feature of these types is the dominance of dipterocarps in most of them, these commonly making up over 50% of the total timber volume over 12 inches D.B.H., and over 75% of the commercial out-turn (Landon, 1957). The dipterocarps range in timber from the heavy hardwoods such as Balanocarpus, the Balau group of Shorea spp., and some Hopea spp., through medium hardwoods such as Dryobalanops spp. and Dipterocarpus spp., to the light hardwoods such as the Meranti groups of Shorea spp. and Anisoptera spp. It should be appreciated that the species or species groups chosen to typify the various types are merely the more outstanding trees in what is characteristically an extremely variable matrix of species. Quite commonly over 100 species greater than 4 inches D.B.H. occur on a single acre, and even in those types which most closely approach single species dominance in given sites (Dryobalanops aromatica, Shorea curtisii, S. glauca) the dominance is limited (in virgin stands at least) to the upper canopy; the associated species of smaller sizes are still very numerous (see Chapter 5).

TABLE 15

Subdivision of Malayan Equatorial Rainforest into Types
(after Wyatt-Smith, 1901b)

Name	Common Species	Site Factors and Occurrence	Notes
1. Red Meranti-Keruing (*Shorea-Dipterocarpus*)	Sh. acuminata, leprosula, macroptera, ovalis, parvifolia; D. baudii, cornutus, costulatus, grandiflorus, kerrii, sublamellatus, verrucosus.	Lowland granitic Soils; S.Pr, S1, W.NS, M1, N & C Jh, C.Ph, S.K1, W.Tr.	High proportion of upper storey trees of Red Meranti group of *Shorea* spp.
2. Balau (Heavy hardwood *Shorea* spp.)	Sh.atrinervosa, elliptica, maxwelliana	E. & S. of Main Range; N. Jh, E.Ns, W.Ph, N.Tr.	High proportion of heavy hardwood *Shorea* spp.
3. Kapur (*Dryobalanops-aromatica*)	Dr.aromatica, Dipterocarpus spp.	Low hills and undulating land, well drained sandy clay loams E.coast (Jh, Ph, Tr), also near K. Lumpur (S1).	Avoids granite. High B.A.
4. Kempas-Kedongdong (*Koompassia malaccensis*-Burseraceae)	K.malaccensis, Canarium spp., Santiria spp., Palaquium spp., Madhuca sp., Dyera costalata.	Low lying, flat land above peat swamps; on poor, heavy white clays from shale and on old raised beaches. Pr, S1, Jh.	Few Dipterocarps. Few large trees, dense shrub layer.
5. Merbau-Kekatong (*Intsia palembanica*-*Cynometra inaequifolia*)	I.palembanica, C. inaequifolia, Sindora spp.	Foothills of Main Range. Kd, Pr.	Very deficient in dipterocarps, few economic spp.
6. Chengal (*Balanocarpus heimii*)	B.heimii, Scorodocarpus borneensis.	Absent from N. W. Malaya, rare in M1, Jh.	Species widespread but particularly common in some areas.

TABLE 15 (contd.)

Name	Common Species	Site Factors and Occurrence	Notes
7. Nemasu (Shorea pauciflora)	S. pauciflora, Balanocarpus heimii, Dipterocarpus spp.	Undulating country and foothills in N; Pr, Kl.	Species wide-spread.
8. Keruing (Dipterocarpus spp.)	Dipterocarpus spp., Dryobalanops oblongifolia, Koompassia malaccensis, Shorea lepidota.	Poorly drained sites, water-logged part of years. N. Jh, C., E. & S. Ph, E. & W. NS, N. Tr, Pr.	Probably marginal to swampy rain-forest.
9. Damar laut merah (Shorea kunstleri)	S. Kunstleri.	Foothills in N. & E., S. Kd, N. Pr, E. Kl, Tr, E. Ph.	
10. Seraya (ridge) (Shorea curtisii)	S. curtisii, Anisoptera laevis, A. curtisii, Hopea beccariana, Tarrietia javanica, sometimes Agathis alba.	On ridges throughout Malaya, usually above 1,000' but lower near coast.	One of richest types in Malaya. Often dense Eugeissona triste (Bertam palm) in under-storey.
11. Balau kumus-Damar hitam (Shorea laevis-S. multiflora).	S. laevis, S. multiflora.	Ridges and upper slopes on Main Ridge. Sl, NS, Ph.	Associated with 10, but not confined to ridges.
12. Balau laut (Shorea glauca)	S. glauca, S. maxwelliana, Sindora wallichii, Vatica cuspidata	Lower and steep slopes of coastal hills, from sea level to a few hundred feet. All states except Sl; also inland (500-1500') in W. Ph, E. NS, Kl.	Almost pure stands on seaward slopes.
13. Balau-Keruing	Shorea atrinervosa, foxworthyi; Dipterocarpus costulatus, appendiculatus.	Common on E. Coast (Jh, Ph, Tr); also in S. Kd, Pr.	

TABLE 15 (contd.)

Name	Common Species	Site Factors and and Occurrence	Notes
14. Merpauh (Swintonia spicifera)	S. spicifera.	Higher altitude ridges. Common in N. Malaya.	Links 10 with sub-montane rain-forest. Some-times al-most pure.

Note: Types 1-9 from Symington's Lowland Dipterocarp Forest, 10-14 from Hill Dipterocarp Forest.

Abbreviations (Occurrence): C, Central; E, East; Jh, Johore; Kd, Kedah; Kl, Kelantan; Ml, Malàcca; N, North; NS, Negri Sembilan; Ph, Pehang; Pr, Perak; S, South; Sl, Selangor; Tr, Trengganu; W, West.

As indicated in Table 15, some of these types are deficient in the main commercial species and represent problem areas, e.g. Kempas-Kedongdong, which is now receiving intensive enrichment in Selangor, and Merbau - Kekatong further north. The most important type has undoubtedly been the Red Meranti-Keruing, while in their areas of occurrence the Kapur type, and at higher altitudes, the Seraya ridge type, are also extremely valuable.

In addition to the undisturbed forests there are considerable areas of secondary vegetation in parts of Malaya. This is either secondary forest (belukar) in which Macaranga, Trema, Glochidion and other fast growing secondary pioneer species are common, often associated with dense blankets of Gleichenia linearis (resam) in the more open patches, or grassland dominated usually by Imperata cylindrica (lalang) where repeated burning occurs. Around the larger towns much secondary vegetation of these types resulted from squatters settling in suitable areas of forest to raise their own food crops during the Occupation; one effect of the Emergency was to resettle these squatters in more centralized "new villages", the one time farmland reverting as secondary vegetation to its previous status as forest reserve or state land

Development of Forestry in Malaya

The first forest service in Malaya was established in the Straits Settlements in 1883, and by 1900 forest officers had also been appointed in Perak, Selangor and Negri Sembilan with the aim of controlling the exploitation of Palaquium gutta (source of gutta percha) and the supply of railway sleepers. In 1901 the first professional forestry officer, A.M. Burn-Murdoch, was appointed as Chief Forest Officer for the Settlements and Federated Malay States, and subsequently the unfederated states established their own forest services under the control of officers of the Malayan Forest Service. Dr F. W. Foxworthy, an American, was appointed the first Forest Research Officer in 1918 and 11 years later he supervised the establishment of the Forest Research Institute at Kepong, 10 miles from Kuala Lumpur. At the F.R.I. also was established the vernacular school in forestry for the training of subprofessional staff (Mead, 1940).

This pattern is maintained in the Federation. Each of the 11 states has its own forest service, legislates on forestry matters within the state, receives all forestry revenue, provides the funds for forestry expenditure, and manages its own forests. Federal responsibility, under the control of the Chief Conservator of Forests, lies in the control of all professional staff, who are seconded to the states; in advising on those matters that affect the Federation as a whole or the relationships between the states; in maintaining the F.R.I., the sub-professional school and the Forest Utilization Branch; and in advising the state services on technical matters such as silviculture. The Utilization Branch operates two timber depots, carries out timber inspection and grading services, and advises on the processing and uses of Malayan Timbers.

At present there are 13,253 square miles of forest reserve in the Federation, made up as follows (Federation of Malaya, 1960).

Mangrove forest		467 square miles
Inland forest:		
Productive	8,510 sq. miles	
Unproductive (mostly protection	4,276 sq. miles	12,786 square miles
TOTAL		13,253 square miles

An additional 2,565 square miles * of forested land are set aside as wildlife and other reserves, and there are 20,840 square miles of unreserved forested crown or state land, much of which is scheduled for rural development. In an obvious move the state land is thoroughly exploited of commercial timber before being opened for agriculture. Ironically this practice is expected to contribute appreciably to a timber deficit in Malaya towards the end of the century: by logging the state lands, the opportunities for carrying out regeneration treatment after logging on forest reserves are reduced, and the areas of high-yielding regenerated forests approaching maturity about 2,000 are correspondingly decreased.

Total production from the Malayan forests in 1959 was (volume in millions cubic feet solid):

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* Including 1,677 square miles in the King George V National Park which surrounds Gunong Tahan in the states of Pahang, Trengganu and Kelantan.

Source	Heavy Hard-woods	Other	Total Log	Poles	Firewood	Charcoal	Total
Forest Reserves	2.33	22.14	24.47	1.01	5.07	8.55	39.10
State Lands	1.93	32.47	34.40	.68	2.23	1.09	38.40
TOTAL	4.26	54.61	58.87	1.69	7.31	9.64	77.50

Log timber is almost entirely from inland forests, but the mangrove forests contribute considerably to the outturn of other produce. About 45 million cubic feet of logs were processed in the Federation's 406 sawmills, 4 ply mills and 3 match factories, and most of the remainder would have been processed in Singapore: except for a few refractory species (e.g. the White Meranti group of *Shorea* spp.) the export of logs to places other than Singapore is prohibited. Exports of sawn timber from the Federation and Singapore in 1959 amounted to 9.27 million cubic feet.

Early Silvicultural Operations

The first decade of professional forestry in Malaya (1900-1910) has been termed the "gutta percha era" by Barnard (1954). Prices of up to M$500 per pikul * prevailed for this latex, which was obtained destructively by felling the trees of *Palaquium gutta*. Highly selective forest working for the more durable hardwoods was also carried out during this period, the most sought after species being *Balanocarpus heimii* (chengal). Smith (1959) has estimated that average yields of about 100 cubic feet per acre were obtained from this type of operation, the forest then being "worked out". In the almost standard pattern of rainforest countries, silvicultural operations were confined to artificial regeneration, plantations of *P. gutta* and of Para rubber being established and enrichment planting of *Balanocarpus* carried out, only to fail through lack of subsequent tending. Probably fortunately for Malayan forestry planting of rubber did not long remain a departmental responsibility.

The first treatments applied to natural forests appear to have been given in Selangor in 1910 and in Negri Sembilan in 1911. These were essentially improvement operations designed to favour the development of existing poles of *P. gutta* and any other more valuable species. According to Barnard (1954) it was considered "inadvisable" to secure regeneration, as this would necessitate returning to the area after a very short period; the aim of the improvement fellings was to increase the crop for future exploitation, accomplishing as much as possible in a single operation. During this period forest exploitation was almost entirely confined to state land outside the forest reserves, and no mention is made in the improvement prescriptions of logging the overmature trees.

* At current rates, M$1 = 2/4 sterling; 1 pikul = 133-1/3 lbs
M$500 per pikul is equivalent to 8/9 sterling per pound.

The treatment prescribed in Selangor was as follows:

First Improvement Felling:

(a) All inferior species with their crowns within 6 ft of any class 1 (i.e. commercially more valuable species, which were specified) crown to be felled or girdled unless the top of the inferior tree is below the lowest part of the class 1 crown.

(b) Eugeissona triste (bertam palm) within 8 ft of any class 1 crown to be cut.

(c) All creepers except rotans (i.e. Calamus spp. and other climbing Palmaceae, for whose canes there was and still is a strong demand) to be cut, whether on class 1 or not.

(d) Rotans to be left whether on class 1 or not.

(e) A record of class 1 trees over 6 ft high, freed or met with, to be kept.

Second Improvement Felling, to be given 2 years later:

As for the first, but increase distance in (a) to 8 ft and in (b) to 10 ft.

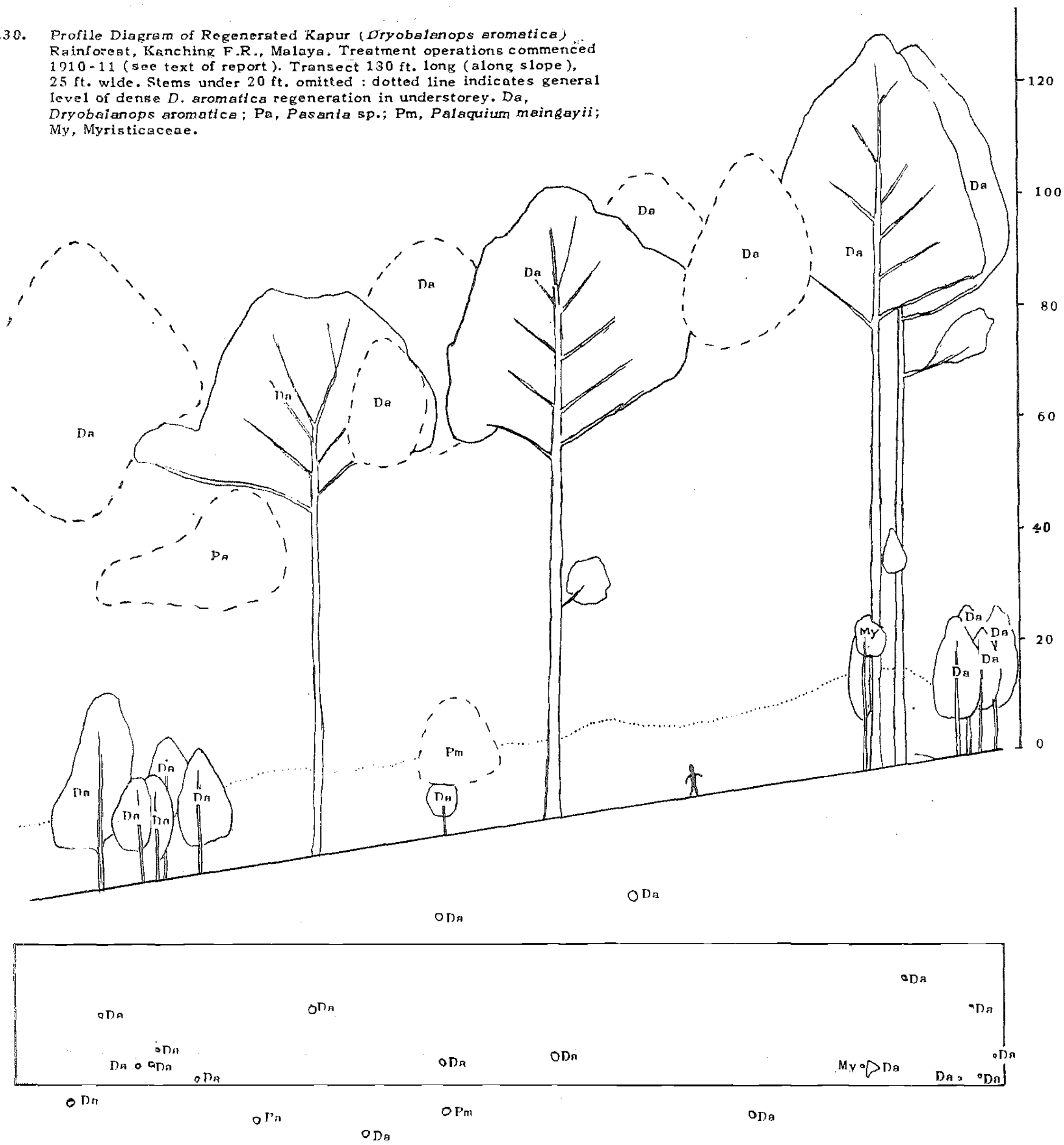
Barnard comments on this treatment that it was simple to apply, but that with inadequate supervision there was much unnecessary undergrowth cleaning, no distinction was made between class 1 species of different value, the Eugeissona cutting was ineffective, and the girdled trees all too frequently failed to die.

One of the first areas to be treated was the local occurrence of Dryobalanops aromatica on Kanching F.R., near Kuala Lumpur. This is the only natural stand of Dryobalanops in western Malaya, and it has been suggested that seedlings may in fact have been brought from the east coast centuries ago and planted by one of the aboriginal tribes. Whatever its origin, it is certainly well suited to the site. Probably because of its accessibility along the main road north from Kuala Lumpur, and probably also because of its outright attractiveness, this stand over the years has received fairly intensive treatment. The history of the oldest compartment to have improvement fellings is:

1910-11	First improvement felling, as prescribed
1912	Second improvement felling
1914	All cass 2 stems (i.e. commercial species less valuable than class 1), and any class 1 interfering with Dryobalanops felled or girdled; Eugeissona cut back; some mature Dryobalanops felled for sleepers.
1915	All trees other than Dryobalanops girdled; Eugeissona and climbers cut.
(1917	Climber-cutting twice in year.
(1918	Climber-cutting
1919	Thinning, removing all growth other than Dryobalanops, all Dryobalanops under $1\frac{1}{2}$ inches D.B.H. and, in larger stems, Dryobalanops that were suppressed, dominated, malformed or with small crowns.
1927	Secondary growth, resulting from thinning, cut back.
1929	Climber-cutting and thinning

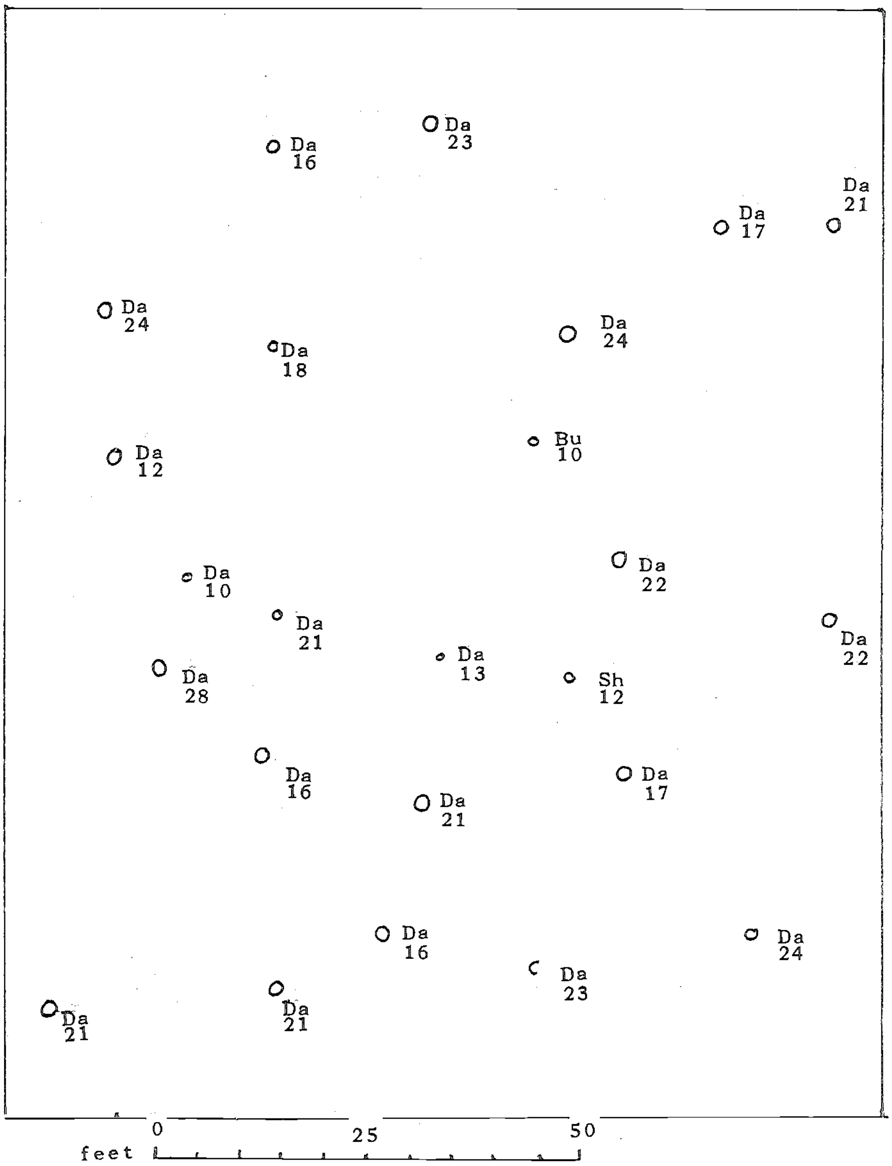
1934	Thinning
1937	Thinning
1942-45	Uncontrolled felling in parts
1947	Thinning.

Fig.30. Profile Diagram of Regenerated Kapur (*Dryobalanops aromatica*) Rainforest, Kanching F.R., Malaya. Treatment operations commenced 1910-11 (see text of report). Transect 130 ft. long (along slope), 25 ft. wide. Stems under 20 ft. omitted : dotted line indicates general level of dense *D. aromatica* regeneration in understorey. Da, *Dryobalanops aromatica*; Pa, *Pasania* sp.; Pm, *Palaquium maingayii*; My, Myristicaceae.



The present stand is regarded as dating from 1912. Figure 30 is a profile diagram taken from within this compartment, and shows clearly the two-layered nature of the stand, with the 50 years old new crop forming a closed canopy up to 120-140 ft high, above an extremely dense undergrowth, mostly saplings of Dryobalanops, between 15 ft and 25 ft high. A 0.5 acre plot established in this vicinity (Figure 31), in a section that escaped felling during the Occupation, showed the presence of 22 stems of Dryobalanops and 2 stems of other species exceeding 4 inches D.B.H. The details for Dryobalanops, converted to a per acre basis, are shown in Table 16; the estimated volume is of merchantable timber to the break of crown, and excludes the volume

Fig.31. Plan of 0.5 acre plot in Regenerated Kapur Rainforest, Kanching F.R., Malaya (regeneration treatments commenced 1910-11). Bu, Burseraceae; Da, *Dryobalanops aromatica*; Sh, *Shorea acuminata*. Figures indicate D.B.H. of stem in inches; upper storey stems only shown.



of past thinnings.

The first area of forest treated in Negri Sembilan received a somewhat similar initial series of operations, but in this case a deliberate attempt was made to induce regeneration, which was absent in 1911 due to a dense ground cover of Eugeissona. The history of this compartment up to 1927 was:

1911	Eugeissona and other palms cut flush to ground; all climbers climbers except rotans cut; some girdling to free class 1 poles.
1917	As in 1911, but class 2 trees felled or girdled if casting too dense shade on class 1 recruits.
1917-18	Logging of overmature class 1 trees (1.1 trees removed

per acre); some damage to regeneration.

1924 All undergrowth cut back, all class 2 trees felled or girdled.

Heavy seed years occurred in 1911 and 1915, and by 1927 the treatment was described as "most successful", with an evenly distributed crop of seedlings, saplings and poles of class 1 species.

Treatments of a similar nature were increasingly applied, and by 1920 improvement fellings had been carried out over 49,000 acres.

TABLE 16

Dryobalanops aromatica New Crop, Kanching F.R., Selangor.

Age: 49 years	Dryobalanops	All Stems
Stems per acre	44	48
B.A. per acre	95.2 sq ft	97.7 sq ft
Mean Dominant Height	130 ft	-
Minimum D.B.H.	10.3 in	9.7 in
Maximum D.B.H.	27.5 in	27.5 in
Mean Diameter	19.9 in	19.3 in
Estimated Volume	3,000 cu ft true per acre	-
Volume M.A.I.	61 cu ft/acre	-

Regeneration Improvement Fellings

About 1922 a change occurred in the pattern of exploitation of Malayan forests. Forest reserves were opened for commercial logging, the demand for firewood increased, and under the impetus of a mining boom there was a strong demand for poles. These developments were considered in relation to the early improvement felling operations at a departmental silvicultural conference held in 1927.

At this conference it was pointed out that the effect of many of the earlier improvement operations had been lost because the treatments were not repeated. Doubt was expressed about the value of treatments aimed solely at improving the existing stock, since immature trees to respond to such treatment were usually scarce. It was also felt, in the face of the rising demand for timber, to be often unwise to girdle trees of potential value as poles or fuel. Finally three classes of treatment operations were distinguished:

1. Improvement Operations:

Aimed to assist existing class 1 trees. Not to be carried out where there was a likely market for class 2 species within 10 years, nor where there was little likelihood of being able to exploit the class 1 stems. The favoured trees should be of value; treatment should be continued until the desired result (specified in advance) was attained; no planting to be carried out if natural regeneration could be successfully obtained; all climbers except rotans to be cut; no operations in areas of heavy Eugeissona until satisfactory control measures determined.

2. Departmental Regeneration Operations:

Aimed to induce and then assist natural regeneration by carrying out "bold improvement fellings", followed by "cleaning after cleaning".

3. Commercial Regeneration Operations:

Similar to (2), but to be carried out by commercial operators removing the less desirable stems at a profit to the department.

The Improvement Operations (1) had the intention of removing the inferior species in several stages to promote the development of the class 1 species before the felling of these was permitted; according to Hodgson (1932) these operations had virtually ceased by 1932. The two regeneration operations aimed at the controlled elimination of useless and inferior species, to make way for existing or expected regeneration of the commercially valuable species. A sequence of trestments was laid down at the 1927 conference for the commercial regeneration operations:

Year		
n - 1	P	Felling of unmarked class 2 poles under 8 inches D.B.H.
n	S1	First seeding felling of marked class 2 trees.
n + 2 or + 3	C1	First cleaning (if necessary)
n + 4	S2	Second seedling felling of marked class 2 trees
n + 5	C2	Second cleaning
n + 6	F	Final felling of marked class 1 trees (provided successful regeneration verified in C2).
n + 7	C	Cleaning after final felling (if necessary).

Hodgson, writing five years later, gives a slightly different schedule to this. Pole felling (P) included the felling of poles up to 12 inches D.B.H., the second cleaning being carried out in year n + 6 or n + 7, final felling in year n + 7, and the cleaning after final felling being performed some time after F if found necessary. The pole felling was to remove those small stems which were liable to be smashed if retained. In the first seeding felling the aim was to produce evenly distributed gaps in the canopy of about 25 ft diameter; understory canopy opening was to be avoided. The long regeneration period of 6 or 7 years gave ample scope for regeneration to become established, but if it was still absent at this stage the final felling was to be delayed, and when final felling did occur, all trees over 20 inches D.B.H. were to be removed. Eugeissona was to be removed, if dense, before any treatment was given. Finally it was appreciated that gaps between class 1 seedlings were better occupied by useless species rather than climbers or grass, and the cleanings were only to remove useless species when these were actively competing with class 1 species. It was expected that after treatment a felling cycle of 40 years, with intermediate thinnings, could apply.

The departmental regeneration fellings differed in being applied to areas where there was no market for class 2 species (charcoal, firewood, poles). The general schedule of operations was similar to those for commercial regeneration fellings, but the inferior species were removed by girdling if over 6 inches D.B.H. Since the canopy was opened more gradually by the slow death of girdled trees, the first girlding operation (G1) was more severe than the broadly equivalent first seeding felling, and where class 1 trees were plentiful all inferior species might be removed in G1. The girdling was accompanied by the first cleaning (GC1), and the treatments were repeated 3 or 4 years later (GC2) when girdling was commonly confined to those stems that had survived the first girdling. Another cleaning might be given one or two years later, and the final felling was carried out 2 to 4 years after GC2. The sequence of operations for departmental regeneration fellings thus was:

Year		
n	GC1	First girdling of inferior species and cleaning
n + 3 or + 4	GC2	Second girdling and cleaning
about n + 5	C3	Cleaning if necessary
about n + 7	F	Final felling of marked class 1 trees

Both regeneration fellings followed a generally similar course in which the original forest canopy was gradually opened over a period of 5 to 8 years, during which regeneration was expected to become established, and was given repeated tendings. The form of both treatments was thus that of a shelterwood system. The departmental regeneration fellings became known as Regeneration Improvement Fellings (R.I.F.), and correctly this name should only be applied to the departmental operations. However, it now appears standard practice to refer to either type of regeneration inducement as R.I.F., and in view of the little difference between them this practice seems quite justified. At the time of the 1927 conference the emphasis was definitely on commercial operations. Barnard (1954) comments that at the conference no decision about the desirability of departmental operations was reached. However, during the next decade, as the demand for firewood decreased in the face of competition from alternative sources of fuel, and as the market for mining poles became more limited, departmental operations became increasingly widely applied.

Other factors besides a reduced demand for firewood occurred between 1927 and 1942. Up until the early 1930's the general demand for timber was limited, and was concentrated almost entirely upon the naturally durable heavy hardwoods; conversion of logs was carried out by hand sawyers. During the thirties the demand for timber increased annually, and medium powered sawmills became more widely established, leading to the exploitation of a wider range of species, though right up until the 1939-45 war the heavy hardwoods were sought to a far greater extent than their presence in the forests warranted. Table 17, modified from Wyatt-Smith (1959b), shows the changing demand for Malayan hardwoods since 1925; the importance of the heavy hardwoods up to 1939 is clearly shown. About 1934 the use of poison to kill unwanted threes was introduced to Malaya, sodium arsenite being used in solution ($\frac{1}{2}$ - 1 lb per gallon of water; Mead, 1940) and poured into frills. This had the effect of giving greater certainty to the removal of unwanted trees, at no greater, or even less, cost than with the previous ringbarking, and made possible the killing of the large but useless trees remaining after final felling; the poison girdling of relics was then added as a routine operation to the schedule of R.I.F. treatments (Mead, 1940).

Another development during the thirties appears to have followed a suggestion of Edwards (1931) that some form of sampling should be employed, as a guide to cleaning treatments and to the desirability of carrying out final felling. About 1935 linear sampling, using milliacre (1/1000 acre = 10 by 10 links = 6 ft 7 in by 6 ft 7 in) quadrats, was introduced and soon became widely used as a means of determining the extent and nature of desirable regeneration (Browne, 1936).

TABLE 17

Outturn of Timber from Malayan Forests, 1925-59.

Year	Total Outturn	Ratio: Heavy Hardwoods to other Species
1925	5.38 million cu ft	1:2.0
1935	9.90	1:2.5
1939	24.74	1:2.9
1950	36.67	1:6.7
1955	55.36	1:11.8
1959	58.57	1:12.8

Suggestions for other forms of silvicultural treatment were periodically made, Arnot and Landon (1937) in particular making a plea for the use of a true selection system on a short (8-12 years) felling cycle in certain forests, notably the steep coastal slopes where Shorea glauca grows almost gregariously. However, the times were against this trend; the establishment of sawmills, the increasing use of mechanical extraction methods, and the rising demand for a greater range of species combined to produce pressure for heavier exploitation in a single, more profitable operation. This in turn required the pretreatment in R.I.F. to be lighter, as more of the stems previously poisoned were becoming merchantable. Studies were commenced to find a satisfactory answer to this problem of regenerating the rain-forests under a more concentrated logging practice. The results of this research indicated that there was frequently considerable regeneration of class 1 species under virgin forest, where it was capable of existing for up to 5 years; that where the regeneration was of the light-hardwood Shorea spp. (merantis), complete opening of the canopy was not too drastic; that the creation of gaps in the overhead canopy did little to assist the regeneration in the absence of similar gaps in the understorey; and that the cutting of Eugeissona alone was useless in encouraging the regeneration (Barnard, 1954). Mead (1940), without the advantage of writing after the event, doubted whether the modifications being suggested would produce results of the standard obtained by R.I.F., and expected they would be suited only to the lighter wooded species. As it happened, no decision had been reached when the Japanese military forces invaded Malaya in December, 1941.

The Results of R.I.F.:

At the end of 1939 30,000 acres had been regenerated by R.I.F., and operations were in progress over 131,000 acres (Mead 1940); by the time the Japanese moved in some treatment had been carried out over possibly 200,000 acres (about 300 square miles). Much of this was on the lowland sites close to the major centres of population, since throughout most of the pre-war period these were the forests being exploited, and therefore receiving treatment. When food shortages during the Occupation forced a large proportion of Malaya's urban population to raise its own crops, these accessible forests were among the areas hardest hit by squatters; very large areas were completely cleared to make way for farms, and illegal felling was carried out in other areas to provide the timber needs for this uncontrolled "rural development" +. Needless to say, silvicultural operations came to a complete halt during the Occupation.

The most extensive study of those regenerated stands which survived the Occupation has been made by Cousens (1957, 1958b) in Perak. This study was carried out in 1956, in a pilot scheme designed to yield information on the most satisfactory methods of sampling the composition and development of regenerated forest by the use of permanent, periodically remeasured plots. Perak was selected as it had a larger area of regeneration to survive the war than any other state, with 17,000 acres which were opened for regeneration between 1916 and 1940 and which by 1956 had been passed as regenerated, i.e. possessing an average at least 30 dominant, well-spaced stems of desirable species per acre. On e acre plots, measuring 10 x 1 chains and subdivided into 10 one square chain subplots, were established, all stems over 4 inches D.B.H. being measured, the best stem of a principal species * in each subplot being selected, and chosen stems being measured for total height and length of clean bole. A 1% random sample, stratified by forest reserve and age class, was originally planned, but forest closures due to the Emergency resulted in only 130 plots being established at the time of Cousens's analysis.

In his analysis, Cousens observed a clear break in the diameter class distribution within plots, stems of smaller diameter being recognized as regeneration obtained (by release or inducement) by the R.I.F. operation, while those usually of appreciably larger size were either advance growth already well established at the time of treatment or relics from the original crop. Because of the presence of these old crop remnants, the B.A. on the plots showed remarkably little variation with age, though the new crop segment of the plots showed an expected increase in B.A. with age, the relationship fitting moderately well to the linear expression:

B.A. (sq. ft per acre) = 2.41 (Age) - 7.97

+ Smith (1959) states that 200,000 acres of regenerated forest were destroyed during the Occupation but this would appear to be an over-estimate, as from Mead's figures barely 200,000 acres could have been under treatment by 1942 and some areas certainly survived.

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* Principal species were those that could be accurately identified at all stages of growth, and that were known to yield an established, commercial timber.

Such a rise in the new crop B.A. must be accompanied by a corresponding decrease in the old crop B.A., and this is reflected in the decreasing percentage of dominants selected from the old crop with age; Table 18 shows this effect, which Cousens states is due to changing methods of exploitation and treatment over the 25 years covered. The oldest crops were in areas where there was a good demand for poles and firewood, and the youngest in areas that failed to receive the full schedule of treatments prior to the war, and hence contained more stems from the old crop.

Because of these old crop stems the regenerated forests tend to have an irregular canopy; only where the fast-growing Shorea spp. are plentiful, and have been favoured in past treatment, do the stands have the even appearance expected in an even-aged forest. For the same reason Cousens was unable to determine any differences in site quality based on such criteria as height at a given age; the effect was masked by the presence of the old crop stems. He did, however, establish general height/age and height/diameter relationships for the various segments of the crop, and probably the most significant of these indicated that the fast-growing, light hardwood Shorea spp. are consistently taller than other new crop stems of the same diameter (by 10-15 ft on stems of 19 inches D.B.H.), and that old crop stems are taller than new crop stems of the same diameter (by 5-10 ft on stems of 19 inches D.B.H.). He also established that a number of species could maintain a diameter increment of 0.65 inches a year (2 inches girth) for up to 30 years; among the recognized "principal species" in this class where Shorea spp. of the red and white meranti groups, Dipterocarpus baudii and Dyera costulata, while among the recognized weed species capable of making such growth were Macaranga gigantea, Styrax benzoin and Ficus, Pasania, Castanopsis and Elaeocarpus spp.

TABLE 18

Effect of Age and Old Crop Stems in Regenerated Forests, Perak

Age Class (Years)	12-16	17-21	22-26	27-31	32-26	37-41	Mean
Mean B.A. per acre (sq ft)	85	89	92	87	86	90	-
Highest B.A.	110	127	117	102	100	112	-
Lowest B.A.	65	67	60	70	77	73	-
Selected Stems -							
Old Crop	77%	43%	35%	33%	13%	6%	38%
New Crop	23%	57%	65%	67%	87%	94%	62%

In 76% of all subplots a principal species was selected as the leading dominant stem, and in a further 9% other species currently regarded as economic were selected. Table 19 indicates the relative importance of the various species groups, and clearly indicates the dominance of the meranti (light hardwood) Shorea spp. in these regenerated forests, and especially in the new crop segment where, in 62% of all subplots with a new crop dominant, the selected stem was a meranti. As Cousens comments, "there can be no disputing the fact that the silvicultural aim of increasing the proportion of fast-growing

Shorea spp. has been highly successful". Only in the subplots where old crop dominants were selected do the heavy hardwoods, such as *Balanocarpus* and the balau group of *Shorea* spp., make up an appreciable proportion of the selected stems.

TABLE 19

Occurrence of Economic Species in Regenerated Forest, Perak

Species	Percentage Occurrence of Selected Dominants					
	New Crop		Old Crop		Total	
	(1)	(2)	(3)	(2)	(4)	(2)
Shorea spp. (light hardwood)	61.9%	32.7%	33.5%	10.8%	51.1%	43.5%
Shorea spp. (heavy hardwood)	1.7	0.9	9.3	3.0	4.6	3.9
Dipterocarpus spp.	2.2	1.2	4.8	1.5	3.2	2.7
Balanocarpus heimii	1.2	.6	3.3	1.1	2.0	1.7
Other dipterocarps	1.0	.5	1.5	.5	1.2	1.0
All dipterocarps	68.0	35.9	53.3	16.9	62.0	52.8
Palaquium spp.	7.7	4.1	13.3	4.3	9.8	8.4
Dillenia spp.	3.2	1.7	2.4	0.8	2.9	2.5
Koompassia malaccensis	0.9	.5	11.4	3.7	4.8	4.2
All Principal Species	87.6	46.2	91.9	29.8	89.3	76.0
Other Economic Species	12.4	6.6	8.1	2.6	10.7	9.2
Total	100.0	52.8	100.0	32.4	100.0	85.2

Note (1) % based on 687 subplots dominated by new crop stems. (2) % based on total of 1,300 subplots sampled. (3) % based on 421 subplots dominated by old crop stems. (4) % based on 1108 (687 + 421) subplots in which a dominant stem selected.

In 15% of the subplots no economic species could be selected. These subplots included local unproductive areas, notably swamps, and also some areas where, due to Emergency closures in untreated forests, salvage fellings had been carried out in the regenerated stands to remove old crop stems of merchantable size. Such fellings caused considerable damage, creating gaps of 1/10 to 1/8 acre in size (and occasionally up to 1/3 acre). No regeneration appeared in these gaps, which were soon covered by vines and some *belukar* species. When this destructiveness became apparent in 1953, salvage fellings were stopped.

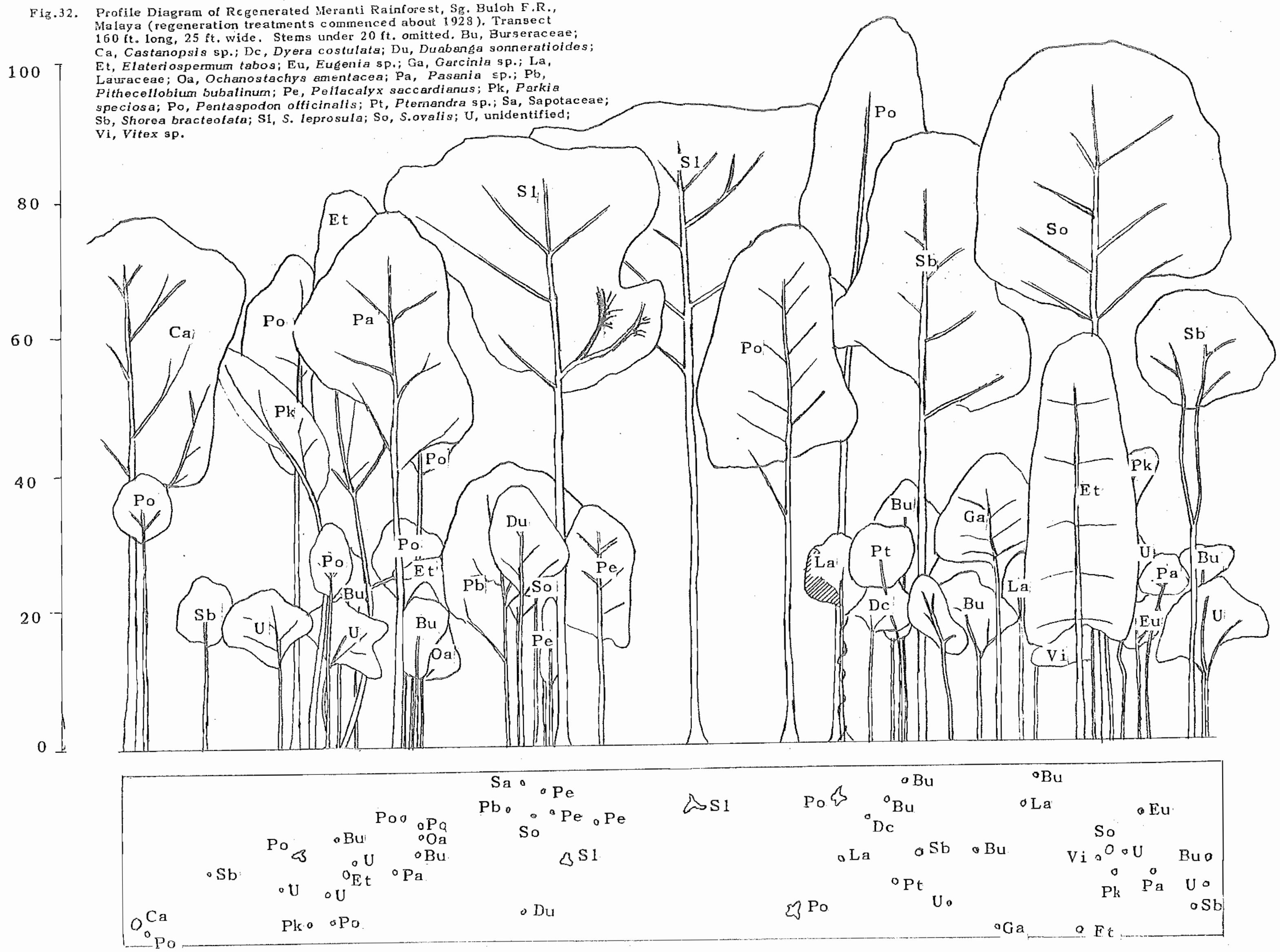


Fig.32. Profile Diagram of Regenerated Meranti Rainforest, Sg. Buloh F.R., Malaya (regeneration treatments commenced about 1928). Transect 160 ft. long, 25 ft. wide. Stems under 20 ft. omitted. Bu, Burseraceae; Ca, *Castanopsis* sp.; Dc, *Dyera costulata*; Du, *Duabanga sonneratioides*; Et, *Elateriospermum tabos*; Eu, *Eugenia* sp.; Ga, *Garcinia* sp.; La, Lauraceae; Oa, *Ochanostachys amentacea*; Pa, *Pasania* sp.; Pb, *Pithecellobium bubalinum*; Pe, *Pellacalyx saccardianus*; Pk, *Parkia speciosa*; Po, *Pentaspodon officinalis*; Pt, *Pternandra* sp.; Sa, Sapotaceae; Sb, *Shorea bracteolata*; Sl, *S. leprosula*; So, *S.ovalis*; U, unidentified; Vi, *Vitex* sp.

Of all subplots in which a selected dominant was chosen, 22% were dominated by Shorea leprosula and 18% by S. parvifolia; these two species also made up 9% of all stems over 4 inches D.B.H. Cousens noted that, in the forests where these and other merantis were very common, there had been a tendency for continued cleanings which resulted in an understorey of adventitious weed species, especially Randia spp., and an upper storey of Shorea with a thin, high canopy, growing slowly. Such stands have been shown in experimental plots to respond when the crowns are freed by thinning, and Cousens considered that the "best hope of obtaining good development with a minimum of treatment lies in early thinnings to ensure that there are not more than 30 dominant (and well distributed) stems of emergent species per acre".

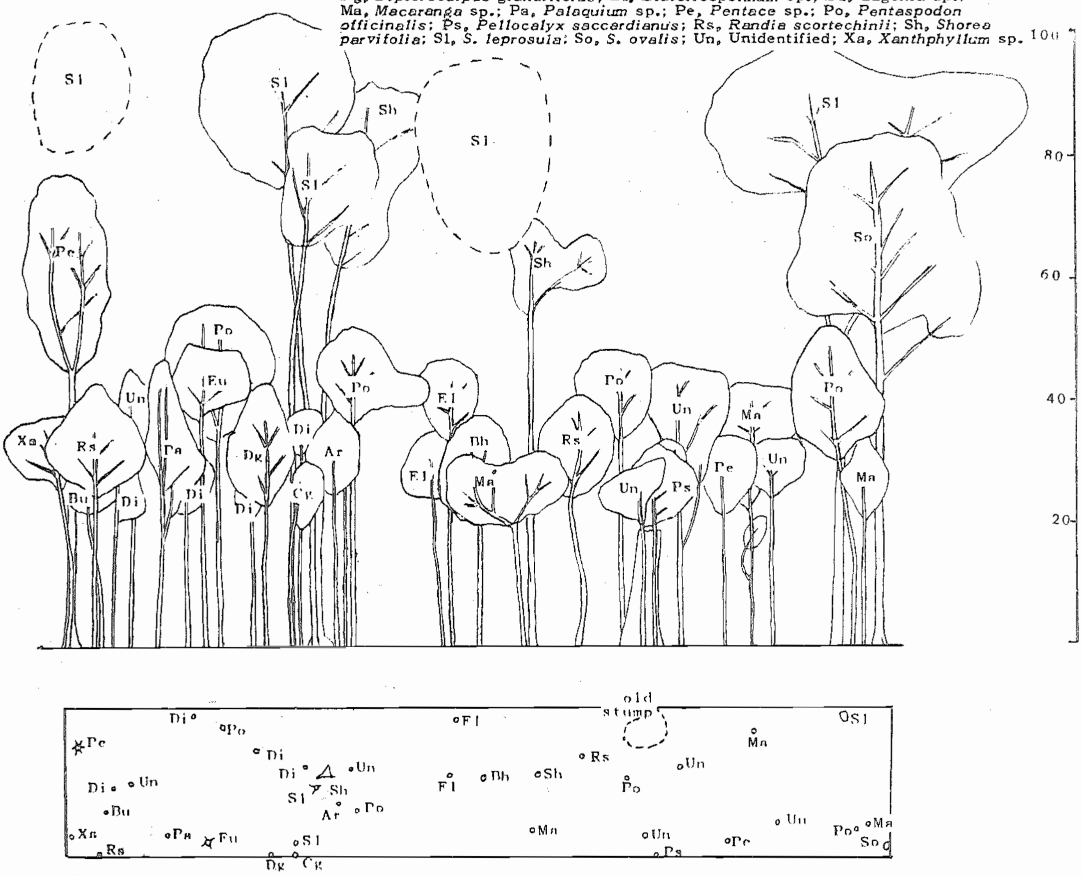
From all plots, Cousens estimated the merchantable volume at age 40 years to be 1,270 cubic ft per acre of principal species, including any sound old crop stems. Since the principal species by no means include all commercial species found in the regenerated forests, this can be accepted as a fairly conservative estimate.

Some idea of the appearance of the stands produced by R.I.F. can be obtained from Figure 32, a profile diagram of one such area on Sungei Buloh F.R., Cpt. 12, in Selangor, and Figure 33, of another area on Pasoh F.R., Cpt. 5, in Negri Sembilan. The treatment received by the two areas, and details of the enumeration of 0.5 acre plots in both sites, are given in Table 20. For simplicity the species present are grouped into the silvicultural classes now used in Malaya; Class A being the heavy hardwoods, B the preferred species (mostly light and fast-growing hardwoods such as the red merantis), C the desirable species, and D the acceptable species (Wyatt-Smith 1960b, see also subsequently).

Both stands show considerable similarity in structure with a fairly continuous overstorey at about 100 ft standing above a relatively low, dense understorey. Probably because of fewer cleanings, the understorey at Pasoh is higher than at Sg. Buloh, and this is reflected by generally greater lengths of clear boles on the overstorey stems. Shorea spp., especially S. leprosula, predominate in the overstorey of both stands. This is shown in Figure 34 where the distribution of stems larger than 10 inches D.B.H. on the Pasoh plot has been plotted: of 28 sound stems at Pasoh, 19 are of 6 meranti-type Shorea spp., while 3 others are also dipterocarps. (Two stems on this plot are defective remnants of the old crop and should have been destroyed; the Lauraceae had in fact been girdled but failed to die, while the Shorea acuminata stem, now senescent, exemplifies the world-wide difficulty in inducing forest workers to destroy even faulty stems of economic species.)

In both plots the proportion of economic: weed: unclassified species is remarkably similar, but the more intensive treatment and intermediate fellings received at Sg. Buloh have produced a less densely stocked stand in which the largest stem of the new crop is 24 inches D.B.H., compared with 18 inches at Pasoh. The lower stocking of group B species and of dipterocarps at Sg. Buloh can probably be attributed to the fellings during the Occupation.

Fig.33. Profile Diagram of Regenerated Meranti Rainforest, Pasoh F.R., Malaya (regeneration treatments commenced 1929). Transect 132 ft. long, 25 ft. wide. Stems under 30 ft. omitted. Ar, *Artocarpus rigidus*; Bh, *Balanocarpus heimii*; Bu, Burseraceae; Cg, *Coelostegia griffithii*; Di, *Diospyros* sp.; Dg, *Dipterocarpus grandiflorus*; El, *Elateriospermum* sp.; Eu, *Eugenia* sp.; Ma, *Macaranga* sp.; Pa, *Palaquium* sp.; Pe, *Pentace* sp.; Po, *Pentaspodon officinalis*; Ps, *Pellocalyx saccardianus*; Rs, *Randia scortechinii*; Sh, *Shorea parvifolia*; Sl, *S. leprosula*; So, *S. ovalis*; Un, Unidentified; Xa, *Xanthphyllum* sp.



The volume figures for these two plots have been calculated for the merchantable, clear-bole length of stems over 10 inches D.B.H., and should be regarded merely as approximations. At Sg. Buloh F.R., the equivalent of 50 stems per acre, with a B.A. of 73 square ft per acre (65% of total plot B.A.), were used in the calculation, and at Pasoh F.R. 56 stems per acre with B.A. 66 square ft per acre (50% of plot total). Both plots show a merchantable volume M.A.I. of about 60 cubic ft true per acre, a value very similar to that shown by Dryobalanops aromatica at Kanching F.R. (Table 16). Total cellulose increment is of course very much greater, and making allowance for past thinnings at Kanching and Sg. Buloh would increase the M.A.I. of these two plots. Both R.I.F. plots are about halfway through their expected rotation (70 years), and it is difficult to imagine the M.A.I. rising very mucher higher during the next 35 years. If this is so, it seems dubious whether a merchantable volume M.A.I. greater than about 75 cubic ft per acre can be expected from these Red Meranti-Keruing type forests in the course of a rotation under the most favourable conditions. However, such an increment would have produced some 5,000 cubic ft by the time of final felling, about equal to the total volume of stemwood on an acre of virgin Malayan forest (Smith, 1959). Even half this volume, which from Cousens's study is well within the bounds of possibility, will produce forests very much more valuable than their natural predecessors.

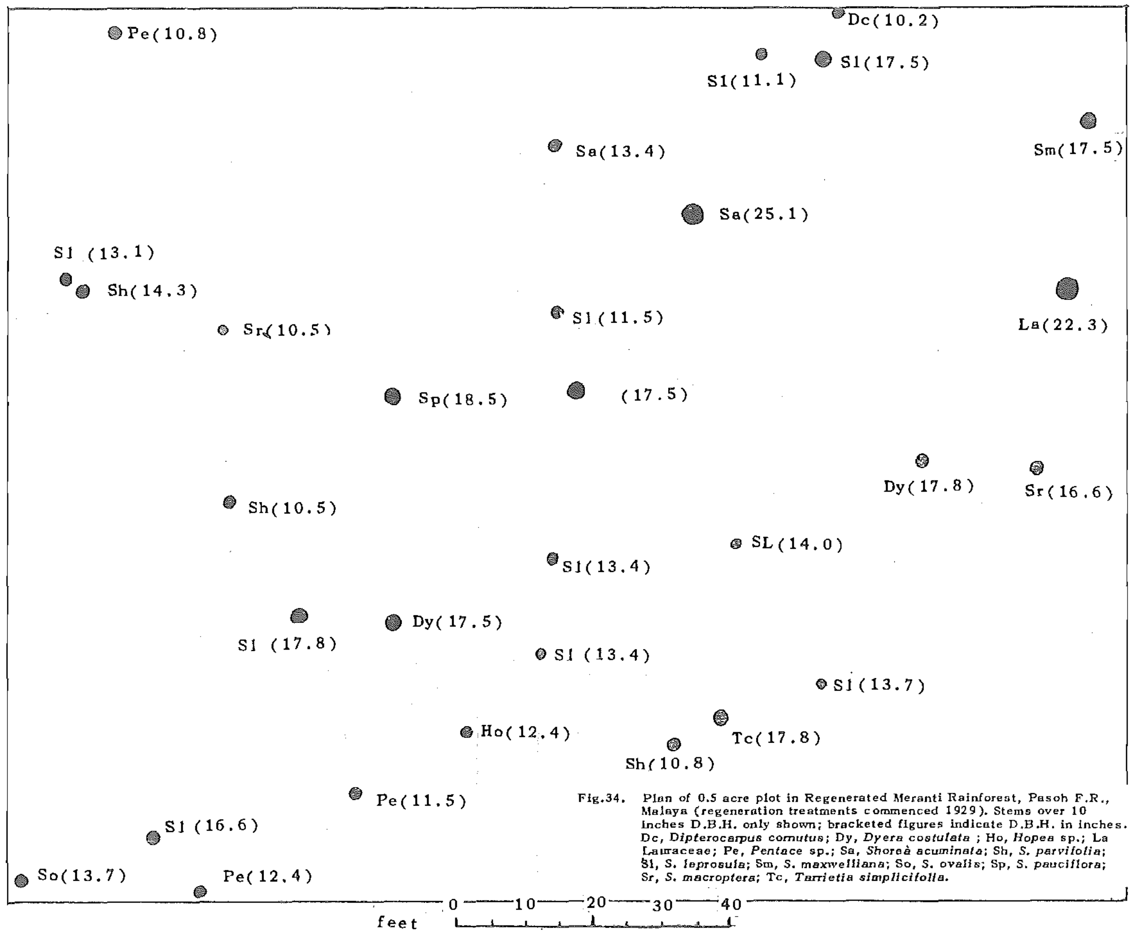


Fig.34. Plan of 0.5 acre plot in Regenerated Meranti Rainforest, Pasoh F.R., Malaya (regeneration treatments commenced 1929). Stems over 10 inches D.B.H. only shown; bracketed figures indicate D.B.H. in inches. Dc, *Dipterocarpus cornutus*; Dy, *Dyera costulata* ; Ho, *Hopea* sp.; La Lauraceae; Pe, *Pentace* sp.; Sa, *Shoreà acuminata*; Sh, *S. parvifolia*; Sl, *S. leprosula*; Sm, *S. maxwelliana*; So, *S. ovalis*; Sp, *S. pauciflora*; Sr, *S. macroptera*; Tc, *Tarrietia simplicifolia*.

TABLE 20

Plot Details for Forests regenerated by R.I.F. (0.5 acre plots)
(Plot figures, except number of species, doubled to provide results on per acre basis)

Forest	Sg. Buloh F.R., Selangor, Cpt. 12		Pasoh F.R., Negri Semblilan, Cpt. 5	
History	About 1928	S1 (Record missing to 1933)		
			1929	CG1
	1933	C2	1932	CG2
	1935-38	F	1935-37	F
	1938	C3, thinning, poison overstorey	1939	CG2 (repeat)
	1943	Pole felling	1940-41	F
	1944	Salvage felling	1947-48	CG3
	1949	Cleaning & Girdling	1957	Climber cutting and girdling
	1951	Salvage felling		
	1958	Climber cutting and girdling		

Approximate Age (from S1 or G1)	34 Years	33 Years

Plot Figures	No. Sp.	Stems/acre No.	Stems/acre %	B.A./acre No. (sq ft)	B.A./acre %	No. Sp.	Stems/acre No.	Stems/acre %	B.A./acre No. (sq ft)	B.A./acre %
(Stems 4 inches D.B.H. and over) Group A	-					3	12	4	5.6	4
Group B										
Shorea leprosula	1	20	9	35.0	31	1	48	14	35.2	26
S. macroptera	-	-	-	-	-	1	46	13	12.4	9
S. parvifolia	1	6	3	3.2	3	1	26	8	9.4	7
Other Shorea sp.	1	4	2	7.4	7	3	8	2	14.2	11
Dipterocarpus sp.	-	-	-	-	-	2	12	4	4.2	3
Other B	2	12	6	13.8	12	5	32	9	17.6	13
All Group B	5	42	20	59.4	53	13	172	50	93.0	69
Group C	5	94	43	32.8	29	4	20	6	4.8	4
Group D	5	10	5	3.4	3	3	20	6	6.6	5
All Commercial Groups	15	146	68	95.6	85	23	224	66	110.0	82
Weed Species	5	14	7	6.0	5	4	20	6	3.0	2
Unclassified Species	-	54	25	11.0	10	-	98	28	21.0	16
Grand Total	-	214	100	112.6	100	1	342	100	134.0	100
Dipterocarpaceae	4	48	22	53.4	47	11	158	46	85.6	64

Volume	cu ft per acre	%	cu ft per acre	%
Group A	-	-	110	6
" B	1640	77	1880	94
" C	420	20	-	-
" D	60	3	-	-
Total	2120	100	1990	100
MAI	62 cu ft/ac./an.		60 cu ft/ac./an.	

These then are examples of the regenerated forests produced by the pre-war R.I.F. treatments. They stand as examples of some of the finest forest crops produced by natural regeneration anywhere within the rainforest zone, and their presence merely stresses the sad loss suffered by Malayan forestry during the Occupation.

The Introduction of the Malayan Uniform System

When civil administration was restored after the Occupation, the Malayan Forestry Department had first to reconstruct its organization from the wreckage of war, and then to face squarely those silvicultural problems that had been threatening in the late thirties, and in particular to that caused by the increasing need for single, heavy, exploitation operations under the impetus of mechanization in extraction and milling practices, and of even greater demands, both local and overseas, for Malayan timber. As explained earlier, this had been receiving attention before the war; its solution now became imperative.

Strugnell (1947) started by pointing out that during the first seeding fellings in R.I.F. it was usually found that regeneration was already present. This necessitated completing exploitation fairly quickly to prevent damage to this regeneration, which was incapable of coppicing once it reached a height of about 12 ft. He also stressed that too much cleaning kept putting back the succession, and produced a persistent growth of climbers and secondary species like Macaranga and Mallotus; if left untended, these soon became sparse-crowned, and the valuable fast-growing species were able to push through them and ultimately suppress them, though for regeneration of heavy hardwoods either more tending was required or slower growth had to be accepted. Walton (1948) took this reasoning a stage further. He observed that areas exploited during the Occupation, with no silvicultural treatment, required only a single tending to produce greatly improved forests, and he suggested that adequate regeneration could be obtained with a single logging operation taking advantage of the regeneration already on the ground. The presence of this regeneration should be checked previously by milliacre sampling, and logging should be followed by a cleaning and by a poisoning of the remaining large trees; he could see no point in retaining seed trees: "In Malayan forests the period of effective and economic 'recruitment', once the canopy has been opened is so short that the retention of seedbearers provides no safeguard ....".

Walton's paper appears to mark the first crystalization in print of what has become known as the Malayan Uniform System. In his own words: "It is suggested that future treatment should aim at the improvement of all forest reserves rather than the conversion of a proportion of them to pure timber crops. There is reason to believe that the former aim will achieve the latter object over extensive areas".

These, and other ideas and observations, were considered at a conference of State Forest Officers in 1949, when an approved technique for treating the forests was formulated. This was written up by Barnard (1950a) and is the authoritative account of silvicultural practice prescribed in the Malayan rainforests over the past decade. Accounts written for wider audiences* were subsequently published by Walton, Barnard and Wyatt-Smith (1952) and by Landon (1957).

The success of the system depends upon four essentials:

1. Adequate stocking of seedlings of economic species at the time of exploitation.
2. Complete removal of the canopy.
3. No tending until the regrowth has passed the ephemeral climber stage and is relatively clear below.
4. Maintenance of adequate new canopy to prevent the redevelopment of climbers.

In order to establish the adequacy of the initial stocking of regeneration, and subsequently to determine the need for and nature of treatment in the developing regrowth, periodic sampling of the regeneration has to be carried out, using linear sampling (transects of quadrats established at regular interval) with the quadrat size varied according to the stage of development of the new crop (Barnard, 1950b). This linear sampling is fundamental to the procedure devised.

As described by Barnard, the first step when a compartment is required for logging is to carry out linear sampling, with milliacre plots, not more than 18 months before logging is due to commence. In conjunction with the linear sampling, a sample enumeration of commercial stems is carried out. If at least 40% of the milliacres carry at least one seedling up to 5 ft high of a recognized commercial species, regeneration is regarded as adequate. If the seedling stocking is inadequate, but seed trees are well distributed, the compartment if possible is to be retained untouched until a seed year occurs.

Where regeneration is adequately represented, felling should start as soon as possible, with all utilizable trees being exploited. If a market exists, pole fellings of small stems (under 12 inches D.B.H.) of species unsuitable as mill logs can precede or accompany the main logging operation. All mill trees to be felled are branded beforehand to ensure complete exploitation of the area in an orderly fashion; relatively inaccessible or poor areas of the compartment should be marked first; and an area of good, accessible forest kept until the remainder has been satisfactorily logged, to serve as an inducement for satisfactory working. Felling should not extend over one area for more than 2 years.

Felling is followed as closely as practicable by the poison girdling of all useless stems down to 2 inches D.B.H.

Three to five years after exploitation, when the regrowth has cleared beneath, linear sampling with quarter chain square quadrats (1/160 acres, $16\frac{1}{2}$ by $16\frac{1}{2}$ ft) is carried out. From the results of this sampling further treatment is determined. This may include any or all

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* Barnard's paper was published with the authority of the Director of Forestry "to serve as a general guide for Malayan Forest Officers (especially those newly appointed)".

all of the following operations:

1. Cutting of all climbers and rotans (Calamus spp. and related climbing palms).
2. Cutting Eugeissona triste and other similar palms.
3. Poison girdling all useless, surviving trees of the old crop.
4. Poison girdling of weed-tree species in the new crop, where these are competing with more valuable regeneration.
5. Poison girdling of defective and diseased stems.
6. Selective thinning (by poison girdling) in favour of the more desirable species, but resisting any temptation to do a general undergrowth cutting or to eliminate everything interfering with the fast-growing Shorea spp.

About 10 years after exploitation, linear sampling with half chain square quadrats (1/40 acre, 33 ft x 33 ft) is carried out, further treatment is prescribed from the results, or the compartment is passed as regenerated. Subsequent treatment is expected to be based upon periodic sampling at about age 20 years, and at roughly 20 year intervals thereafter, when thinnings and other intermediate fellings will be carried out while maintaining the mixed nature of the crop.

The normal sequence of operations for the Malayan Uniform System as originally prescribed thus is:

Year	
n - $1\frac{1}{2}$ to n	Linear sampling (milliacre) of regeneration, and enumeration of merchantable trees.
n to n + 1	Exploitation, followed by poison girdling down to 2 inches D.B.H.
n + 3 to n + 5	Linear sampling ($\frac{1}{4}$ chain square) of new crop, followed by cleaning, climber cutting and poison girdling as required.
n + 10	Linear sampling ($\frac{1}{2}$ chain square) of new crop, followed by treatment as required or passing as regenerated.
n + 20, n + 40 etc.	Sampling and thinning as required.

Diagnostic Sampling

It is obvious that the Malayan Uniform System depends very largely on the periodic sampling of the regeneration to provide an accurate guide to the treatment required: diagnostic sampling, as it has been aptly termed (Dawkins, 1958). Of all the operations in the normal sequence, only the poison girdling after exploitation is carried out as a fixed, routine operation; all other treatments are devised to suit the needs of the young stand as determined by prior sampling.

To gain this information on which to base treatment a new sampling technique had to be developed. Milliacre sampling had been employed in Malaya since the mid-thirties (Browne, 1936), but was suited only to small regeneration, and in the form used did not provide a record of the size or freedom from competition (or otherwise) of the small trees. Landon (1948) evolved the basis of the system finally adopted, and after field trail for several years a more polished version was presented by Barnard (1950b) in a supplementary paper to his one on the Malayan uniform system. As circumstances permitted, the sampling was carried out in this way for 10 years, when Wyatt-Smith (1960b) suggested some modifications that were subsequently made standard practice.

The basic features of the system are:

1. The use of varying plot size depending on the average size of the regeneration being sampled.
2. The selection of the stem of an economic species within the plot most likely to survive.
3. Recording the size, class, and dominance class of the chosen stem (in the first, pre-exploitation sampling, dominance is not recorded, but is replaced by an indication of the abundance of the selected species in the quadrat).
4. Recording the presence of any stems of a more desirable species, less well established within the plot.
5. Recording the presence of climbers, palms, etc. in the quadrat.

Three plot sizes are used, milliacre for determining the extent and distribution of small regeneration in advance of felling, quarter chain square for determining the development of the sapling stand 3 to 5 years after exploitation, and half chain square for the young pole crops some 10 years after exploitation. Details of the intensity of sampling, and of the size classes recorded in each operation are given in Table 21.

TABLE 21

Plot size, interval and Size Classes in Malayan Linear Sampling

Sample Unit	Area	Length of Side	Transect Interval	Sampling %	Size Class & Group No.	
Milliacre	1/1000 ac.	6 ft 7 in	5 chs	2	Under 1 ft high	1A
					1-5 ft high	1B
¼ chain square	1/160 ac.	16 ft 6 in	5 chs	5	5-10 ft high	2
					10 ft high - 2 in D.B.H.	3
					2-4 in D.B.H.	4
½ chain square	1/40 ac.	33 ft	5 chs	10	2-4 in D.B.H.	4
					4-8 in	5
					8-12 in	6
					12-16 in	7
					16-20 in	8
					20 in D.B.H. and over	9

In each quadrat the stem of a desirable timber species, within the acceptable size range and considered best established and most likely to survive, is selected as the chosen stem. In milliacre sampling the frequency of the chosen species on the quadrat is also roughly estimated; a single seedling (1), up to 5 seedlings (+), or more than 5 (++). If a stem of a more desirable, but less well established, species also occurs on the quadrat, this is recorded as the second choice. The acceptable species, which are those known to reach timber size and produce a merchantable grade of timber, and which are identifiable in their young stages, are grouped into silvicultural classes and are known as LS (i.e. Linear sampling) species. In the original list (Barnard, 1950b) three classes were given, class A (the most desirable) containing essentially only the slower-growing, heavy hardwood species. In the revised list (Wyatt-Smith, 1960b) all heavy hardwoods are included in group A, which is now tallied separately, while the other species are split into an expanded list of 3 classes, B, C, and D, containing the medium and light hardwoods in order of silvicultural desirability. Thus in present linear sampling, both a heavy hardwood (A) and a light or medium hardwood (B, C or D) may be jointly the chosen species in a quadrat, and in addition a more desirable species from the second group (B or C) may also be selected as the secondary stem.

In quarter and half chain square samplings, the dominance status of each selected stem (including secondary stems) is also recorded, four dominance classes being recognized:

D1 Dominant stem, unimpeded above or at sides

D2 An otherwise dominant stem in competition with another LS stem.

CD Co-dominant stem, unimpeded above but crown partly shaded by other stems.

d Dominated stem, shaded vertically.

A selected stem that is one of a group of LS species at roughly the same stage of development is classed as D2. In addition, the occurrence of competing palms in a quadrat is noted in all samplings, and of climbers and competing relics of the old crop in quarter and half chain square samplings. Examples of field sheets for milliacre and quarter chain square samplings are given in Tables 22 and 23.

When sampling is completed the results are summarized and the recommendations for treatment drawn up: Table 24 gives an abbreviated example from a reserve in the Kapur forest type of eastern Johore after half chain square sampling. A stock map is also prepared, showing the position of stocked quadrats. As well as its value for general management purposes, this map is also useful in indicating those areas that may require special treatment, such as sections of a compartment particularly rich in heavy hardwoods.

With milliacre sampling, the summary is mainly intended to indicate whether there is sufficient regeneration present for exploitation to occur, and also to indicate whether special treatment may be needed to reduce the palm competition or to favour especially rich areas of heavy hardwoods.

Malayan Uniform System During 1950-1960

The Malayan uniform system was based upon experience gained in the lowland, meranti-rich forests, and the treatments prescribed by Barnard were intended primarily to be applied to these forests under more or less ideal conditions. Strugnell (1954) pointed out that conditions were often far from ideal; in many compartments exploitation, for various reasons, was incomplete; sometimes it was impossible to follow felling immediately with poison girdling; and in some forests the schedule of treatment was not suitable for the species present. These points were well appreciated by Barnard, who dealt with them to some extent in his manual of silviculture (Barnard 1954). However, the major problem during most of the fifties was caused by the Emergency, which affected forest operations of all types throughout virtually the whole of the Federation. Either because of direct bandit activity, or through military or police counter-actions, forests were frequently closed for lengthy periods, with the result that planned management became impossible. Until the last few years of the decade, the Malayan uniform system was scarely ever applied with the sequence of operations as laid down.

Some indication of this is supplied by Wyatt-Smith (1960b) who, ten years after the introduction of the system, could obtain records of only 12 compartments that had had both milliacre and quarter chain square sampling - and four of these had received atypical treatment. Exploitation by necessity continued spasmodically in compartments for much longer than the two years specified; sudden closures forced the exploitation of other areas without prior milliacre sampling; girdling often had to be postponed for years after felling had been completed. Despite these great difficulties, but aided by the ability of diagnostic sampling to indicate the type of treatment most needed, the forest services carried out treatment over a surprisingly large area of reserve. In all, some 730 square miles of rainforest were opened for regeneration during the 10 years following the introduction of the system, and over the greatest proportion of this area the ultimate results should differ little from those obtained under the standard treatment.

However, the difficulties outlined by Strugnell still held, and as conditions became more normal the significance of these became more widely appreciated. Their importance was increased with the growing awareness that, in the long run, much of the Meranti-Keruing forest type was unlikely to remain under forestry control; these sites, for which the Malayan uniform system was particularly designed, generally represent some of the better agricultural lands in the Federation and, with a population estimated to reach 28,000,000 (four times the present figure) in the course of 70 years, it is apparent that the forestry services will be increasingly forced to rely on forest situated on areas of poorer soil and more rugged topography.

These points were considered by Wyatt-Smith (1961a, revised 1962) in a review of experience with the system and in the light of changing conditions. The main conclusions reached by Wyatt-Smith are:

1. The results of milliacre sampling need be carefully examined for species composition; a low percentage stocking made up largely of the more desirable species is to be preferred to a high percentage

TABLE 22

Milliacre Sampling Field Sheet. Pasoh F.R., Negri Sembilan (Virgin Forest)

Chain and Milliacre No.	Chosen Seedling						Secondary Seedling	Palms	Notes
	Group A			Group B-D					
	Species	Abundance	Size Class	Species	Abundance	Size Class	Species		
0-4				MTB	1	1B			MTB = Shorea leprosula
5				BN	1	1A		+	BN = Calophyllum sp.
6	C	1	1B	MW	1	1B		+	MW = Hopea sp. C = Balanocarpus heimii
7				KD	+	1B			KD = Burseraceae
8				MTB	1	1A			
9				KD	1	1A	MLG		MLG = Shorea lepidota
10				-					
1-11				MTB	+	1A			

TABLE 23

Quarter Chain Square Sampling Field Sheet. Pasoh F.R. (3 years after felling)

Chain and Sample No.	Chosen Tree						Secondary Tree			Domination by relics	Climber incidence	Domination by Palms	Notes
	Group A			Group B - D			Group B-C						
	Species	Size Class	Dominance	Species	Size Class	Dominance	Species	Size Class	Dominance				
0-1				MTB	3	d				+	+		MTB-Shorea leprosula
2	BKH	2	d	MTB	3	CD							BKH=S. maxwelliana
3				MTB	3	CD					+		
4				KKT	3	CD					+		KKT=Diptercarpus sublamellatus
1-5				-									
6				SPLN	3	CD	MTB	2	d				SPLN=Sindora coriacea
7				MKP	4	D1							MKP=Shorea ovalis
8				MTB	3	D2							

TABLE 24

Summary of Half Chain Square Sampling. G. Arong F.R. (13 years after felling)

GROUP	Quadrats Stocked		Size Class				Dominance Class			
	No.	%	3	4	5	6+	D1	D2	CD	d
Class A (Heavy Hardwoods)	36	7.1	1	4	11	20	32	-	1	3
Dryobalanops aromatica (Class B)	122	24.2	38	46	13	25	63	7	16	36
All Class B	174	34.5	39	60	26	49	107	8	20	39
Class C	177	35.2	11	56	48	62	147	9	4	17
Class D	90	17.8	8	42	21	19	69	-	3	18
Total B-D	441	87.5	58	158	95	130	323	17	27	74
Unstocked	63	12.5								
Total Quadrats & % (B-D)	504	100.0	13.1	35.8	21.6	29.5	73.3	3.8	6.1	16.8

Recommendation: general climber cutting; poison girdle all useless relics, all weed-tree species, and any unclassified stems over 4 inches D.B.H. if dominating an 18 stem of class 4 or larger.

stocking inflated by the less valuable species. In view of this, Wyatt-Smith (1960b) recommends that a 30% stocking of milliacres can be considered satisfactory, provided 20% of all milliacres have, as the selected seedling, a class B or C species.

2. Where regeneration of the more desirable species is scarce, but seed bearers are fairly plentiful, exploitation should be delayed until a seed year has occurred.

3. Forests rich in certain species that are slow growing in their younger stages should receive special, intensive tending, starting within 2 years of exploitation. Such species include the heavy hardwoods (Class A) and also Shorea curtisii, the very common hill ridge species that produces a red meranti grade of timber, but that does not have the rapid early growth of the lowland merantis.

4. Quarter chain square sampling is particularly valuable in assisting treatment prescription in abnormal forest (especially where exploitation was incomplete or selective), but its omission from normally treated Red Meranti-Keruing type forest is rarely serious. In sampling abnormal forest it may be desirable to increase the range of sizes below the 5 ft height and above the 4 inches D.B.H. recommended by Barnard (1950b).

5. Similarly in half chain square sampling in abnormal forest, it may be desirable to include smaller size classes than the 2 inches D.B.H. prescribed by Barnard, while also in abnormal forest consideration should be given as to whether quarter or half chain square sampling, modified if necessary, will provide the most useful information. This can only be determined after prior inspection by the responsible forest officer.

6. In both types of sampling in abnormal forest within 20 years from exploitation, no stems larger than 20 inches D.B.H. (class 8) should be selected.

7. Seedlings of Dryobalanops aromatica do not like sudden exposure to full light*, yet because of the gregarious nature of this species exploitation usually results in much greater canopy opening than in most other Malayan forest types. In some areas (e.g. eastern Johore) the Kapur type is also liable to invasion by the blanketing fern Gleichenia linearis when drastically opened. To avoid these dangers of sun-scorched and fern-smothered seedlings, both delayed girdling and a higher minimum diameter to be girdled have been used; the former appears preferable, but since it is desirable to destroy relics as early as possible, girdling down to 6 inches D.B.H. after exploitation is recommended.

8. Shorea curtisii is similarly unable to respond rapidly to complete canopy opening, and again raising the minimum diameter for poisoning from 2 to 6 inches is recommended.

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* The compartment history for cpt. 11, G. Arong F.R. (Eastern Johore), provides an example of this. The area, rich in D. aromatica regeneration, received a very heavy poison girdling after logging in 1949. The forest officer's comments at the time are: "Kapur looks very pretty". Three years later the comment on the same compartment is: "Kapur regeneration ... absolutely miserable".

9. S. curtisii, in the Seraya type, is normally confined to sites close to the ridge tops. Because of the richness of these stands compared with the lower slopes (Wyatt-Smith, 1960e), and because of logging methods in the steep topography of these sites, exploitation tends to be concentrated along the ridges and upper slopes. Except on particularly steep slopes or in areas with abundant rock outcrops and boulders, girdling should extend for 5 chains beyond the area actually exploited, in an attempt to increase the area of Seraya type in the next rotation.

10. Even light-loving species like S. leprosula will droop during the heat of the day when in the open, and the associated species, which it is considered desirable to retain in the regenerated forests, are more affected by heavy opening of the canopy. It is therefore suggested that, even in the Red Meranti-Keruing type, girdling to 6 inches D.B.H. should be carried out in those parts of a compartment that have been most drastically opened by logging, but that in the still dark, unsmashed, shaded patches, girdling to 2 inches should be performed as previously, and over the entire compartment all heavy crowned, shade-casting species should be poisoned down to 2 inches D.B.H.

11. It is stressed that a matrix of slower-growing, lower storey trees should be maintained in regenerated forest to help produce a greater length of clear hole on the main economic species in the new crop, and the increase in minimum girdling diameter should assist in this regard.

12. Swampy rainforest on peat has not previously been subject to treatment after logging, but the suggestion is made that it should receive treatment similar to the Red Meranti-Keruing type, except that sound stems of Koompassia malaccensis should be retained if below 23 inches D.B.H., and the quarter chain square sampling and subsequent treatment 3 to 5 years after logging can be excluded.

13. Because of the extent of logging operations on state land forests (i.e. not reserved forest), in advance of clearing for agriculture, the less popular commercial species tend to be left standing in the exploitation of the more remote forest reserves. These (and indeed any stems above the minimum diameter for girdling) should only be retained if they are of good form and capable of lasting for the full rotation (70 years). In the case of medium and light hardwoods (LS species in classes B, C and D), these should not normally be retained if larger than 19 inches D.B.H., though in forests where the minimum felling girth is 6 ft (23 inches D.B.H.) stems up to this size may be retained. (In the more accessible forests, minimum felling girth is usually 4 ft 6 inches, i.e. 17 inches D.B.H.).

14. Trials of various arboricides have failed to reveal any as efficient and cheap as sodium arsenite, and to ensure the elimination of unwanted stems a solution of 2 lb sodium arsenite per gallon of watter, applied to a frill girdle, should be used. (However, in town water catchment areas, e.g. sections of G. Arong F.R., the arsenic poison is replaced by the less dangerous butyl ester of 2, 4, 5T applied as a 2% solution in diesel oil.)

In addition to the above comments on existing practices in the Malayan uniform system, Wyatt-Smith suggested that certain treatments carried out in advance of exploitation might profitably be introduced.

These fall into 3 classes:

1. In certain areas, and particularly in the Seraya (ridge) type, the stemless palm Eugeissona triste forms a dense understorey. Individual clumps, spaced 10 ft to 20 ft apart, completely shade the ground and prevent the establishment of regeneration beneath them, though seedlings of economic species may survive in quantity for several years beneath the shade (Wyatt-Smith, 1960a). In such areas control of the palm is essential before logging, and control measures applied at least 3 years ahead of exploitation are recommended. Spraying the clumps with 2% 2, 4, 5T in diesel has given effective control, as has cutting the clumps close to ground level and then smashing the growing shoot and pouring in standard sodium arsenite solution (Wyatt-Smith, 1960e). The treatment of alternate clumps only reduces the cost of treatment, and probably also provides better conditions for the establishment of such species as Shorea curtisii.

2. To take advantage of dipterocarp seed years in areas where seed bearers are scarce, limited canopy opening should be carried out on the occasion of good seed years in compartments scheduled for exploitation in from 3 to 10 years. The canopy opening should take the form of climber cutting and the poison girdling of heavy crowned, useless trees of all sizes. Such treatment is most necessary in the forests of northwestern Malaya, where the equatorial rainforest verges towards the evergreen seasonal rainforest*. Such treatment is not required in areas to be logged within 3 years of seed fall, as it is felt that an establishment period is normally necessary if the seedlings are to withstand sudden and drastic canopy opening, and also because of the hazard during logging from the poisoned, but still standing, trees.

3. In forests unlikely to be opened for logging for many years improvement operations by poison girdling, aimed at favouring the smaller sized trees of valuable species, are suggested as a means of increasing the yield from such areas when exploitation finally occurs. The operations would also enable field staff to carry out some silvicultural work in those areas where, at present, logging is almost entirely on state lands intended for alienation.

The first two of these suggested pretreatments have now become authorized practice (Mohd. Alwy bin Haji Suleiman, 1961), along with the treatment of areas heavily infested with bamboo and areas where climbers are very abundant. Bamboo is common in parts of the evergreen seasonal rainforest zone, and also in parts of central Malaya following aboriginal shifting cultivation; control is effected by spraying with 10% TCA in water at least 3, and preferably 5, years ahead of exploitation. Climbers abound in some of the old "storm forest" areas of Kelantan (Browne, 1949), and also constitute a hazard in some areas where advance growth is plentiful, such as some Dryobalanops aromatica stands; cutting should occur 2 years ahead of felling and the vine stumps should be swabbed with the standard arsenic solution.

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* Walton, Barnard and Wyatt-Smith (1952) observe that in 3 years up to 1952, milliacre sampling carried out over 7,500 acres in Malaya revealed adequate regeneration in all forests except some of this evergreen seasonal type in Kedah and Perlis.

The Malayan Uniform System in Practice

As has been shown, the Malayan uniform system, which has been defined as a "clearfelling release of selected natural regeneration" (Cousens, 1957) was derived from the pre-war R.I.F. in the face of the necessity to exploit the forest in a single operation. Wyatt-Smith (1959b) states "....it was entirely management problems rather than ecological grounds which forced the change and ....it was just fortunate that ecological information did not run contrary to it but supported it". The system has been modified in various ways, mostly of a relatively minor nature, in the light of experience over the first decade, and the general pattern for the system now is:

Year	
n - 3 to n - 7	Canopy opening at time of good seedfall, in areas where regeneration and seed bearers are scarce.
n - 3 to n - 5	Treatment of areas heavily infested with bamboo.
n - 3	Treatment of areas with dense Eugeissona.
n - 2	Climber cutting in areas of heavy vine infestation
n to n - $1\frac{1}{2}$	Milliacre sampling and enumeration of utilizable stems.
n	Exploitation of all merchantable stems (normally to 17" D.B.H.). Poison girdling all unwanted stems down to 6" D.B.H. in Kapur and Seraya types and in heavily opened patches in other types (except for dense shade-casters), and down to 2" D.B.H. in shaded patches in other types. Retention of any potentially valuable stems below 19" D.B.H. (larger where minimum felling limit larger).
n + 2	Commence tending in areas designated as heavy hardwoods sites.
n + 3 to n + 5	Quarter chain square sampling (not in swampy rainforest).
	Such treatment as indicated by diagnostic sampling, e.g. climber cutting. eradication of weedtree species, removal of competing stems above a stated diameter, etc.
n + 8 to n + 10	Half chain square sampling. Such treatment as indicated by diagnostic sampling.

The pretreatments concern special sites only. The silvicultural operations involved as a routine measure are the exploitation of all merchantable trees in a single operation, followed by the poison girdling of all unwanted larger stems, and such subsequent treatment as is required to keep the regeneration in a healthy and vigorous condition. Although rightly regarded as a clear felling system, the appearance of a coupe at no stage resembles that after falling in pine or eucalypt forest, for example. Even if the girdled stems are disregarded, there remain above the small regeneration stems of sound, economic species below the minimum felling girth and up to 100 ft in height, plus stems below the minimum girdling diameter, ranging in height from up to 30 ft where the 2 inch D.B.H. limit is in force, to over 60 ft where the 6 inch limit applies.

Virgin equatorial rainforest in Malaya carries about 200 stems per acre larger than 4 inches D.B.H. and has a basal area in the order of 170 sq ft per acre (Walton and others, 1952; Cousens, 1957). On the average there are about 15 trees per acre larger than 15 inches D.B.H., and 10 per acre over 19 inches, and of these about seven trees are normally exploited to yield some 860 cubic ft of log timber per acre (Vincent, 1960a). These are of course merely average figures, and Table 25 gives actual examples of the composition of three distinct types of Malayan rainforest. The plots at Bt. Lagong F.R. and Bt. Bauk F.R. are in stands with a tendency towards single species dominance, the former by Shorea curtisii and the latter by Dryobalanops aromatica, and in both these types the merchantable yield probably tends to be above the Malayan average. Profile diagrams of Red Meranti-Keruing and Kapur forest types are given in Figures 9, 10, and 11.

In the main commercial forest types, milliacre sampling normally reveals an adequate stocking of regeneration though it should be noted that, out of 8 compartments that could be regarded as normal (i.e. negligible earlier felling operations) in the review by Wyatt-Smith (1960b), only five had a stocking of 35% or more and only four of these had over 20% of the quadrats stocked with species from groups A, B and C; on present criteria half these compartments should not have been logged when they were. Low stockings are commonly encountered in the evergreen seasonal rainforests of Kedah and Perlis and in such intrinsically poor communities as the Kempas-Kedongdong forest type, but regeneration is usually adequate in the swampy rainforests (Wyatt-Smith, 1959d). A summary of the regeneration present in the vicinity of the three profile diagrams for virgin forest is given in Table 26. In all three sites palms are common (over 40% of plots in each site carried palms), but these are mostly small palms such as Licuala spp. and present little hazard to regeneration.

Compartments due for exploitation are normally let to sawmillers or contractors by competitive tender, the operator submitting a tender for the premium to be paid to the department for the right to exploit the area. The premium is based on the accessibility and richness of the forest, and is paid in addition to royalty based on the actual timber extracted. Royalty rates are fixed in each state of the Federation and differ only slightly between the states: Table 27 indicates the royalties rates applying in Johore in 1962.

However, there is a growing tendency in Malaya for larger areas to be granted to sawmillers on longer term conditional contracts, the compartments being systematically worked under departmental direction, with the premium rates being determined by the department. Premium rates under this system tend to be lower than where they are obtained by tender, but this is compensated for in a number of ways, not the least of which is in a much higher standard of miller-constructed roading through the permit area.

TABLE 25

Stocking of Virgin Malayan Rainforest - 1 Acre Plots
(Data from Malayan F.R.I.)

Reserve: / Forest Type: / Species Groups	Sungei Menyala, N.S. Red Meranti - Keruing — Stems: 4" D.B.H.+					19"+		Bukit Lagong, Sel. Seraya (ridge) — Stems: 4" D.B.H."					19"+		Bukit Bauk, Treng. Kapur — Stems: 4" D.B.H.+					19"+	
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
A	4	6	3%	4	2%	-	-	3	8	3%	10	5%	2	9	4	7	3%	13	9%	3	10
B	15	45	20	82	52	12	62	6	20	9	60	27	6	51	8	35	16	48	32	7	32
C	4	6	3	5	3	1	3	10	16	7	49	22	8	43	3	3	1	4	3	1	3
D	8	19	9	13	9	2	6	9	13	6	6	3	-	-	6	11	5	6	4	-	-
All Economics	31	76	35%	104	66%	15	71	28	57	25%	125	57%	16	103	21	56	25 %	71	48%	11	45
Weedtree	9	14	6	7	4	-	-	8	22	9	19	9	4	14	9	13	6	4	3	-	-
Unclassified	-	130	59	47	30	2	5	-	152	66	76	34	6	19	-	153	69	73	49	7	24
TOTAL	-	220	100%	158	100%	17	76		231	100%	221	100%	26	136	-	222	100 %	148	100%	18	69
Dipterocarps	12	38	17	67	43	9	49	10	37	16	100	45	12	86	10	41	19	64	43	1	46

NOTE: Species classes (economics) after Wyatt-Smith 1960b; weed-tree species after Barnard, 1954.
(1) No. species over 4" D.B.H. in group
(2) No. stems per acre
(3) Stems as % of total
(4) B.A. per acre in square ft
(5) B.A. as % of total
(6) No. stems per acre over 19" D.B.H. (5 ft girth)
(7) B.A. per acre over 19" D.B.H. in square ft

TABLE 26

Regeneration indicated by Milliacre Sampling, Malayan Rainforest.

Forest Reserve	Type	Chosen Seedling %				Second Choice % B & C			Abundance			Size	
		B	C	D	Tot.	B	C	1st & 2nd choice	1	2-5	6+	1'	1-5'
Gunong Arong, Joh.	Kapur	100%	-	-	100%	-	-	100%	-	30%	70%	30%	70%
Pasoh, Negri Sembilan	R.M.-Keruing	20	-	45	65	5	-	25	50	10	5	25	40
Kemasul, Pahang	R.M.-Keruing	46	6	8	60	3	-	52	29	26	5	52	8

TABLE 27

Royalty Rates for Log Timber, Johore, 1962

(M$ 1 = 100 cents = 2/4 sterling)

Balanocarpus heimii (chengal)	50c. per cubic foot
Heavy hardwood species of *Shorea* (balau), *Hopea* (giam) and *Vatica* (resak); *Fagraea* spp. (tembusu), *Intsia bakeri* (merbau), *Mesua ferrea* (penaga), *Sloetia elongata* (tempinis).	30c.
Dryobalanops aromatica (kapur), *D. oblongifolia* (keladan)	30c.
Dipterocarpus spp. (keruing)	20c.
Other species, (including meranti group of *Shorea*)	15c.

NOTE: The high royalty for *Balanocarpus* reflects the past importance of this species, but in view of the diminishing demand for heavy hardwoods there are now suggestions that this royalty might be reduced to that of the other heavy hardwoods, while at the same time the increased demand for Meranti timbers suggests that these *Shorea* spp. could probably be slightly increased in royalty. The royalty rates are essentially a mirror of the market prices and demand for the various timbers, and are not an indication of the costs of production.

All trees to be felled are marked by forestry department sub-professional staff, the minimum felling diameter varying from 17 inches (4 ft 6 inches girth) in the more accessible areas, such as on the west coast, to 23 inches (6 ft girth) in the less accessible areas (central Malaya and east coast). Fines are imposed on the contractor if careless falling results in unnecessary damage to regeneration or small trees, and royalty is imposed, after exploitation is complete, on any marked trees remaining in the forest.

Logging inevitably causes damage to many of the trees not removed in felling. The damage produced in an area of Kapur forest type in Mentas F.R., Pahang, has been studied by Wyatt-Smith and Foenander (1962). It was found that 39% of the area was covered, after logging, by roads, tree crowns or holes, with crowns occupying the greatest area (28%). The relative loss to various groups of trees was:

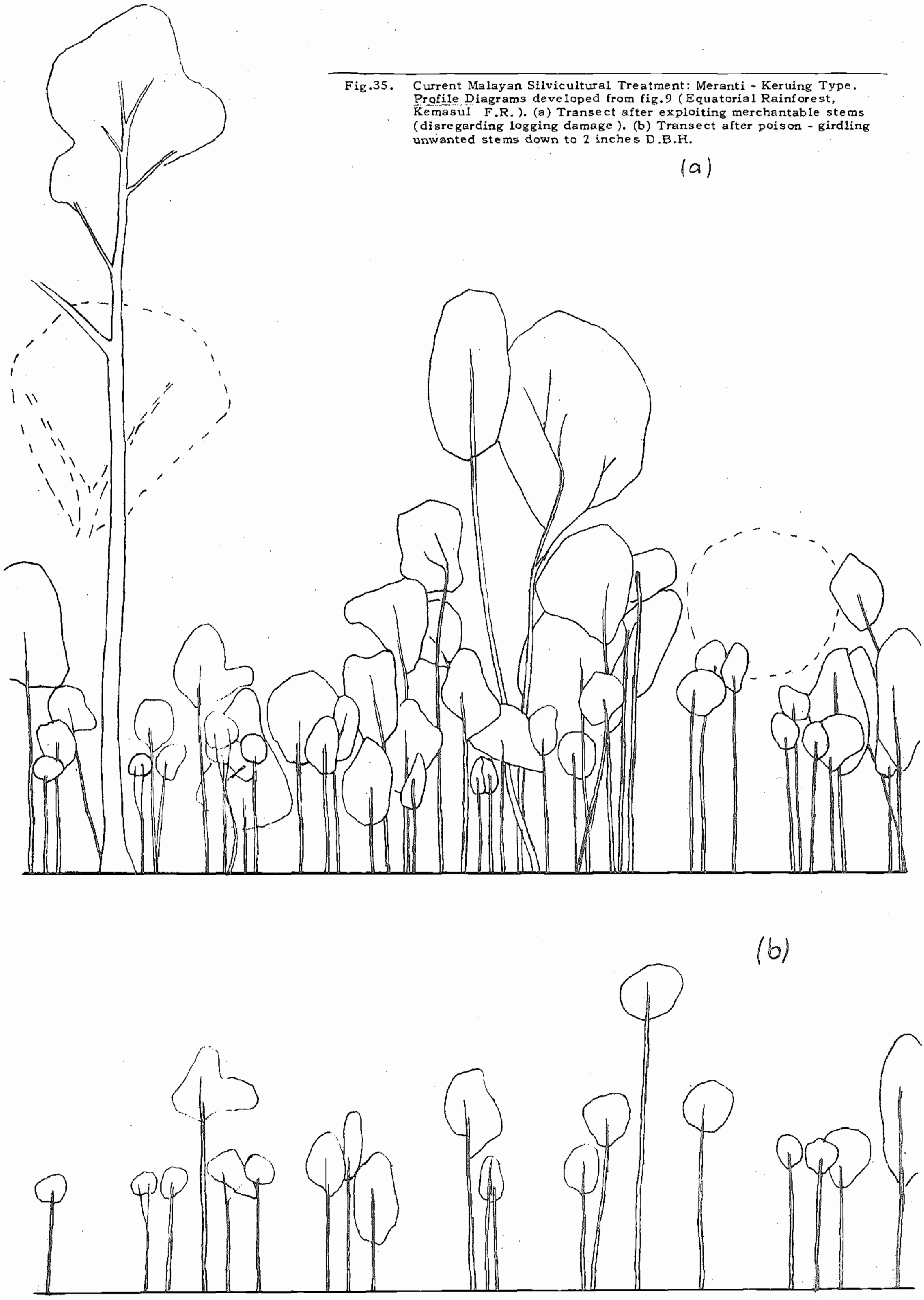
Class A species	35% destroyed
Class B	40%
Class C	17%
Class D	30%
All classified species	33%
Unclassified species	41%
Weed Tree species	21%
All species	37%
Dryobalanops aromatica	52%
Red Meranti group of _Shorea_ spp.	34%
Shorea macroptera	41%

The highest losses occurred in the 10 ft high to 2 inches D.B.H. size class, where 56% of the stems of all classified species were destroyed. However, there remained an average of 43 classified stems per acre between 4 and 23 inches D.B.H., made up of 2.7 stems per acre of group A species, 17.8 group B, 3.8 group C and 18.8 group D. The authors suggest that the little damage to weed tree species confirms the choice of these species as undesirable, since they respond vigorously to canopy opening. The low degree of damage to group C was due to the rapid response made by _Pometia_ spp. Despite the damage that does occur, there is clearly a valuable residue of advance growth that survives the "clear felling" of all the merchantable trees.

When logging is completed, poison girdling is carried out by departmental staff. Work normally proceeds along strips 5 chains wide and, if they can be readily relocated, the traces used in the earlier milliacre sampling are reopened as guide lines. If these traces are too difficult to find, new lines are cut to subdivide the compartment.

Each labourer in the poisoning gang selects the trees to be destroyed, and he both cuts the frill and then applies the arsenic solution from a fine-spouted, splash-proof can. Chisels are carried so that the frills can be cut into the angles of buttressed or fluted stems. Work is supervised by a subprofessional forester who, in some areas at least, marks the advance growth stems for retention. The girdling

Fig.35. Current Malayan Silvicultural Treatment: Meranti - Keruing Type. Profile Diagrams developed from fig.9 (Equatorial Rainforest, Kemasul F.R.). (a) Transect after exploiting merchantable stems (disregarding logging damage). (b) Transect after poison - girdling unwanted stems down to 2 inches D.B.H.



is carried out on the general lines already mentioned, poisoning down to 6 inches D.B.H. in the Kapur and Seraya types and in the more smashed and opened parts of other types, and down to 2 inches D.B.H. in the shaded parts of other types; proceeding for 5 chains beyond the logged areas of the Seraya ridge forests; and retaining those stems of economic species that are of good form, and that can be expected to survive the rotation.

Figures 35 and 36 show the theoretical appearance of stands of Red Meranti-Keruing and Kapur forest types after exploitation and poison girdling to 2 inches and 6 inches D.B.H. respectively. The diagrams are theoretical in that no allowance has been made for logging damage, the smaller stems omitted from the original profile diagrams (figures 9 and 10) are again not shown, and the poisoned stems have disappeared, but they nonetheless show the considerable difference in the final results where the smaller poisoning limit is applied, and they also illustrate the general richness of the Kapur type in well developed advance growth. It was this richness that led Arnot and Landon (1937) to suggest using a selections system of management for these Dryobalanops forests. As hinted by the diagrams, Kapur forest after treatment retains a two-storied appearance that is usually lacking in treated Meranti forests; the latter do in fact have an upper storey, but it is made up mostly of the dead girdled trees and it constitutes both a psychological and indeed a very real physical hazard to workers in the forest for some years after treatment. The difference between figure 35 a and b is entirely due to the poisoned stems.

A more factual representation of an area of Malayan rainforest after logging and poison girdling is given in figure 37, where the location of stems in an area of Kapur forest type on Kluang F.R. (Johore) is shown. The plot area is 0.2 acres, and the details of the stems, both alive and dead, located within it are given in table 28. It is probable that the figure for broken stems is an underestimate, due to some trees, knocked over in logging, being hidden beneath the debris.

The unclassified species retained after girdling in this plot at Kluang F.R. include 40 per acre below the minimum diameter for poisoning (i.e. between 4 and 6 inches), and also include larger stems of good form, excluded from the list of silviculturally classified stems, but nonetheless known to yield merchantable timber. Many of these, such as Eugenia spp., Myristica spp., and Elateriospermum tapos, were indeed included in Barnard's original list of classified species (1950b), but for various reasons were omitted from the revised list of Wyatt-Smith (1960b) who, however, stresses that they should not necessarily be destroyed in treatment. Perhaps the most interesting feature of table 28 is that, after all initial treatment is completed, a third of the original B.A. has been still retained and the greater part of this is in classified species. In Red Meranti-Keruing forest a smaller proportion of retained stems would normally be expected.

In areas shown by milliacre sampling to be rich in heavy hardwoods, tending may commence within two years of poison girdling to ensure that these slower-growing species remain free of impedance, though Wyatt-Smith (tour notes printed in the Malayan Forestry Department Headquarters Bulletin) has pointed out that these species are often unsatisfactory if grown as crop dominants, when many have a tendency to form double leaders, and that better results are obtained when they are grown more slowly under a canopy of light hardwood

Fig. 36. *Current Malayan Silvicultural Treatment: Kapur Type. Profile Diagram* developed from fig. 10 (Equatorial Rainforest, G. Arong F.R.). Transect after exploitation and poison - girdling unwanted stems down to 6 inches D.B.H.

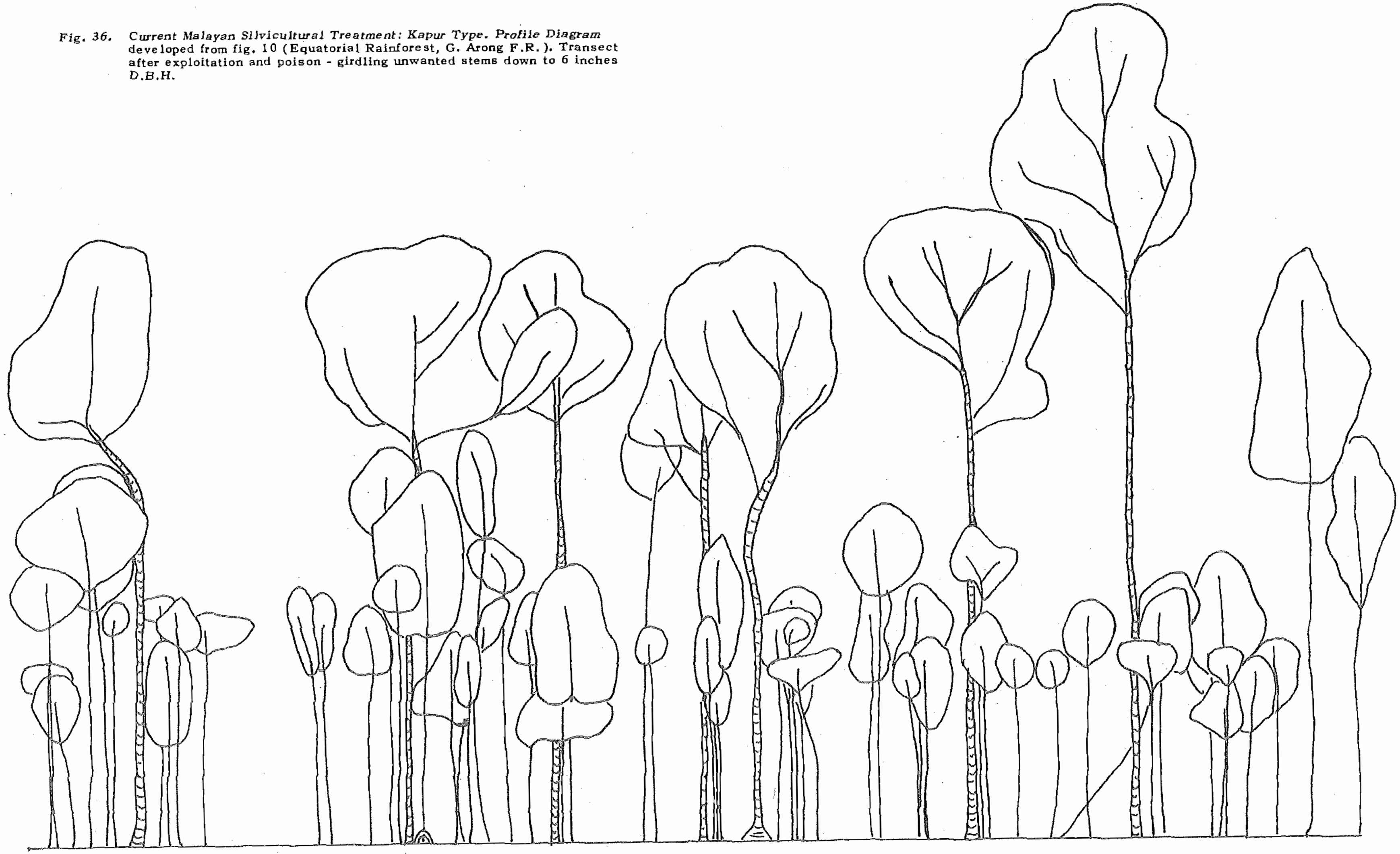


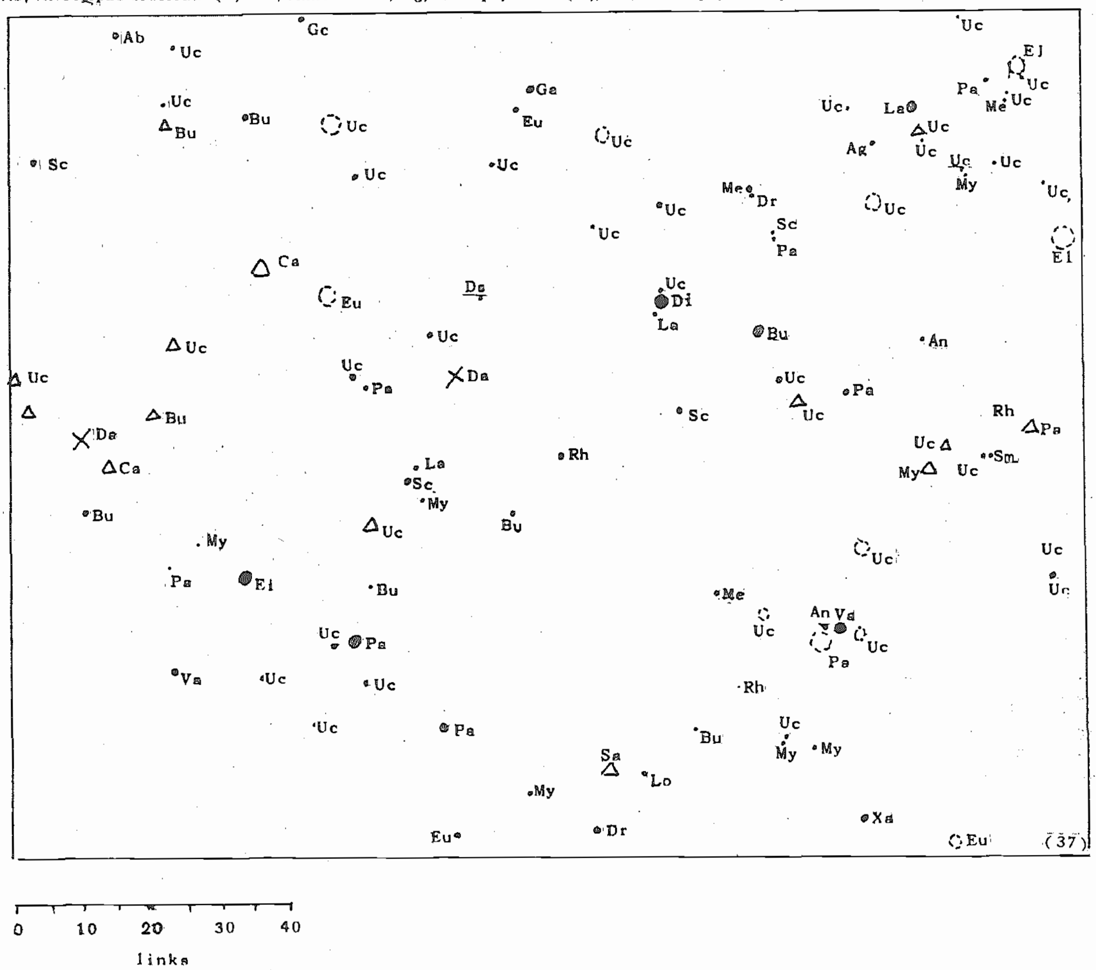
TABLE 28

Effect of Logging and Poisoning on Kapur Forest Type, Kluang F.R., Johore

(Stems 4 " D.B.H. and over)

Stem Type	Number of Stems: Number per Acre	Number of Stems: Percentages	Basal Area: Basal Area per Acre (Square ft)	Basal Area: Percentages
Removed in logging	10	4%	30	19%
Broken in logging	55	20	22	13
Standing after logging:	210	76	112	68
Poison girdled	55	20	54	33
Retained stems:	155	56	58	35
Group A	15	5	14	9
Group C	10	4	2	1
Group D	45	16	16	10
Unclassified	85	31	26	15
TOTAL before logging	275	100%	164 square feet	100%

Fig.37. Plan of 0.2 acre plot in Kapur Rainforest after exploitation and treatment, showing fate of stems in virgin stand. Kluang F.R., Malaya. Symbols: Cross, tree removed in exploitation; Hollow - triangle, tree (4inches D.B.H.+) broken in logging; Dotted circle, tree poison - girdled; Solid circle, standing tree (2inches D.B.H.+) remaining after treatment. Species (bracketed letter indicates silvicultural class; where no class is given the species is unclassified; see Wyatt - Smith, 1960b): Ab, *Artocarpus bracteata* (D): An, Annonaceae; Ag, *Anisophylla griffithii*, Bu, Burseraceae (D); Ca, *Calophyllum* sp. (D); Da, *Dryobalanops aromatica;* (B) Di, *Dialium* sp.(A); Dr, *Dillenia reticulata* (C); Ds, *Diospyros* sp,; El, *Elateriospermum tabos*; Eu, *Eugenia* sp.; Ga, *Garcinia* sp.; Gc, *Gordonia concentricicatrix* (D); La, Lauraceae; Lo, *Lophopetalum* sp. (C); Me, *Melanorrhoea* sp.; My, Myristicaceae; Pa, *Palaquium* sp. (D); Rh, *Rhodamnia trinervia*; Sa, *Shorea acuminata* (B); Sc, *Scaphium affine*; Sm, *Shorea macroptera* (B); Uc, other unclassified spp.; Va, *Vatica* sp. (A); Xa, *Xanthophyllum* sp.



species. Girth increment is less under understorey conditions, but form is better, and the stems have the ability to respond well to ultimate delayed release.

Growth of the previously established regeneration, and of the host of secondary species that become established after the canopy has been opened, is rapid in the Red Meranti- Keruing forest type, but somewhat less rapid in stands that receive the less drastic girdling treatment. Table 29 shows the stocking of a 0.1 acre plot on Pasoh F.R. cpt. 38, a meranti-rich area that received exploitation from 1958 to 1960, and girdling in 1960 and 1961. The plot was established 18 months after girdling was completed, and the results have been converted to a per acre basis.

Among the weed-tree species present in the plot are Pternandra sp. (which includes the stems over 4 inches D. B. H.), Glochidion sp., Pasania sp. and Gironniera sp. All these are marked by fast growth, heavy spreading crowns, and a persistence and longevity that distinguishes them from the other relatively ephemeral secondary species.

TABLE 29

Stocking Per Acre, 18 Months After Completion of Girdling, Pasoh F.R.

Species Group	Number of Species	5' - 10' High	10' High to 2" D.B.H.	2"-4" D.B.H.	4" - 6" D.B.H.	6" - 8" D.B.H.	TOTAL
All classified:	16	560	540	60	-	-	1160
Group A	3	160	60	10	-	-	230
Group B	5	320	360	10	-	-	690
Shorea leprosula (B)	1	240	330	10	-	-	580
Group C	5	-	50	10	-	-	60
Group D	3	80	70	30	-	-	180
Weed-tree sp.	6	-	240	90	10	10	350
Unclassified	-	1120	1190	180	-	-	2490
All species	-	1680	1970	330	10	10	4000

The more transitory secondary species, such as Trema sp. and Macaranga spp. are included among the unclassified stems which make up more than 60% of all stems over 5 ft high on the plot; many of these are already nearing old age, and can be expected to die without interfering with the growth of the economic species, which make up nearly 30% of the total stocking. Despite the large number of economic species (116 on 0.1 acre) these are not evenly distributed throughout: on the basis of dividing the plot into 16 quarter chain square quadrats, the selected stems in each quadrat are as shown in table 30, and the effective stocking is reduced to 130 stems per acrs.

In this plot the dense growth, that develops after the initial treatment, has already cleared at ground level, and progress through the area is not unduly difficult; routine quarter chain square sampling could in fact take place at once, though it is not scheduled for another two or three years.

As mentioned previously, the quarter chain square sampling has in the past been very often neglected, largely as a result of the Emergency. With the return of settled conditions, however, this is again being carried out from three to five years after girdling and the results are used to determine what type of tending is required. Climber cutting is usually needed, though in areas that have been heavily infested with Gleichenia the climbers may be retained till a later treatment as an aid to shading out the rampant fern growth. Other treatments carried out may include undergrowth cleaning and further girdling, whilst retaining a closed structure to the young stand: the aim is invariably to liberate selected stems of economic species. Where sampling shows that most chosen stems have a dominant crown classification little treatment other than climber cutting is normally required; the stems obviously are suffering little impedence. Where, on the other hand, many of the chosen stems are codominant or dominated, a girdling of the trees competing with chosen saplings above a certain height is required, but should be carried out without unnecessarily destroying all stems above the general canopy level of the regeneration. The one exception to this is that the listed weed-trees* through the compartment are usually poisoned during such treatment. Undergrowth cleaning is less commonly required, but may be needed in areas heavily infested with Gleichenia, or where bamboos or palms such as Eugeissona are still suppressing the desirable regeneration. Barnard (1950a) also states that planting may be carried out as a treatment at this stage, if regeneration is shown to be deficient, but this appears rarely, if ever, to have been applied and, provided milliacre sampling ahead of logging reveals adequate regeneration, it is probably seldom needed; the results quoted by Wyatt-Smith (1960b) suggest that there is more likelihood of adequate regeneration being present at the time of quarter chain square sampling, although deficient at milliacre sampling, than of the reverse occurring.

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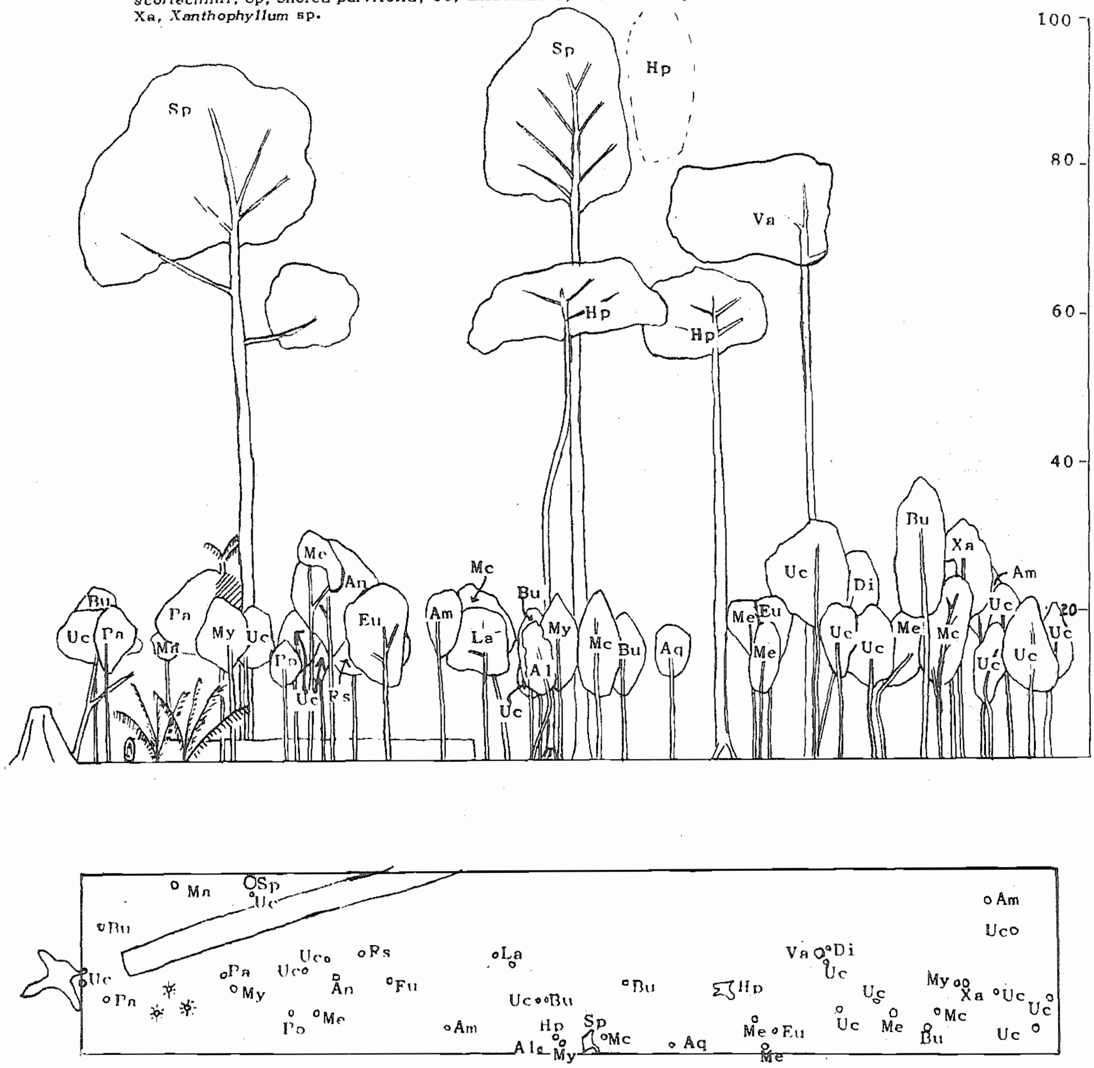
* Species listed as weed-trees by Barnard (1954) include Anisophylla, Barringtonia, Castanopsis, Elaeocarpus, Ficus, Gironniera, Glochidion, Hydnocarpus, Pasania (and Quercus), Pellacalyx and Pternandra spp., certain Lauraceae and Myrtaceae, Ixonanthes icosandra, Macaranga gigantea, Maesa ramentacea and Milletia atropurpurea.

TABLE 30

Chosen Stems on 1/160 Acre Quadrats in 0.1 Acre Plot, Pasoh F.R.

Group	Number of Species	Stocked		Size			Dominance			Climbers
		Number of Quadrats	Percentage	5' - 10' High.	10' High 2" Dia.	2"-4" Dia.	D2	CD	d	
Shorea leprosula (B)	1	8	50	1	6	1	1	4	3	5
Other B	2	2	12	-	2	-	1	1	-	1
C	1	1	7	-	-	1	-	1	-	-
D	2	2	12	-	2	-	-	-	2	1
Total Stocked	6	13	81	1	10	2	2	6	5	7
Percentage of stocked quadrats	-	100	-	8	77	15	15	46	39	54
Unstocked	-	3	19	-	-	-	-	-	-	-

Fig.38. Profile Diagram of Meranti Rainforest under Treatment, Kemasul F.R., Cpt. 144G, Malaya. Transect 132 ft. long, 25 ft. wide. Stems under 20 ft. high omitted. Area exploited *1949 - 52*, poison - girdled 1956 (diagram prepared 1962). Al, *Artocarpus lanceifolius*; Am, *A. maingayii*; An, Annonaceae; Aq, *Aquilaria malaccensis*; Bu, Burseraceae; Di, *Diospyros* sp.; Eu, *Eugenia* sp.; Hp, *Hopea pubescens*; La, Lauraceae; Ma, *Macaranga* sp. (1); Mc, *M.* sp. (2); Me, *Melanorrhoea* sp.; My, Myristicaceae; Pa, *Pasania* sp.; Po, *Pometia alnifolia*; Rs, *Randia scortechinii*; Sp, *Shorea parvifolia*; Uc, unidentified; Va, *Vatica* sp.; Xa, *Xanthophyllum* sp.

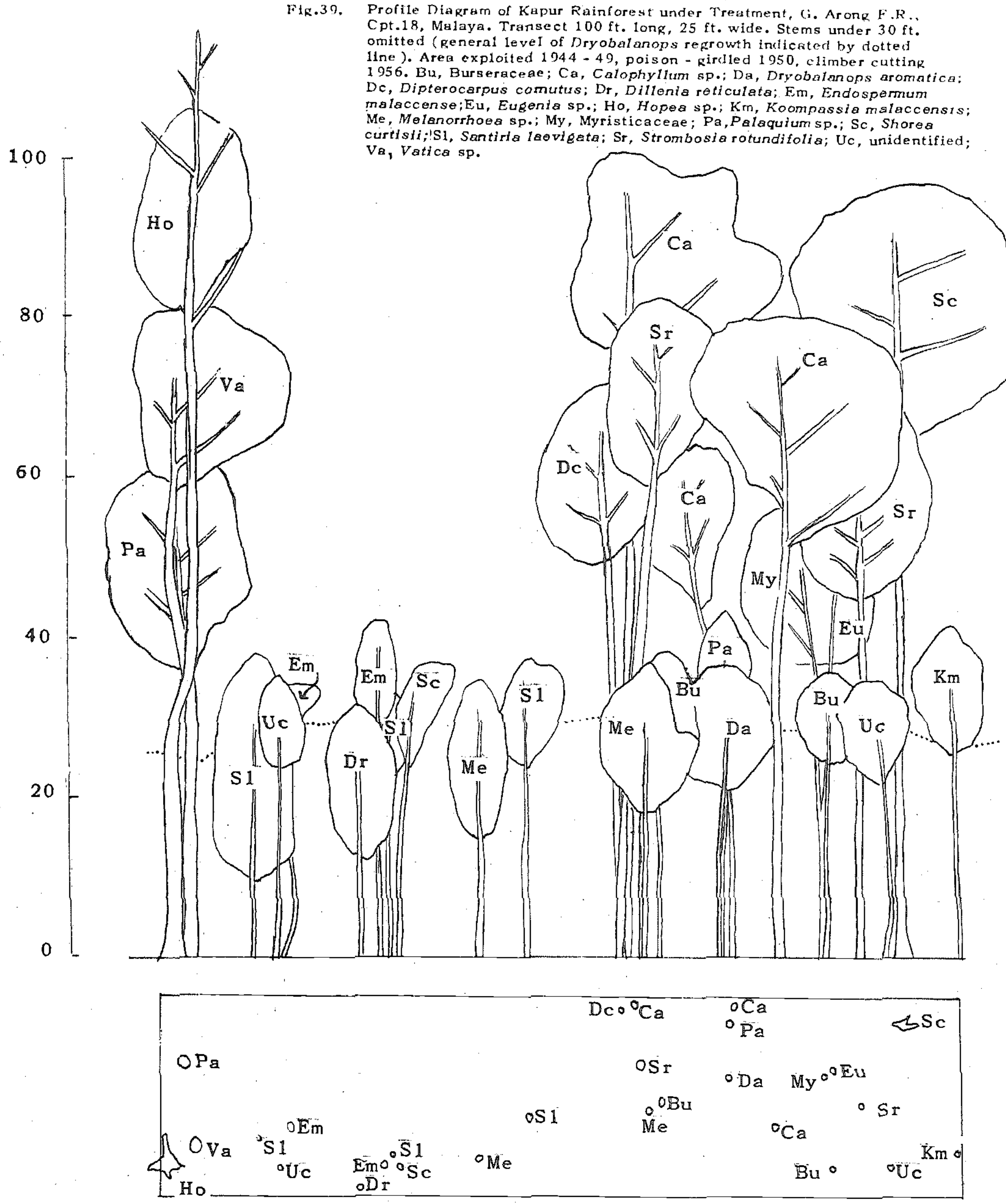


Half chain square sampling is scheduled from eight to ten years after poison girdling. To the present this has mostly been applied to the abnormally worked forests, but as more areas treated under the Malayan Uniform System attain the requisite age, half chain sampling and the subsequent treatments diagnosed as being needed are being increasingly carried out in the manner prescribed by Barnard. The treatments performed as a result of the half chain sampling are broadly similar to those occasioned by quarter chain sampling, and again the object is to free selected stems without disturbing the general structure of the forest.

Figures 38, 39 and 40 are profile diagrams of three areas from ten to fourteen years after the completion of logging, and thus close to the stage when half chain square sampling normally occurs.

Details of the history and stocking of 0.2 acre plots in the immediate vicinity of each diagram are given in table 31, converted

Fig.39. Profile Diagram of Kapur Rainforest under Treatment, G. Arong F.R., Cpt.18, Malaya. Transect 100 ft. long, 25 ft. wide. Stems under 30 ft. omitted (general level of *Dryobalanops* regrowth indicated by dotted line). Area exploited 1944 - 49, poison - girdled 1950, climber cutting 1956. Bu, Burseraceae; Ca, *Calophyllum* sp.; Da, *Dryobalanops aromatica*; Dc, *Dipterocarpus comutus*; Dr, *Dillenia reticulata*; Em, *Endospermum malaccense*; Eu, *Eugenia* sp.; Ho, *Hopea* sp.; Km, *Koompassia malaccensis*; Me, *Melanorrhoea* sp.; My, Myristicaceae; Pa, *Palaquium* sp.; Sc, *Shorea curtisii*; Sl, *Santiria laevigata*; Sr, *Strombosia rotundifolia*; Uc, unidentified; Va, *Vatica* sp.



(except for number of species) to a per acre basis. (Stems under two inches D.B.H. are based on 1/40 acre plots.)

All three plots have to some extent an abnormal history, as is common in most stands of about this age at the present time. The Kemasul plot received delayed poison-girdling and no subsequent treatment, both plots at Gunong Arong F.R. had exploitation spread over about five years, and the plot in cpt. 20 received no silvicultural treatment after logging for fourteen years, when climber cutting and girdling were carried out. In this girdling operation weed-trees, useless relics and any stems over 4 inches D.B.H. competing with classified species over 2 inches D.B.H. were poisoned; stems poisoned in the profile transect are shown dotted in the diagram. 140 stems per acre over 2 inches D.B.H. (105 over 4 inches) were removed in this poisoning in cpt. 20, their B.A. being 53 square feet per acre (51.5 square feet per acre over 4 inches). The weed species shown in the

Fig.40. Profile Diagram of Kapur Rainforest under Treatment, G. Arong F.R., Cpt. 20, Malaya. Transect 110 ft. long 25 ft. wide. Stems under 30 ft. omitted; general level of *Dryobalanops* regrowth indicated by dotted line. Area exploited 1944 - 48, poison - girdling and liberation treatment 1962: hatching indicates climber clumps, dotted trees have been poisoned. Ae, *Artocarpus elasticus*; Am, *Anisoptera megistocarpa*; Ar, *Artocarpus maingayii*; Bs, Bu, Burseraceae (spp. 1 and 2); Ca, *Calophyllum* sp.; Da, *Dryobalanops aromatica*; Di, *Dillenia* sp.; Dr, *D. reticulata*; Em, *Endospermum malaccense*; Eu, *Eugenia* sp.; Ga, *Garcinia* sp.; Gi, *Gironniera* sp.; Ho, *Hopea* sp.; La, Lauraceae; Me, *Melanorrhoea* sp.; Rs, *Randia scortechinii*, Uc, unidentified.

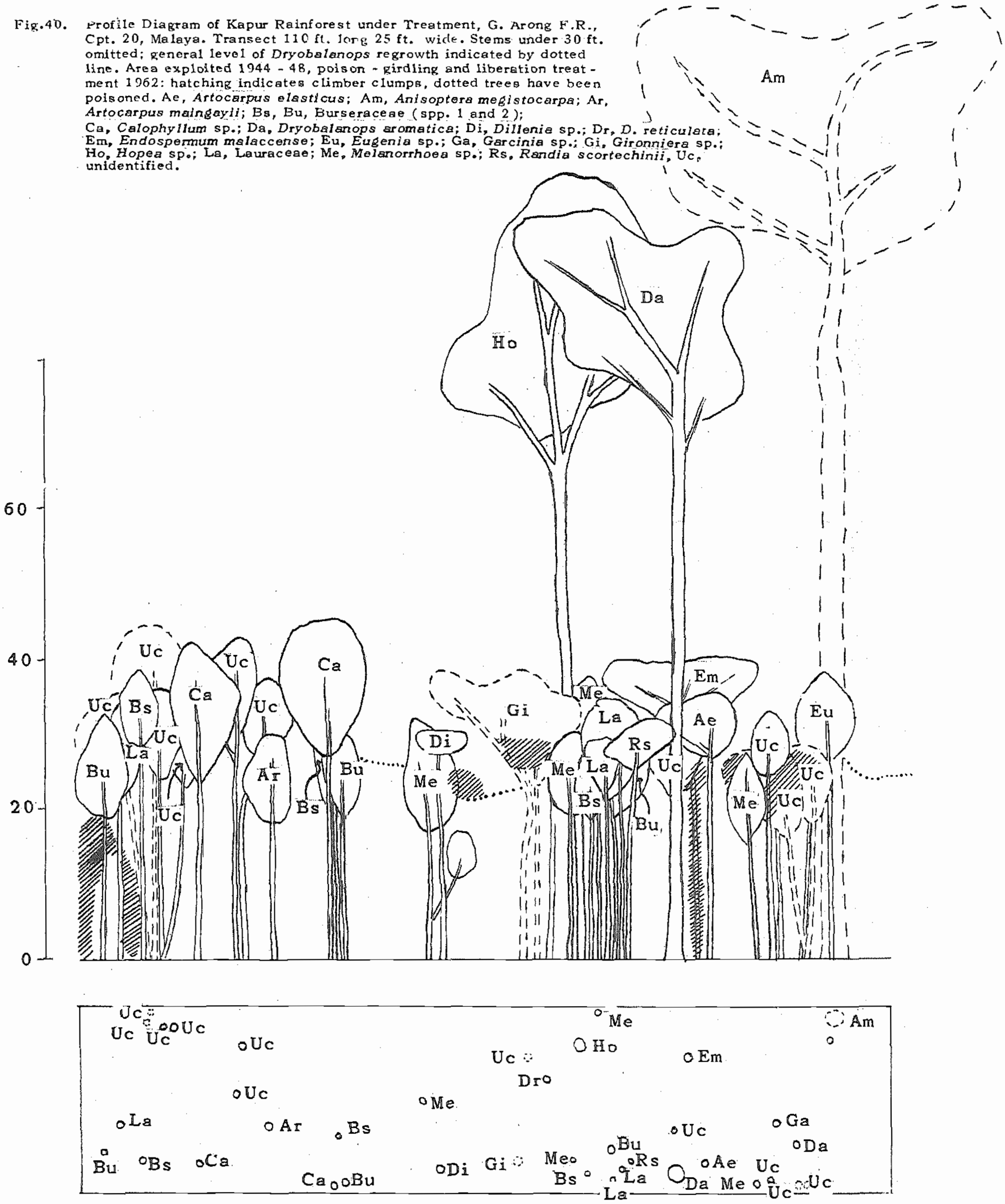


table as surviving in this plot can be attributed to human error on the part of the poisoning gang.

The structure of the communities in these plots approximates fairly closely with that expected theoretically (c.f. figures 35 and 36). The Kemasul plot has a somewhat surprising deficiency of Shorea spp., and it is probable that had milliacre sampling been done before logging, the results would have indicated a postponement of exploitation. Even so, on the basis of chosen stems on half chain square quadrats, this plot has 8 out of 8 quadrats stocked with economic stems, five of them

TABLE 31

Plot Details of Malayan Rainforest, 10 to 14 Years After Logging

Species Group	Forest Reserve: Compartment: History:*		
	Kemasul, Pahang; 144G; F1949–52; GCL1956	G. Arong, Johore; 18; F1944–49; GCL1950; LS¼1955; CL1956; LS½1960	G. Arong, Johore; 20; F1944–48; LS½; GCL1962

Stocking per acre of stems 2" D.B.H.+

Kemasul, Pahang, Compartment 144G

Species Group	Number of Species	Number of Stems Per Acre	Number of Stems Per cent	Basal Area Per Acre	Basal Area Per cent
Group A	1	5	1	2.0	3
Group B	7	45	9	28.5	50
Dryobalanops	—	—	—	—	—
Shorea	4	30	6	25.5	44
Group C	3	35	7	2.0	3
Group D	8	70	14	11.0	19
All economic	19	155	31	43.5	75
Weed	2	30	6	1.0	2
Unclassified	—	315	63	13.5	23
GRAND TOTAL	—	500	100	58.0	100
Stems 4"+	—	100	—	43.5	—

G. Arong, Johore, Compartment 18

Species Group	Number of Species	Number of Stems Per Acre	Number of Stems Per cent	Basal Area Per Acre	Basal Area Per cent
Group A	2	50	4	8.0	5
Group B	7	220	19	60.5	35
Dryobalanops	1	115	10	15.5	9
Shorea	—	—	—	—	—
Group C	4	70	6	8.5	5
Group D	9	330	30	61.5	36
All economic	22	670	59	138.5	81
Weed	2	25	2	1.0	1
Unclassified	—	435	39	30.5	18
GRAND TOTAL	—	1130	100	170.0	100
Stems 4"+	—	325	—	134.0	—

G. Arong, Johore, Compartment 20

Species Group	Number of Species	Number of Stems Per Acre	Number of Stems Per cent	Basal Area Per Acre	Basal Area Per cent
Group A	1	10	1	1.0	1
Group B	6	195	17	32.0	32
Dryobalanops	1	95	8	24.0	24
Shorea	—	—	—	—	—
Group C	3	95	8	7.5	8
Group D	6	230	22	24.5	24
All economic	16	530	48	65.0	65
Weed	3	35	3	3.0	3
Unclassified	—	550	49	32.5	32
GRAND TOTAL	—	1115	100	100.5	100
Stems 4"+	—	205	—	59.5	—

Size Class Distribution

Kemasul, Pahang, Compartment 144G

Species Group	2"–4"	4"–8"	8"+	TOTAL
Group A	—	—	5	5
Group B	15	10	20	45
Dryobalanops	—	—	—	—
Shorea	10	5	15	30
Group C	30	5	—	35
Group D	40	15	15	70
All economic	85	30	40	155
Weed	30	—	—	30
Unclassified	285	30	—	315
GRAND TOTAL	400	60	40	500

G. Arong, Johore, Compartment 18

Species Group	10'H–2"D	2"–4"	4"–8"	8"+	TOTAL
Group A	120	35	5	10	170
Group B	1640	65	15	40	1860
Dryobalanops	1560	100	10	5	1675
Shorea	—	—	—	—	—
Group C	40	20	50	—	110
Group D	280	195	70	65	610
All economic	2080	415	140	115	2750
Weed	120	25	—	—	145
Unclassified	2240	365	60	10	2675
GRAND TOTAL	4440	805	200	125	5570

G. Arong, Johore, Compartment 20

Species Group	10'H–2"D	2"–4"	4"–8"	8"+	TOTAL
Group A	—	5	5	—	10
Group B	2160	155	20	20	2355
Dryobalanops	1600	80	—	15	1695
Shorea	—	—	—	—	—
Group C	120	75	15	5	95
Group D	360	160	660	10	230
All economic	2640	395	100	35	3170
Weed	80	20	15	—	115
Unclassified	1920	495	50	5	2470
GRAND TOTAL	4640	910	165	40	5755

* F Exploitation
GCL Poison girdling and climber cutting
CL Climber cutting
LS¼ Quarter chain square sampling
LS½ Half chain square sampling

of class B species. The two G. Arong plots show a high stocking of economic stems, and in particular a very dense and well distributed stocking of Dryobalanops aromatica between 10 feet high and 2 inches D.B.H. Few of these feature in the diagrams as they were mostly below the 30 feet profile limit, but the general level of this mass of regeneration is indicated by dotted lines on the diagrams; with the necessary selective treatment both these plots in Kapur type could readily yield stands similar to the plot at Kanching F.R. (figure 30, table 16).

The half chain square sampling is also used to determine whether the compartment can be formally passed as regenerated, the basis being that 40% of the quadrats (i.e. 16 stems per acre) are stocked with economic species (Wyatt-Smith, 1962). In the examples quoted above there can be no doubt that the stands are sufficiently well stocked to qualify as regenerated.

At twenty years after exploitation, and thereafter at about twentyyear intervals, the regenerated forests are scheduled to receive thinnings. Originally (Barnard, 1950a) it was intended that the larger stems, from the advance growth remaining after logging, should be removed in these operations, along with thinning in the regeneration, but the damage caused by salvage fellings during the Emergency has produced the present policy that only stems capable of surviving the full rotation should be kept during poison girdling; the idea of removing these during the rotation has fallen into disfavour. However, a carefully controlled intermediate felling in Malacca in 1958, when stems over 23 inches D.B.H. were removed from an area treated by R.I.F., showed that, after felling, there remained 55 undamaged economic stems per acre over 4 inches D.B.H. (6.5 per acre over 15 inches), and it has been concluded that, when the stocking of economic species is high, and the operations can be carefully controlled, such salvage operations with a high minimum felling girth can be contemplated (Wyatt-Smith and Ja'afar bin Sudin, 1961). At the same time it seems likely that the thinnings in most cases will be concerned with smaller, pole-sized trees, leaving the larger and better shaped trees to form the final crop. In this connection it has been noted that the form of meranti-type Shorea spp. is usually much better in stands that are not thinned at an early stage. In the case of Dryobalanops aromatica forests, Wyatt-Smith (silvicultural notes, see Vincent, 1961) recommends more intensive treatment with heavy crown thinnings at about ten year intervals to produce a pure stand of about fifty stems per acre at age forty years. He notes that Dryobalanops areomatica is a sufficiently valuable species to justify this intensive treatment, and certainly in the Kapur type the current Malayan policy is to produce virtually pure stands.

The Future of Rainforest Management in Malaya

In the preceding pages the development of a silvicultural system for the Malayan rainforests has been traced, from the early work on improvement fellings to the present uniform system which, in the years since 1950, has been applied to over 700 square miles. This uniform system was devised primarily for the lowland rainforests, particularly those rich in the meranti-type Shorea spp., and there can be little doubt that it is proving very satisfactory as a means of establishing new crops in this type of forest. Cousens (1958b) has expressed doubts as to whether it will prove as successful as the earlier R.I.F. system, and his concern may be justified when the abnormal stands, exploited during the Occupation and Emergency, are considered. However, when the uniform system is applied in the form now prescribed there should be little reason for it to be less successful than the earlier, more intensive system applied to similar stands. The less intensive nature of the present system is amply compensated for by the use of diagnostic sampling, which ensures that the treatments carried out are those most necessary for the optimum growth of the new crop, while the recent modifications that have been prescribed, particularly with regard to the treatments ahead of logging, should do much to reduce the areas where regeneration is deficient at the time of exploitation.

The problem ahead of Malayan forestry is not essentially silvicultural. It arises from the fact that a rapidly increasing population will demand, and indeed already is demanding, the release of much forest land for agriculture. At present the demand is mostly being met from the still extensive tracts of unreserved state land, and the exploitation of these sites ahead of rural development produces a corresponding decrease in the area of reserved forest logged each year, with a similar reduction in the area that can be regenerated each year. With time the pressure will also mount for the alienation of those lowland forest reserves most suitable for agriculture, and in view of the relatively large areas of Malayan forests which are unsuitable for agriculture on account of topography, this pressure will be hard to resist.

Thus, as Wyatt-Smith (1962) has pointed out, the time can already be foreseen when forestry in Malaya will be practised on the upland sites and on the poorer lowland sites, in both cases areas where the Malayan uniform system is far from being proved as satisfactory. In view of this the emphasis of forestry research in Malaya is being directed increasingly to land unlikely to be required for agriculture, and it appears that, on these sites, the intensive forestry needed for a densely populated country must ultimately rely largely on artificial forms of regeneration.

NIGERIA

The Environment

The Federation of Nigeria lies between latitudes 4° 30' N and 14° N, in the northern angle of the West African "bulge". It has a total area of 356,000 square miles and a population approaching 50,000,000, the highest of any African country. Politically it is a federation of three locally autonomous regions*: the Northern Region, with nearly four-fifths the area of the whole country, and about half the total population, and the more densely settled Western (area 45,400 square miles) and Eastern (area 29,500 square miles) Regions which face the Gulf of Guinea in the south of the country. There is strong evidence that the population of the country has been relatively large for a considerable period.

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* At time of writing. Subsequently the political status has changed considerably.

The land surface is free of any outstanding topographic features apart from the Jos Plateau in the centre of the Northern Region and scattered inselbergs towards the south. Under the influence of this even topography rainfall shows a gradual reduction from south (Forcados, 144 inches mean annual rainfall) to north (Geidam, 14 inches), with a corresponding increase in the severity of the dry season. Temperatures are high and the dry season, which is experienced even in the areas of highest rainfall, is marked by the extremely dry harmattan wind blowing south from the Sahara Desert. Severe line squalls (locally "tornadoes") are common at the beginning and end of the dry season in the south. The vegetation zones (Keay, 1959a) show a fairly close correlation with the annual rainfall. The present limits of rainforest are confined to a belt about 100 miles wide running parallel to the coast, but narrowing towards the western boundary *. To the north of the rainforest zone is a belt of varying width carrying derived savanna (Keay, 1959a) or forest - savanna mosaic (Keay, 1959b); at its furthest limits this zone reaches 200 miles inland and it is believed to represent the climatic limit of rainforest. Beyond this lie the Guinea, Sudan and Sahel savanna zones. On the coastal side, the rainforest zone is separated from the littoral by mangrove and freshwater swamp communities: these extend along the full length of the coast, but are most widely developed in the vicinity of the Niger River delta.

The area of rainforest in Nigeria (including the former British Camaroons trusteeship) has been estimated as 42,500 square miles, with another 7,000 square miles occupied by freshwater swamp communities, which consist in part of the swampy rainforest sub-formation (Anon., 1953). Of this total area, about 43,000 square miles lie within the present boundaries of the Federation, where it is virtually confined to the Eastern and Western Regions. Very little of this is undisturbed by man; most is being used for bush fallow agriculture or for cash plantation crops such as cocoa, rubber and oil palm, and even within the 6,700 square miles of forest reserve in high forest in the two regions, only a small proportion shows no signs of past settlement or farming.

Within the Western Region rainforest zone, which is the more important from a forestry viewpoint, two main groups of soil parent materials are present. In the south and southeast are extensive Tertiary sedimentary deposits, of which the most important series are the Post Middle Eocene unconsolidated sediments often referred to as the "Benin Sands", while to the north of these soil is derived from Pre-Cambrian metamorphic rocks, including schist and gneiss. The swamp communities occur on Recent alluvial deposits. The rainforest within this zone shows considerable variation in both structure and floristic composition. In the moister areas evergreen seasonal rainforest occurs, and this grades into semi-evergreen rainforest (the mixed deciduous forest of MacGregor, 1934) as rainfall decreases; the boundary between the two is sharp only where soil conditions suddenly alter. Swampy rainforest occupies some of the sites with impeded

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* The rainforest belt disappears completely in the Republic of Dahomey, which adjoins Nigeria on the west, but re-appears still further west in Ghana, whence it continues westward to Sierra Leone.

drainage. These structural changes are accompanied by floristic differences: in a general way the evergreen seasonal rainforest tends to have a high representation of Meliaceae and certain Leguminosae, whereas the semi-evergreen rainforest is rich in Sterculiaceae, Moraceae and Ulmaceae. However the past history of human disturbance largely overshadows these structural and floristic changes. Most of the rainforest throughout Nigeria is secondary, and species such as Triplochiton scleroxylon, Terminalia superba and Terminalia ivorensis, which would be uncommon in climax rainforest, are widespread. At the same time the forests present a very broken appearance, with scattered emergents, a discontinuous second storey and abundant climbers: such features could be expected over limited areas in mature forest as the result of wind damage, the deaths of large emergents, and the effects of elephants in the gaps so created, but the extent of these physiognomic characteristics throughout Nigeria suggests that they are largely a result of past cultivation and settlement. It is perhaps significant that Akure-Ofosu F.R., with no known history of previous disturbance by man, has a well developed structure with few gaps. On the other hand, Omo F.R. which has apparently been equally little disturbed in the past, has a very broken structure. Profile diagrams showing this type of structure (or lack of structure) are given for semi-evergreen rainforest by A.P.D. Jones (1948); for evergreen seasonal rainforest by Richards (1952, figure 6), Keay (1959a, profiles 1 and 2), and as figures 14 and 16 of this report; and for swampy rainforest by Keay (1959a, profile 5) and as figure 19 of this report.

Development of Forestry

Timber was little used by the native inhabitants of Nigeria. The first recorded shipment of logs to England took place in 1833, but the export trade in timber did not make its real start until 1886 (Pollard, 1955). The trade was initially concerned mainly with mahogany-type logs (particularly Khaya ivorensis), and developed under the impetus of the reduced availability of Swietenia from tropical America, and of improved medical knowledge gradually depriving the area of its reputation as the "white man's grave". Exports slumped during the First World War, and again during the trade depression of the 1930's, but received a boost during the Second World War, and have continued to expand since, despite periodic fluctuations in demand. Major developments since the depression have been the acceptance of an ever-growing number of species by the export market, and the expansion of local timber processing facilities, outstanding among which is the large ply and sawmill operated by African Timber and Plywood Limited at Sapele.

The first forest superintendent in Nigeria was appointed to the Colony and Protectorate of Lagos in 1897. A unified forest service operating over the entire country was created in 1915, and this continued to function till 1952 when regional forest services were established, the federal government's role being confined to forestry research, forest products research, and education. Much of the early work of the forest services dealt with establishing a permanent forest estate, and as a result most of the remaining areas of relatively mature forest were created forest reserves. Many such areas were in disputed territory between two or more large towns; others were acquired by agreement with the native authorities, the forest service contracting to manage the reserves on behalf of the local people. By

1959 there were 7.240 square miles of forest reserves in the Western Region (16% of the land area), and of this total, 4,230 square miles were classed as high forest, the remainder being mostly savanna. At this time this estate was being managed by the Forestry Division of the W.R. Ministry of Agriculture and Natural Resources by 23 professional forestry officers, over 500 technical and field staff, nearly 80 clerical staff, and a labour force of 1,500. Of the total area of forest reserves, 3,600 square miles, mostly in the rainforest, were under working plans (Western Nigeria Forestry Division, 1959).

Early Silvicultural Work

Most of the early silvicultural work in Nigeria dealt with plantation establishment. In the rainforest areas progressively larger concessions were leased out for the highly selective logging of the time. Control over the operations was rudimentary; minimum girth limits (commonly 10 feet) were imposed, without reference to the stocking or to the time of passage through girth classes, in the forlorn hope that the forests might at least not deteriorate under this crude form of "selection system". At one stage leaseholders were required to plant new seedlings or to tend natural ones during logging operations, but it is doubtful whether this provision was ever honoured, and certainly its results, in the absence of subsequent tending, would hardly have justified the effort (Rosevear, 1947; Rosevear and Lancaster, 1952).

In 1927 J.D. Kennedy was sent to Sapoba F.R. as silvicultural research officer. As well as working on artificial regeneration, Kennedy started the first investigations in Nigeria dealing with the treatment of natural rainforests. Four systems were tried, Walsh's system, group system, transition method, and uniform system. Walsh's system was clear falling and burning with the retention of about four seed trees per acre, and it resulted in the development of dense climber tangles: this may have been the first, but was certainly not the last, time that climber tangles were produced in the name of silviculture. In the group system (Kennedy, 1935), trees that were undersize for exploitation, but large enough to produce seed, were selected, and at the time of flowering the undergrowth, climbers and some lower storey trees were cut and the debris heaped and burnt over about 2 acres, the openings being extended downwind at the time of seedfall. The results were moderately successful in regeneration, but the system suffered from intensive but dispersed work at a time when logging was still extremely extensive. The transistion method consisted of obtaining regeneration in groups, usually artificially, and then linking the groups up; again it suffered from the fatal defect of dispersed working. The uniform system was adapted from the European system and involved the gradual opening of the stand by climber cutting and the girdling of undesirable species, over a period of about three years, before logging the economic species; where regeneration did not appear seed was dibbled into ground in year 2. This system was relatively successful and showed that natural regeneration could be obtained and made to grow with the letting in of light (Lancaster, 1961a).

Kennedy left Sapoba in 1936, and little further work was done till 1943, though poisoning (1936) and removal of the middle storey (1937) were tried on a small experimental scale. In 1943 one of the spasmodic heavy seed years of Triplochiton occurred in the forests of the Benin area, and G.W. Somerville, on wartime secondment from the Malayan forest service, carried out operations to take advantage of this. His treatment was strongly influenced by the Malayan regeneration improvement felling system, and although the operations were not successful in their prime object of inducing Triplochiton regeneration (owing to insufficient canopy opening for this strongly light-demanding species), they showed that the more valuable Meliaceae could be regenerated over large areas fairly simply (Rosevear and Lancaster, 1952). Faced with this result; with the increasingly impressive regrowth in Kennedy's uniform blocks; with the failure of the past selective logging, under girth control, to produce adequate regeneration; and with the more concentrated forest working as a consequence of the increased demand for Nigerian timbers, the forest service decided to introduce a system for the better management of the rainforests. Thus was born the tropical shelterwood system in Nigeria.

Tropical Shelterwood System, 1944

In some respects the introduction of T.S.S. was not the most important forestry development in Nigeria in 1944. Of even greater significance was the associated decision to introduce systematic and orderly working of the forests by the concession holders. This decision was an essential prerequisite to the application of T.S.S., and at the same time it converted the picture of forest operations in the rainforests from one of exploitation in its worst sense, to one where the aim of most managers of production forests, sustained yield management, became feasible. The concessions at the time were mostly held on 25 year leases, they were commonly 200 to 300 square miles in extent, and were worked very much as they had been forty years earlier. When T.S.S. was introduced, it was decided to adopt a rotation of 100 years, the working circles being divided into four periodic blocks each with 25 annual coupes. The choice of the first periodic block was left to the leaseholders, subject to their nominating the first five annual coupes immediately, subsequent annual coupes at least five years in advance of logging, and all annual coupes in the first periodic block within ten years (Rosevear, 1947). Selected annual coupes had to be as far as possible contiguous to previous workings. It speaks volumes for the persuasiveness of the then Chief Conservator of Forests and his staff, and for the farsightedness of the leaseholders, that these radical proposals, involving virtually a 75% reduction in the effective concession areas, were agreed to amicably (Rosevear, 1956).

The aim of T.S.S. was to produce a more or less even-aged forest by establishing a pole crop of economic species before logging. The actual operations to be employed were decided on at a conference of forest officers during 1944, and came into effect towards the end of that year. The detailed instructions for this first version of T.S.S. are given in appendix 1, and the time-table of operations was as follows, (D.S. and R.S. indicate dry season and rainy season):

Year		Operation
1		Demarcation of compartment.
1	(i)	Climber cutting and seedling assistance.
1 D.S.	(ii)	Removal of middle storey canopy.
2 R.S.	(iii)	1st regeneration count and climber cutting.
2 D.S.	(iv)	2nd opening of canopy.
3 R.S.	(v)	1st and 2nd cleanings.
4 R.S.	(v)	3rd and 4th cleanings.
	(vi)	2nd regeneration count.

Year	Operation
5 R.S.	(v) 5th cleaning (or exploitation)
8,12,16, etc. R.S.	(vii) Pre-exploitation cleanings
n	(viii) Exploitation
n + $\frac{1}{2}$ to 1 R.S.	(ix) 1st Post - exploitation cleaning
n + 3	(ix) 2nd Post - exploitation cleaning
n + 8	(ix) 3rd Post - exploitation cleaning
n + 13	(ix) 4th Post - exploitation cleaning

Several points about these operations should be emphasized. It was initially believed that climber cutting (operation i) had no value as a regeneration operation, the intention being chiefly to allow freedom of movement through the forest. However, it soon became apparent that it served a most valuable function in the generally very viney, disturbed forests of Nigeria by letting in considerable light, to the extent that Lancaster (1961a) likens it to the seeding felling of the European uniform system. Thus, although not originally intended that way, climber cutting was actually the first stage in the opening of the forest canopy before logging, this gradual opening being the essential feature of T.S.S. Seedling assistance, carried out in conjunction with climber cutting, consisted of slashing small, shade-casting saplings and coppicing any misshapen saplings of economic species already present. It removed most of the undergrowth up to 15 to 20 ft high.

The opening of the canopy was to occur over a period of at least 5 years before logging (but preferably more; Rosevear, 1947). The main operation was the removal of all or part of the middle storey (20 to 50 ft high) (op.ii), followed if necessary a year later by the removal of small, misshapen economic species and some uneconomic upper storey trees, plus any corrections required to the first canopy opening (op. iv). The need for the second canopy opening was determined by the first regeneration count (op. iii) which was carried out by the "6ft by 6 ft" method, i.e. no economic plant within 6 ft of one already counted was included in the tally. The canopy openings were normally performed by frill-girdling and poisoning with sodium arsenite solution, but in one strategically located forest (Gambari F.R., near Ibadan) it was possible to sell the unwanted stems for fuel at a profit.

Canopy opening was, and indeed still remains, "the most difficult and the most critical of all the silvicultural operations" (Western Nigeria Forestry Division, 1961). The aim was to admit sufficient light to encourage regeneration, but insufficient to permit a lush tangle of weeds and vines to flourish, "but it soon became clear that, if enough light was let in to allow economic saplings to develop, weeds would grow too" (Lancaster, 1961a). To cope with this weed growth, cleaning operations (op. v) were laid down, 5 weedings being given if logging occurred in the 6th year, and further cleanings (op. vii) at 4 yearly intervals if logging was delayed. The instructions were far from explicit as to the nature of these cleanings, and the tendency was for them to be rather heavy with a ruthless slashing back of uneconomic regrowth and, doubtlessly also, by accident, more than a few of the economic species. These conditions favoured the development of dense climber tangles in which the climbing palms (Ancistrophyllum spp. and Calamus spp.) and acacias (especially Acacia ataxacantha) commonly predominated, these being by almost any measure the most harmful weeds in the treated forest. There was thus a vicious circle established:

climber tangles, which were common even in most untreated forests of Nigeria, tended to spread like a cancerous growth under the canopy openings of T.S.S., and the efforts to control these be repeated cleanings only led to increasingly vigorous climber regrowth.

The fourth cleaning was accompanied by a second regeneration count (op. vi), of a similar nature to the first. If this showed the presence of at least 40 well grown seedlings and saplings of economic species per acre, the regeneration was considered satisfactory; if less than 40 were present, the Assisted Tropical Shelterwood System, in which seed or seedlings were artificially introduced into the stand at wide spacing, was applied (Rosevear, 1947). The minimum stocking was attained in most areas, though it appears that seed dibbling was not infrequently carried out in parts of even the most successful areas as a "window-dressing" measure (P.W.T. Henry, pers. comm.).

Logging normally commenced in year 6, and sometimes continued in a compartment for more than one year. The post exploitation cleanings that were laid down were apparently never carried out; instead, these were replaced by a single operation to repair logging damage, the work being done by a labourer under the supervision of the forest guard who measured the felled logs (Lancaster, 1961a). Damage caused by the falling trees was regarded as slight (Rosevear and Lancaster, 1952).

The treatment unit was the compartment, which was typically an area one mile square divided by cut lines into quarters, each 20 chains by 80 chains, and these in turn subdivided by grid lines $2\frac{1}{2}$ chains apart. The gentle relief of Nigerian forests made possible this systematic compartment layout, which is still in use.

T.S.S. in this form was applied for 9 years up to 1953. During this period over 150 square miles were brought under treatment in the Western Region*, mostly in the forests owned by the Benin Divisional Council. The results were generally considered encouraging, although there were some disturbing features, particularly in the spread of climber tangles: indeed at an early stage a policy, that in political circles might be called "hands-off", had been brought into effect, tangles present when treatment commenced being left untouched. No efforts were made to remove the shelterwood of large, uneconomic trees that remained after logging: such an operation was considered both unnecessary and impracticable.

The results varied somewhat in different parts of the Western Region. In the Benin forests much regeneration of Meliaceae was obtained, particularly of the shade-tolerant Guarea cedrata, which could persist for long periods even in fairly dense untreated forest, while the climber problem was extremely severe. In Ondo Province, a rather drier area (semi-evergreen rainforest), little regeneration of the Meliaceae appeared, but there was an abundance of the less valuable Sterculiaceae, including much Mansonia altissima which does not occur at Benin; here, also, the climbers were less of a problem, but there was much shrubby weed growth.

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*T.S.S. has never been employed on more than an experimental scale in the Eastern Region, where the lower stocking of economic trees has made it impossible to pay for extensive regeneration measures out of log sale revenue. Instead, the emphasis has been on artificial regeneration over limited areas (Eastern Nigeria Forestry Division 1959, 1961).

E. W. Jones (1950) has discussed some of the aspects of T. S. S. during this period, based on observations made in Okomu F.R. (Benin Division) in 1947-48. Most of the emergent species appeared to be regenerating continuously, but suffered heavy mortality by the time they reached pole size, and he felt that limited silvicultural treatment should enable many of these poles to grow on to tree size. There was always a heavy population of seedlings on the ground in untreated forest, but its distribution was patchy and, except in gaps, emergent species were poorly represented. However, the canopy openings of T. S. S. permitted the establishment of many more seedlings, particularly of the light-demanding secondary species: in forest patches where the canopy was closed, with a continuous understorey, the main influx of these seedlings appeared to come from the understorey removal in operation (i). Jones considered that, with the existing selective logging, regeneration treatment would be successful if delayed until exploitation was completed, and would also be cheaper as the logging operation itself caused some canopy opening and money would not be spent on obtaining regeneration that was subsequently destroyed or damaged when the economic trees were removed: such post-exploitation treatments were, in fact, applied to parts of the so-called "sacrificial blocks", those compartments logged during the period 1944-49 without pre-exploitation treatment. However, he felt that, with the heavier exploitation likely in the future, such an approach might be dangerous due to damage to the advance growth and the removal of most seed trees; for those reasons the pre-exploitation treatment appeared safer. He also felt that the forest service should have much greater control over the course of fellings, as was the case in those European forests where the broadly similar compartment shelterwood system was used, pointing out that heavy and careless logging by the exploiting agency could render useless the preparatory work of the forest service.

Dealing with climber tangles, Jones could find little evidence that these would not revert to useful forest without assistance. Trees would gradually lift the tangles, but became very deformed in the process. However, if desirable regeneration subsequently came in beneath these raised tangles, it appeared worthwhile extending T. S. S. operations to the tangle areas.

Jones concluded that T. S. S. seemed moderately effective under present selective logging, but could be hazarded by more intensive working, and that greater flexibility was needed to permit treatment to vary with individual stand condition.

Tropical Shelterwood System, 1953

The first major revision of T. S. S. appeared as Western Nigeria Forestry Department Instruction No. 1/1953. The reasons prompting this revision were not primarily silvicultural, but rather the expense and physical difficulty of maintaining the 1944 schedule of operations over the large areas exploited each year. In the Benin Division alone about 20 square miles were being logged annually: with 10 prescribed treatments to be carried out between the first climber cutting and the final repear of logging damage, this involved covering 200 square miles a year. At the same time, labour costs were rising without there being a corresponding increase in log sale revenue.

The new instructions described 10 basic operations for T. S. S., plus two further ones (dibbling and line planting) which were added for completeness, but which could only be carried out with permission from the Chief Conservator of Forests. Several of these were subsequently modified, and in 1956 a further operation (post-exploitation enumeration of economic stems) was added. Most of the operations were similar to those used from 1944 to 1953, but they were more precisely described. However, the new instructions differed from the old in two important ways. Firstly, the removal of the shelterwood was included as a definite operation to be performed some time after exploitation was complete, and secondly much greater use was made of the results of the regeneration counts to introduce considerable flexibility into the system.

The operations as laid down were as follows:

I. Demarcation

As practised from 1944.

II. Climber Cutting and Cutting of Small Trees and Control of Shrub and Herb Layers

This was now recognized as a silvicultural operation of great importance. All climbers were cut, usually at ankle height and at head height, and stems of uneconomic species under 2 inches diameter were slashed. However, for a distance of 4 yards around existing climber tangles all standing poles were left, though the climbers were cut right to the edge of the tangles: the previous "hands-off" policy had changed to a policy of "containment". In areas of broken or open canopy the stem cutting was reduced, and in 1956 it was abandoned completely. Where herb growth (particularly monocotyledonous weeds such as Palisota and Afromomum) was dense, this was slashed back to ankle height. Economic saplings that had double leaders were trimmed, and small malformed economics were coppiced.

III Pre-poisoning Cleaning

This was intended as a tidying-up, to follow op. II after one year. In 1955 its title was altered to pre-poisoning climber cutting, and it was stressed that only in exceptional circumstances should woody growth be slashed back; the emphasis was on climber cutting and, if necessary, a further cutting back of the herbs. In 1956 the operation was regarded as quite unnecessary, and was abandoned.

IV. Regeneration Count and Enumeration of Pole Crop

As in 1944, this was done by the 6 ft by 6 ft method, but only one quarter of each compartment (every fourth strip between grid lines) was assessed. Economic stems were tallied in four classes (0-3 ft high 3-10 ft high, 10 ft high - 1 ft girth, 1-5 ft girth), and a list of 17 species or or species-groups were provided: normally the larger stem of any two within 6 ft of each other was tallied, but where two of similar size occurred, the one higher on the list was selected.

V. Seeding Poisoning

This was a light poisoning to be applied where the regeneration count showed less than 40 stems per acre present, the aim being to give additional light to those that were present and at the same time to increase the ground light in dense patches, where regeneration was lacking, by partially poisoning the lowest tree storey.

VI. Clearance Poisoning of Shade-Casting Uneconomic Trees of Middle and Lower Storey.

This operation aimed at giving ample light and crown space to economic regeneration when more than 40 stems per acre were present, by poisoning all uneconomic, shade-casting stems in the lower tree storeys, but leaving any straight boled trees with small crowns. Shade-casters were to be left around climber tangles and could be left where the canopy was otherwise absent. At the same time economic species of useless stem form could be poisoned if it was thought to be desirable. It will be noted that the 1944 attempts to manipulate canopy opening, so that the regeneration was encouraged but the weeds were retarded, were no longer maintained.

VII. Post-Poisoning Cleaning (altered to Post-Poisoning Climber Cutting in 1955)

This operation had two forms, (a) where useless stems were cut to below knee-height, and (b) where they were cut to knee height. Originally intended as a cleaning on the 1944 pattern (op. v), the growing realization that too much cleaning does more harm than good prompted the 1955 change, in which it was emphasized that op. VII (b), like op. III, should be primarily a climber cutting. The two variations in the treatment depended for application upon the results of a regeneration count, op. VII (a) being given for two successive years after a seeding poisoning (op. V) or for at least one year after clearance poisoning (op. VI) when there were less than 20 economics per acre over 3 ft high; and op. VII (b) being applied for at least one year after clearance poisoning, when there were more than 20 economics 3 ft high but less than 20 over 10 ft high.

VIII. Freeing of Established Saplings and Poles Forming New Crop

This was normally considered as a post-logging treatment, but it could be given any time after clearance poisoning where there were more than 20 economics per acre over 10 ft high, and where the regeneration under 10 ft high was so poor as not to merit further consideration. The operation consisted of cutting climbers, creepers and any weed growth interfering with saplings or poles over $4\frac{1}{2}$ ft high. The cutting of economics was sanctioned where these were interfering with the growth of more valuable species, and it was stressed that special attention should be paid to trimming double leaders and to cutting away climbers from poles and saplings. Under certain circumstances, despite the stocking being correct for this operation, a post-poisoning cleaning (op. VII) would be preferred, for example where the regeneration of stems over 10 ft high was of a relatively low value species while plentiful regeneration of a more desirable species occurred in the 0-3 ft class: the instructions quoted an actual case from Okomu F.R. where the 20 items per acre over 10 ft high consisted 90% of Guarea spp. (no. 7 on the list), but where Khaya ivorensis (no. 1 on the list) was plentiful in the 0-3 ft class; in this case op. VII (a) was prescribed to bring on the Khaya seedlings.

IX. Exploitation and Repair of Exploitation Damage

Exploitation was carried out in year 6, and the repair of logging damage was performed immediately by a labourer assisting the forest guard, his task being go free all economic poles and saplings obstructed by logging debris and to coppice any damaged stems of economic species.

X. Removal of Shelterwood

This was to be carried out when exploitation was completed by destroying all uneconomic trees and malformed economic stems which were in any way interfering with the growth of the new crop. This operation was only carried out from 1956.

XIII. Final Enumeration of all Economics

This operation was prescribed in 1956 and was to be performed after the removal of the shelterwood.

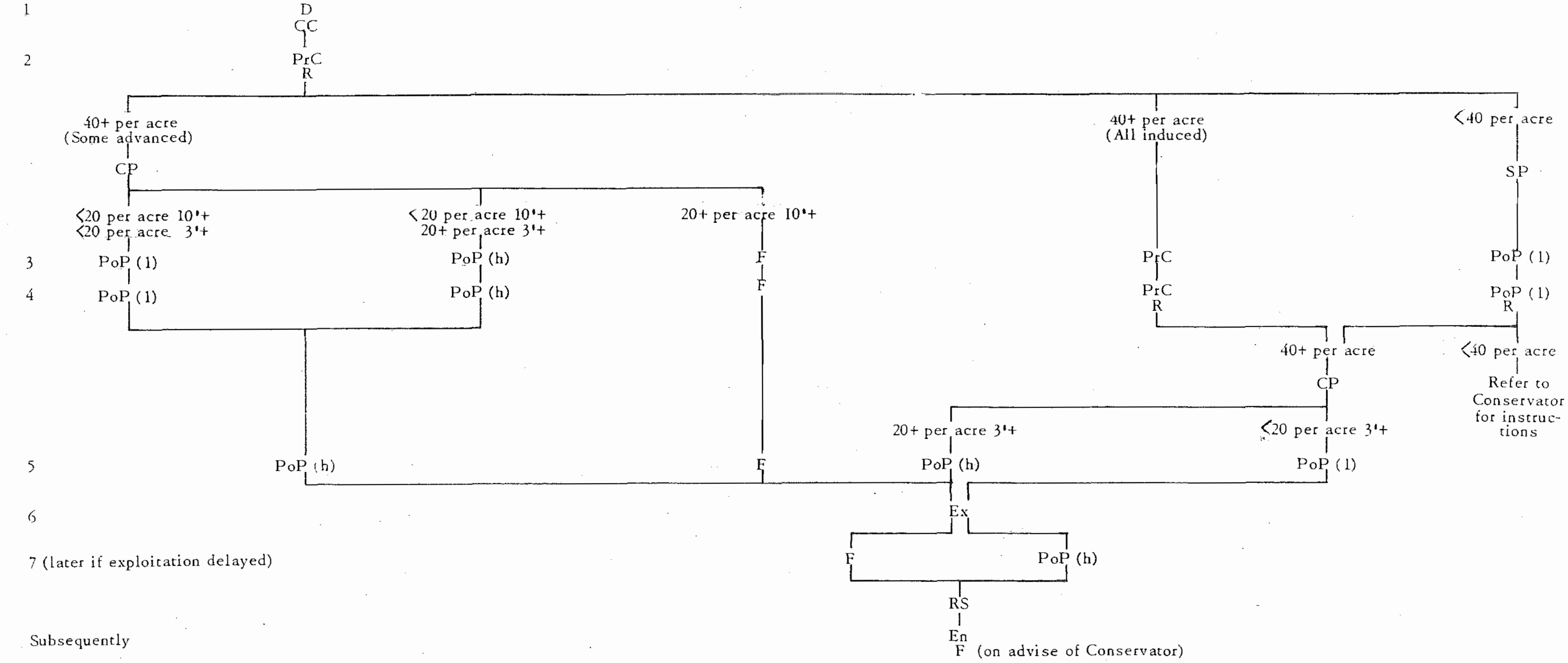
As laid down the treatment was fairly flexible, and different sequences of operations were to be carried out as circumstances warranted. The " circumstances" were largely determined by the regeneration counts, but additional flexibility was given within operations, as for example in the differing approaches to the cutting of uneconomic stems in op. II. The timetable was fixed by the climber cutting in year 1 and logging in year 6, and the theoretical possibilities of the intermediate operations are indicated in Table 32. In actual fact these were never all applied together, as by the time the final enumeration was introduced, the pre-poisoning climber cutting had been abandoned, the post-poisoning climber cuttings were being infrequently used, and the freeing operation had been altered to include climber cutting and the cutting of all uneconomic woody growth interfering with the growth of economic species; the earlier type of freeing operation was then abandoned, and the modified form largely restricted to a late post-exploitation treatment. According to Lancaster (1961a) "it is doubtful if the complicated sequences of operations laid down have ever been rigidly carried out"; subsequent to 1956 the nearest approach to normal practice appears to have been:

Year 1	I	Demarcation
	II	Climber cutting
Year 2	IV	Regeneration count
	V or VI	Opening of canopy by poisoning (sometimes delayed to year 4 if the canopy was very open).
Years 3 and 4		Sometimes VII Post-poisoning climber cutting, but usually nothing.
Year 5		Sometimes VIII Freeing
Year 6	IX	Exploitation and repair of damage
Year 7-11		Nothing
Year 12	VIII	Freeing
	X	Removal of shelterwood
	XIII	Post-exploitation enumeration

Thus, in the most frequently applied sequence, the number of operations was reduced from 10 in the 1944 instructions to 7, exclusive of demarcation in both cases, despite the addition of several new operations after logging was completed. Local variations in treatment

TABLE 32

Timetable to T.S.S. (1953–60)



Key to Operations: D, Demarcation (op.I); CC, Climber cutting & cutting of small trees (op.II); PrC, Pre-poisoning climber cutting (op.III); R, Regeneration count (op.IV); SP, Seeding poisoning (op. V); CP, Clearance poisoning (op.VI); PoP, Post-poisoning climber cutting; (l) low, below knee height (op.VII (a)); (h) high, at knee height (op.VII (b)); F, Freeing of established saplings (op.VIII); Ex, Exploitation and repair of damage (op.IX); RS, Removal of shelterwood (op.X); En, Final enumeration of economics (op.XIII).

Figures refer to the stocking of regeneration of economics, determined by the previous regeneration count.

prevailed in some forests; for example at Shasha F.R., where the infrequently seeding and strongly light-demanding Triplochiton is an important constituent, clearance poisoning was only performed in year 2 over areas where Triplochiton was already established as regeneration or where it was producing fertile seed at the time of poisoning; it could occur in year 3 if that was a seed year, or other wise was delayed to year 4: the aim was to keep unregenerated areas of the forest floor receptive to Triplochiton seed during practically the whole of the 5 year pre-exploitation period (Robson, 1956).

R.C. Barnard, of the Malayan forest service, visited Nigeria in 1955 to examine T.S.S. and to compare it with current rainforest regeneration treatments in Malaya. Although not a keen disciple of T.S.S. (Barnard, 1955), he conceded that T.S.S. had established adequate natural regeneration in most areas despite difficult basic material in the form of huge uneconomic trees, few seedbearers, a dominance of climbers in the undergrowth, the stringencies of relying to a large extent upon the export market for exploitation, and unreliable labour; its main shortcomings were the failure to control climbers and to eliminate the large uneconomic trees, and the number of operations involved. Barnard stressed particularly the importance of the climbers. He believed that in Nigeria the frequency of climber tangles was probably the result of past forest clearing and that they were not a feature of climax forest, and he advised that the aim in Nigeria, as in Malaya, should be to establish and maintain a low, closed, thicket canopy as soon as possible for the passing climber phase to straggle over. He suggested that the only fixed operation should be the initial but thorough climber cutting, subsequent work being based on the results of regeneration counts, and on the maxim of not "can we do a treatment?", but "need we do a treatment now?".

The same idea was receiving thought from the forest officers carrying out T.S.S. operations in Nigeria at that time, and it is perhaps more than coincidence that the year following Barnard's visit should see both the abandonment of much of the earlier cleaning operations and the start of shelterwood removal as a routine operation.

Tropical Shelterwood System, 1961

With the changes noted above, the 1953 instructions for T.S.S. continued to apply until 1961. In the meantime, the Federal Department of Forest Research and, on a smaller scale, the Western Region Forestry Division had been carrying out investigations into various aspects of rainforest silviculture. There was a growing realization that in the important forests of Benin the indiscriminate cutting of uneconomic saplings encouraged the development of climber tangles, and at the same time resulted in the accidental slashing of much valuable advance growth of economic species. Thus an assessment of a compartment at Sapoba F.R. by Redhead (1960a) had shown seedlings of the climbing palms and acacias to be widely distributed through the forest, all being potential nuclei of tangles once additional light was permitted to reach the ground, while in the same compartment an average of 63 economic saplings per acre had been carelessly cut during the climber cutting and cutting of small uneconomic trees (op. II) - in an area where the establishment of only 40 such stems per acre was considered satisfactory! The 6 ft by 6 ft method of regeneration assessment had also been shown to give a gross underestimate of the actual stocking of economics present, usually in the order of only 25% of the number recorded by the use of milliacre quadrats (Lancaster, 1955; Redhead, 1960a).

As a result of these developments the third major amendment to T.S.S. instructions was issued in 1961 as W.R. Forestry Division Instruction No. 1/1961. Within 12 months this had been further modified: the instructions as amended are given in appendix 2.

The amended timetable of operations is as follows *:

Year 1 — Op. I Milliacre assessment
Op. IA Demarcation

	Advance growth stocking sufficient	Advance growth stocking insufficient
Year 1	Op. III Climber cutting only	Op. II Climber cutting and cutting of uneconomic saplings
	Op. V Clearance poisoning	
Year 2		Op. V Clearance poisoning

Year 6 — Exploitation

Year 8 — Op. VIII Repair of exploitation damage
Op. X Post-exploitation climber cutting and freeing
Op. XI Removal of overwood

Year 15 — Op. XIII Sample enumeration

Once again excluding demarcation and redemarcation, the operations of T.S.S. have in reality been reduced to six since operations VIII and X are given at the one time.

The milliacre assessment (op. I) is based on the Malayan system. Normally a 1% stratified sample is used, but this may be increased if the probable sample error exceeds 20%. Stems are classified into a number of size classes and only the 3 ft high to 3 ft girth classes are used in determining whether the regeneration stocking is adequate or not: only one listed stem (the one "most likely to survive and form a useful constituent of the new crop") is chosen for each quadrat from within this size range, smaller or larger stems being listed separately on the assessment sheet; 40 species are given in the list of economic trees; the increase over the 17 listed in 1953 comes partly from separating out individual species of a genus, but also includes 15 new species or species groups not included previously. These 40 species are divided into two classes, I and II, on the basis of their economic value, growth rate and frequency. Advance growth stocking in an area is considered sufficient when there are either at least 100 stocked quadrats per acre of which at least 30 contain class I advance growth, or else at least 60 stocked quadrats with advance growth of class I species per acre.

*This is simplified from the timetable given in the original instructions, and it corresponds to normal practice at present (March, 1962).

If advance growth is sufficient, the area is given a thorough climber cutting, but other woody growth (except for the vigorous and distinctive Musanga) is only cut if it is directly overtopping an economic sapling. As in earlier prescriptions, economics with double leaders are trimmed and any malformed economics are coppiced (op. III). This is then followed in the dry season of the same year (year 1) by clearance poisoning (op. V) which follows the same general pattern as in 1953, leaving an unpoisoned ring of trees around existing tangles, concentrating on the wide-spreading shade-casters, but where the canopy would otherwise be completely absent leaving scattered shade-casters to provide some shelter.

If advance growth is insufficient, the climber cutting is coupled with the cutting of small uneconomic trees (Op. II) as in the similar 1953 operation, the intensity of the understorey cutting depending upon the density of higher tree storeys. In this case clearance poisoning is delayed until the dry season of year 2.

No further treatment is given until exploitation in year 6, and then in year 8 the area is given a climber cutting and freeing of economic advance growth (op. X), and at the same time any damage caused by the exploitation two years earlier is repaired (op. VIII). This is followed the same year by the poisoning of all overwood trees which are either malformed or not included in the list of economics and which are interfering with the growth of the new crop (op. XI). Finally, in year 15 the new crop is reassessed, using a 10% sample of $\frac{1}{2}$ chain square quadrats (op. XIII).

As can be seen the operations in the 1961 instructions are very similar to those of 1953. The main differences between the two lie in the use of stocked quadrats to determine stocking, and in the fewer alternatives for treatment and the reduced programme of treatment. During the 18 years that T. S. S. has been practised, it has remained little altered in its basic outline: the initial climber cutting, the opening of the canopy by poisoning, and exploitation about year 6, these remain integral features of T. S. S. today just as they were in 1944, while the introduction of overstorey poisoning in 1953 occurred sufficiently soon to be applied to most, if not all, of those compartments. The big differences that have occurred can be traced to the growing awareness of the need to disturb the understorey as little as possible if the prolific, and indeed frightening, climber growth is to be kept in check. T. S. S. is now a much simpler, cheaper (in man-hours) and more efficient operation than it was in 1944.

T. S. S. in Practice

Apart from coupes treated in the first few years after 1944, no compartment in Western Nigeria has received all its T. S. S. operations under a single set of instructions, and even the first areas were given shelterwood removal as prescribed in 1956. When the major amendments of 1953 and 1961 were introduced, compartments still in various stages of treatment were given subsequent operations in forms that conformed as closely as possible to the new instructions. However, as has been pointed out, the changes were mainly in degree and in the direction of increasing simplicity, so that an examination on the earliest treated compartments gives a fair indication of what may be expected under T. S. S. even today except that the excessive cleanings, up to 1953 at least, have probably left more climber tangles than the future will see.

Figures 16 and 41 show the course of T.S.S. in an area (compt. 58) at Sapoba F.R. currently receiving treatment. The first profile diagram (Fig. 16) was taken in the field shortly after clearance poisoning and some months after initial climber cutting. Three tree storeys can be recognized: a scattered storey of emergents over 120 ft high, a fairly continuous middle storey between 40 ft and 60 ft, and another fairly continuous storey at about 15 ft to 20 ft. In the two lower storeys, dense patches in one tend to coincide with more open patches in the other. The ground plan of an area including the profile transect is given in Fig. 42, and an assessment of 1 acre (of which Fig. 42 represents half) showed the presence of 64 species and 262 stems over 4 inches D.B.H. (1 ft G.B.H.), with a total basal area of 173 square ft. Of these, 19 species and 70 stems, with a B.A. of 84 square ft, were species listed as economics, though only 9 were obligatory species*. In addition there were about 350 stems in the 1-4 inch diameter class, of which 64 were economics. Milliacre sampling showed the presence of a satisfactory stocking of regeneration, so that climber cutting alone constituted the first silvicultural operation.

The effect of the climber cutting cannot be adequately shown on a profile diagram, though comparison with Fig. 14 (in an adjoining, but untreated, compartment) will show how the vines enter into the composition of the canopy. In the field the effect of climber cutting is most marked, and produces a significant lightening of the entire area treated.

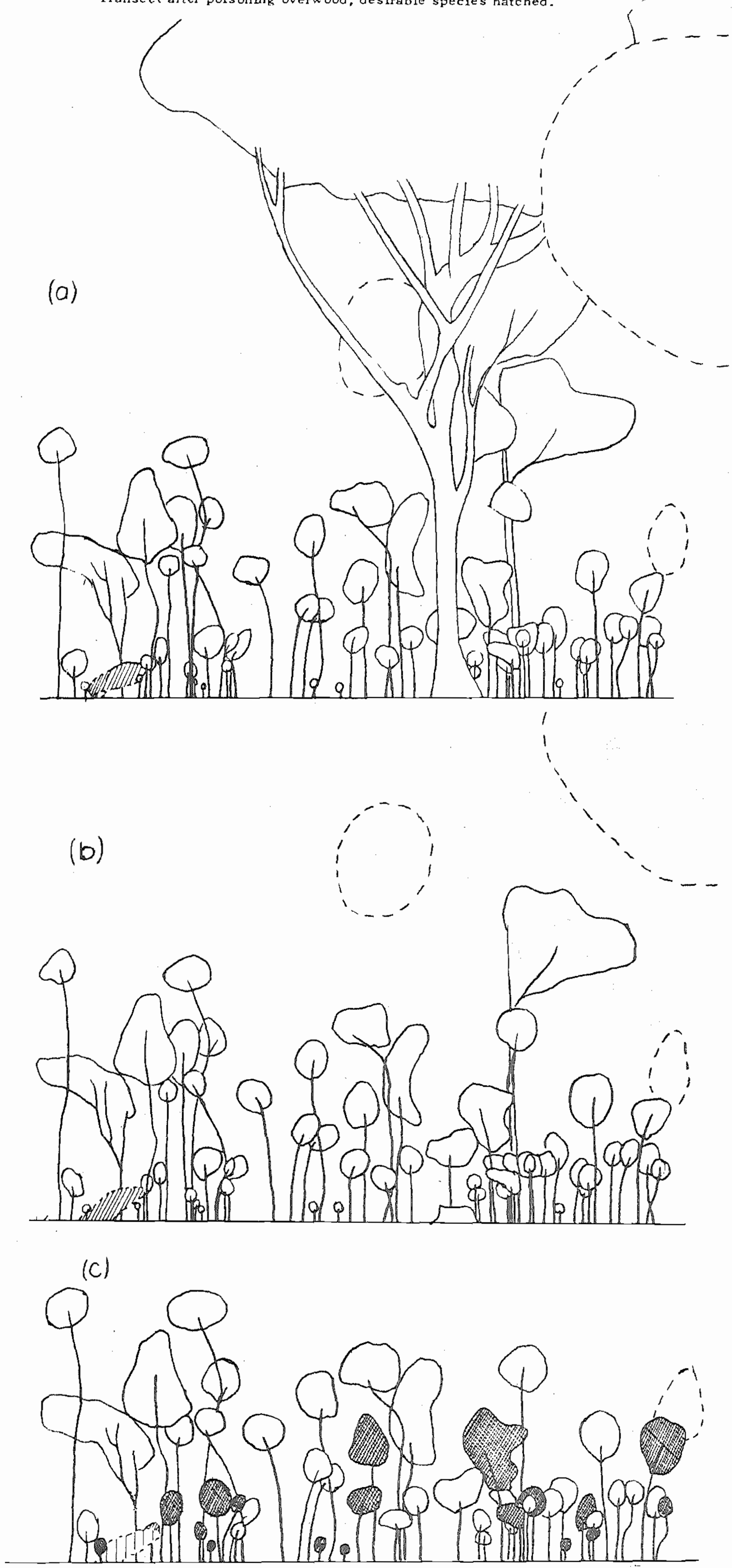
Clearance poisoning had been carried out using the standard solution of 1 lb sodium arsenite to 1 gallon of water, applied in frill girdles and normally requiring about one gallon per acre. Fig. 41a shows the appearance of the same transect when the poisoned trees have died: over the whole acre 75 stems over 4 inches D.B.H., with a B.A. of 28 square ft., were poisoned, along with 8 stems of less than 4 inches D.B.H. This is how the stand can be expected to look just prior to logging and about 5 years after climber cutting.

The study acre is unusually rich in economics, having 5 stems which would be removed in exploitation. Two such exploitable stems are shown in the profile diagram (one actually being outside the acre plot, but with its crown contributing to the canopy of the transect). These 5 stems have a B.A. of 65 square ft, though damage from the felling of large crowned trees such as the Cylicodiscus shown in the profile diagram would cause the standing B.A. to be reduced by more than this amount. As a more typical figure, 10 acres adjoining the plot contained 22 exploitable stems with an average diameter of 31 inches and an average crown diameter of 56 ft: these trees have a total crown area of about 1.2 acres, and damage in logging could be expected to be severe over at least this area, somewhat more than one tenth of the ground area where logging occurs. Fig. 41b shows the profile transect after logging, disregarding possible logging damage.

The final operations of T.S.S. are freeing and overstorey

*Obligatory species are those which the logging contractors are obliged to fell and extract from the forest during exploitation. The removal of other "economics" is optional.

Fig.41. Current Nigerian Tropical Shelterwood System. Profile Diagrams based on fig.16. (a) Transect after clearance poisoning, (b) Transect after exploitation of merchantable logs (disregarding logging damage), (c) Transect after poisoning overwood; desirable species hatched.



poisoning in year 8. The course of these operations will be determined largely by the need of individual economic species for release, but from the assessment figures it seems likely that about 25 square ft B.A. on the acre would be removed: the probably effect on the transect is shown in Fig. 41c.

Disregarding logging damage on the one hand and growth during the 8 years on the other, the effect of T.S.S. on the area examined can be summarized as shown in Table 33.

Fig.42. Plan of 0.5 acre plot in Evergreen Seasonal Rainforest in early stage of T.S.S., Sapoba F.R. Cpt. 58, Nigeria. Area after climber cutting and clearance poisoning; poisoned stems shown as dotted circles. Climber tangles hatched. Stems over 4 inches D.B.H. shown. Aa, *Antiaris africana*; Ab, *Albizia adianthifolia*; Ad, *Annonidium mannii*; Al, *Allanblackia floribunda*; An, *Angylocalyx oligophyllus*; At, *Anthonotha macrophylla*, Be, *Berlinia confusa*; Bl, *Blighia sapida*; Bn, *Baphia nitida*; Bx, *Bombax buonopozense*; Ca, *Carapa procera*; Ce, *Celtis zenkeri*; Cl, *Cola* sp.; Cm, *Combretodendron africanum*; Cy, *Cylicodiscus gabunensis*; Da, *Diospyros crassiflora*; Dd, *D. dendo*; Dp, *Discoglypremna caloneura*; Ds, *Diospyros soubreana*; Ea, *Entandrophragma angolense*; Ec, *E. cylindricum*; En, *Enantia chlorantha*; F, *Fagara macrophylla*; G, *Gossweilerodendron balsamiferum*; Ga, *Garcinia mannii*; Gc, *Guarea cedrata*; Gr, *Grewia coriacea*; Gt, *Guarea thompsonii*; Ho, *Homalium* sp.; Hy, *Hymenostegia afzelii*; L, *Lovoa trichilioides*; My, *Myrianthus arboreus*; Pa, *Pachystela brevipes*; Pb, *Parkis bicolor*; Pe, *Pentaclethra macrophylla*; Pi, *Piptadeniastrum africanum*; Sg, *Strombosia grandifolia*; Sp, *S. pustulata*; St, *Sterculia tragacantha*; Te, *Tetrapleura tetraptera*; Tp, *Trichilia prieureana*; Tr, *Treculia africana*; Ts, *Triplochiton scleroxylon*; X, unidentified; Xy, *Xylopia quintasii*.

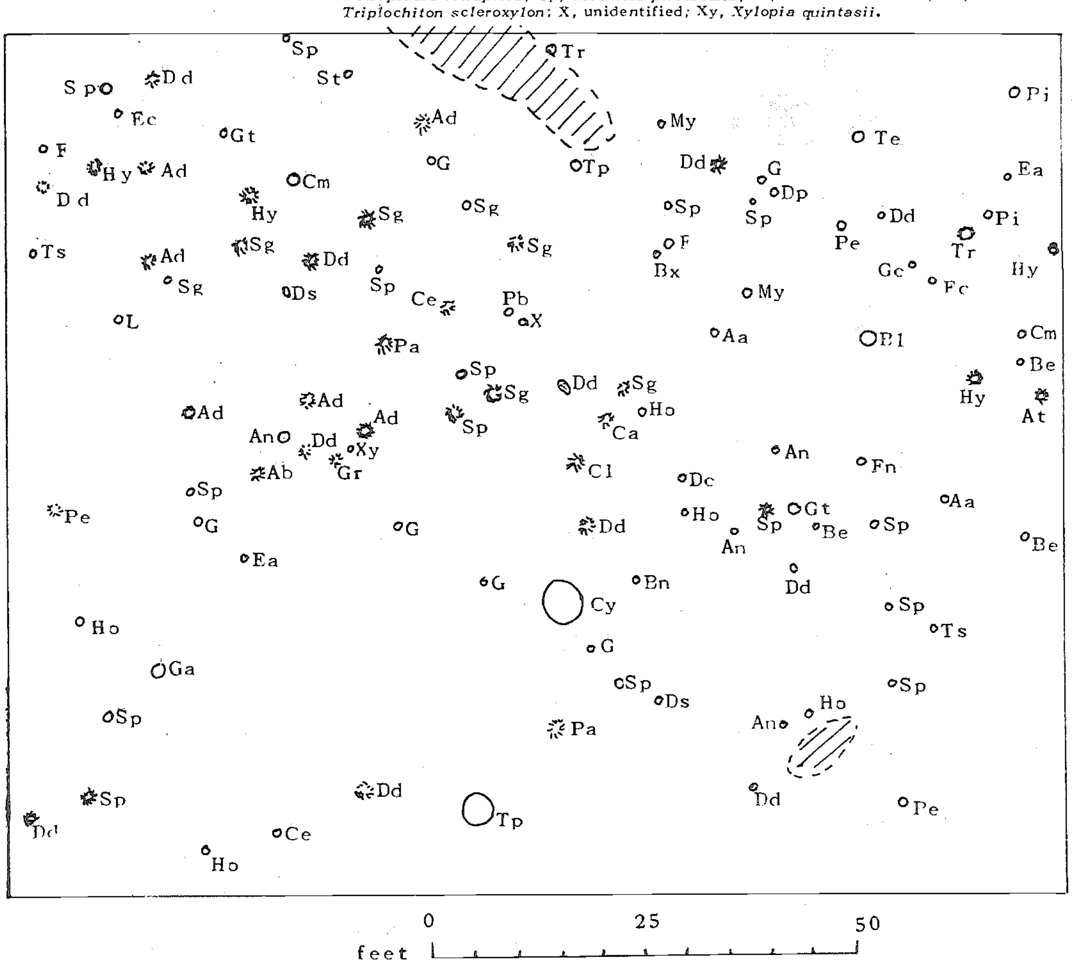


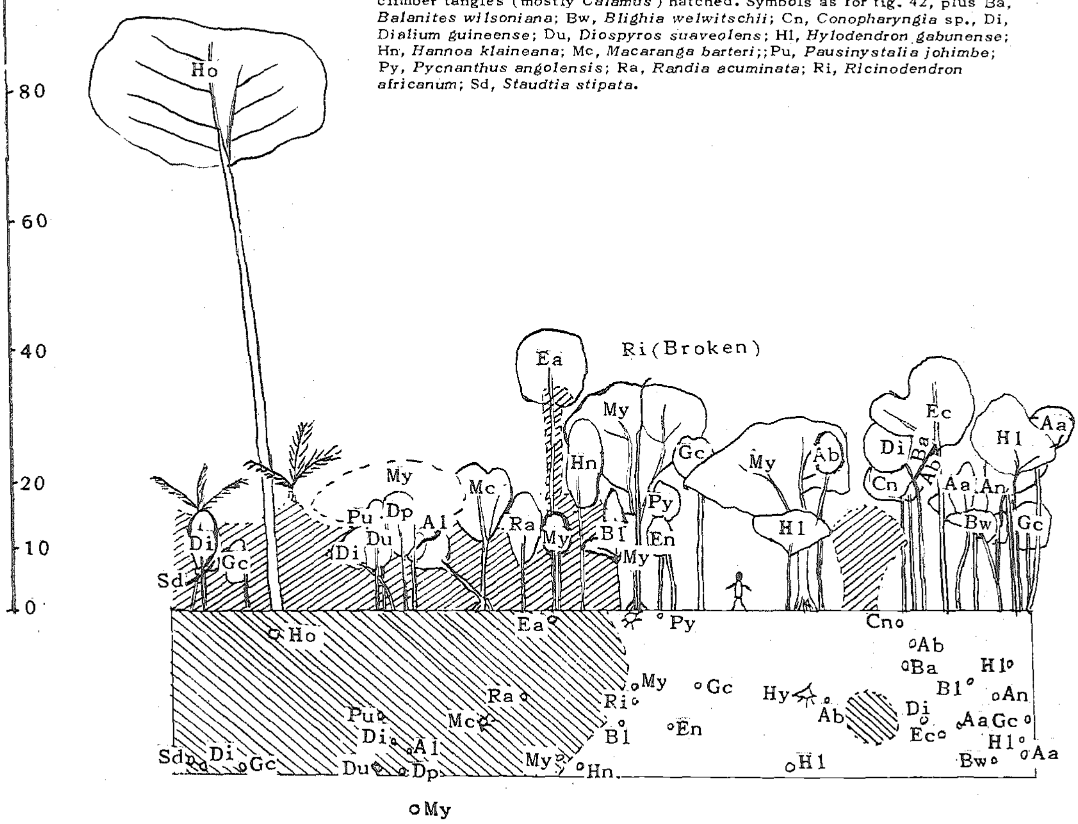
TABLE 33

Effect of T.S.S. on 1 Acre Plot; Compartment 58, Sapoba F.R.

	Standing Crop		Removed	
	Stems 4" +	Basal Area	Stems 4" +	Basal Area
At Start of T.S.S.	262	173 square ft	-	-
After Clearance Poisoning	187	145	75	28 square ft
After Exploitation	182	80	5	65
After Overstorey Poisoning and Freeing	162	55	20	25

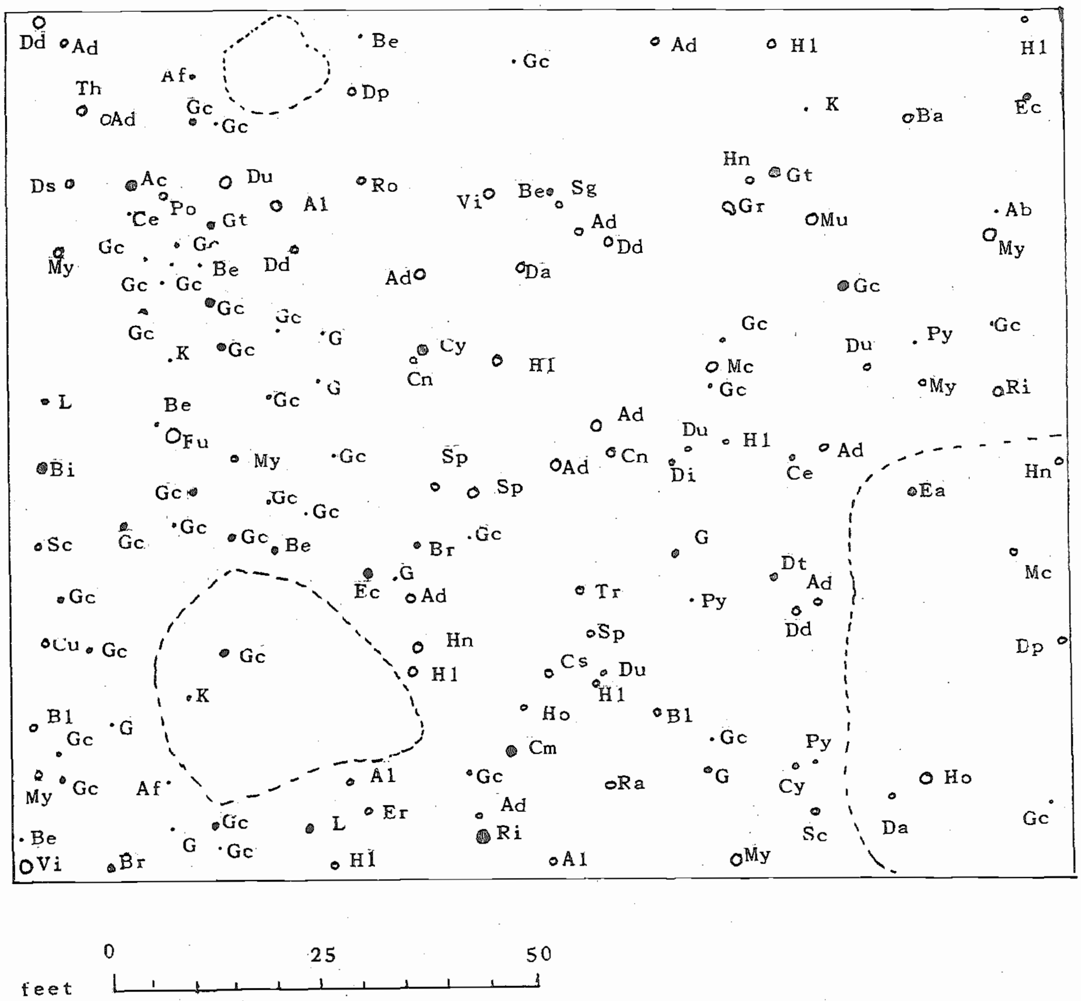
Of the remnant crop of about 160 stems per acre and 55 square ft B.A. over 4 inches D.B.H., some 60 stems and 20 square ft B.A. are of of economic species. By comparison, Fig. 43 shows an actual area on compartment 146 Sapoba, where T.S.S. commenced in 1946, with

Fig.43. Profile Diagram of Evergreen Seasonal Rainforest under T.S.S., Sapoba F.R. (cpt. 146), Nigeria. Treatment commenced 1946, exploited 1954, overwood removed 1956, diagram prepared 1962. Transect 132 ft. long, 25 ft. wide; climber tangles (mostly *Calamus*) hatched. Symbols as for fig. 42, plus Ba, *Balanites wilsoniana*; Bw, *Blighia welwitschii*; Cn, *Conopharyngia* sp., Di, *Dialium guineense*; Du, *Diospyros suaveolens*; Hl, *Hylodendron gabunense*; Hn, *Hannoa klaineana*; Mc, *Macaranga barteri*;; Pu, *Pausinystalia johimbe*; Py, *Pycnanthus angolensis*; Ra, *Randia acuminata*; Ri, *Ricinodendron africanum*; Sd, *Staudtia stipata*.



exploitation completed in 1954 (1.5 trees per acre removed over the whole compartment) and overwood removal two years later. The physiognomy of the stand is very similar to what is expected in compartment 58, though climber tangles are more widespread. Stocking, however, is greater: on a 0.5 acre plot (Fig. 44) there was the equivalent of 230 stems per acre over 4 inches D.B.H., with a B.A. of 110 square ft per acre, and of these 80 stems and 29 square ft were economics. This higher stocking can be attributed largely to the fewer exploitable stems originally on the second area, coupled with the growth that has occurred in the meantime. Potential stocking of economics in the new crop is higher than the above figures indicate, as in both areas there are over 60 economics per acre in the 1-4 inches diameter class. The size class distribution of non-exploitable (undersize) economic species in the two areas, in the one case before treatment and in the other at the conclusion of T.S.S., brought in both cases to a per acre basis, is:

Fig.44. Plan of 0.5 acre plot in Rainforest Regenerated by T.S.S., Sapoba F.R., Cpt. 146, Nigeria (same stand illustrated in fig. 43). Merchantable species between 2 - 4 inches D.B.H. indicated by dot; merchantable species larger than 4 inches D.B.H. by solid circle; unmerchantable species larger than 4 inches D.B.H. by hollow circle (merchantable species as listed in appendix 2). Dotted lines indicate limits of climber tangles. Species as for figs. 42 and 43, plus Ac, *Alstonia congensis*; Af, *Afzelia bipindensis*; Bi, *Beilschmedia* sp.; Br, *Brachystegia* ? Cs, *Canarium schweinfurthii*; Cu, *Cuviera nigrescens*; Da, *Diospyros albiflavensis*; Dt, *Distemonanthus benthamianus*; Er, *Eriocoelum macrocarpum*; Fu, *Funtumia africana*; K, *Khaya ivorensis*; Mu, *Musanga cecropioides*; Po, *Polyalthia suaveolens*; Ro, *Rothmannia hispida*; Sc, *Scottelia coriacea*; Th, *Trichilia heudelotii*; Vi, *Vitex rivularis*.



Diameter Class - Inches

Compartment	1-4	4-8	8-12	12-16	16-20	20-24 (6 ft girth)	Total Per Acre
58 (Untreated)	64	50	6	5	2	2	129
146 (Treated)	64	58	14	4	4	-	144

Too much emphasis should not be placed on a comparison of these two areas, representing as they do a very small sample of two rather distant compartments on a single reserve. However, they do suggest three things:

1. In the Benin area the main effect of T.S.S. has been to release the adequate regrowth already present, rather than to induce fresh regeneration.

2. The range in size of undersize economics, together with the differential rates of growth both between and within species (see chapter 6), is going to produce a new crop that is not even-aged and

is certainly not even-sized: the effect will be far from that obtained in a pure plantation.

3. The stands, even after T.S.S., contain a large number of stems of uneconomic species. In the two areas the percentages of uneconomic stems are 59% and 65%, and of uneconomic B.A. 64% and 74%, respectively, and the suggestion is that subsequent freeing operations will be needed if the new crop of economics is to produce anything like the volume increment possible for the site: in the immediate future much of the cellulose production will be going into useless, and therefore virtually weed, species.

Experiments Bearing on T.S.S.:

The early experimental work which helped form the basis of T.S.S in Nigeria has already been mentioned. However, since 1952, when organized forest research in the country was recommenced* a number of experiments into various aspects of the silvicultural treatment of rainforests in Nigeria have been carried out. Some of these, e.g. F.D.F.R. investigations 208, 211, and 212, consisted essentially in examining the effects of prescribed T.S.S. operations and certain modifications of these in different forest reserves. Inv. 211 and 212 duplicated the same treatments in two forests, 212 being at Sapoba F.R. in the moister type of rainforest on deep sands, while 211 was at Idanre F.R., a somewhat drier area on soils derived from metamorphic rocks. Four treatments were given: A, T.S.S. as prescribed in 1944; B, T.S.S. as prescribed in 1953; C, an annual climber cutting only; and D, climber cutting followed by clearance poisoning, but no other treatment (D is similar to one form of the 1961 prescriptions for T.S.S.). The results from the start of the experiment in 1953 up to exploitation in 1958 have been summarized by the Federal Department of Forest Research (1960). The two areas differed significantly at the commencement of operations, Sapoba having an average of 21.4 economic trees per acre over 4 inches D.B.H. (1 ft girth), of which 9.1 were the fairly tolerant Guarea cedrata, whereas at Idanre there were only 6.5 such trees per acre, the most common species being Khaya ivorensis (2.2 per acre) and Terminalia superba (2.1 per acre) of which the former is moderately, and the latter strongly, light-demanding. Unfortunately the treatments were not replicated within either area so that the results must be regarded cautiously. Some of the more interesting results determined by 6 ft by 6 ft counts are shown in Table 34.

Again there is the strong indication that in the Benin area the effect of treatment is largely to release already established regeneration, though in the drier site inducement of new regeneration has occurred. At Sapoba, where Guarea is the most common species in the new crop, there has not been much difference between the results of the different treatments, but at Idanre the two heavier treatments (A and B) have resulted in a good establishment of Khaya and T. superba, whereas these species are poorly represented in the treatments with a relatively slight canopy opening.

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*Research had been carried out between Kennedy's departure and the formation of the Federal Department of Forest Research by both individual officers and the sub-professional Forestry School, but the rebirth of co-ordinated research can be regarded as occurring in 1952.

TABLE 34

Development of Regeneration, Idanre and Sapoba F.Rs.
(See text for treatment details)

Forest Reserve	Treatment	Regeneration per acre (3' High-5' Girth)		
		1953-54	1957	Increase
Idanre	A	11.4	155.6	144.2
	B	8.9	116.0	107.1
	C	8.8	72.3	63.5
	D	7.0	41.5	34.5
	All treatments	9.0	96.3	87.3
Sapoba	A	56.6	88.5	31.9
	B	51.9	73.6	21.7
	C	58.2	63.3	5.1
	D	52.4	83.7	31.3
	All treatments	54.8	77.3	22.5

Investigation 208 was carried out in Omo F.R., a reserve poor in economic species and located in the drier (semi-evergreen) rainforest belt. Three treatments were given: A, T.S.S. as prescribed in 1944; B, Annual climber cutting only; and C, Walsh's system of clear falling with seed trees and burning the debris. The study started in 1952 and the treatment blocks were logged in 1959. The results obtained up to the time of logging have been recorded by Lancaster (1961b). At the start of the investigation there were only 2.4 economic trees per acre over 4 inches D.B.H. present, though the list of economics was much more restricted then than now. Sterculia rhinopetala, which was common in the stand, was not regarded as economic in 1952 though it is now, and the same applies to several other less frequent species. The results in regeneration per acre (by 6 ft by 6 ft counts) are given in Table 35.

Although it obviously induced regeneration, including the valuable Chlorophora excelsa, Walsh's system (C) was not considered successful, as most of the regeneration was heavily suppressed by weed growth and the cost was very high. In both other treatments the Sterculia made up a large proportion of the regeneration, Terminalia superba also being common. In the area treated by T.S.S. (A) the regeneration appeared healthy and was growing well, but in the climber cutting block (B) the regeneration, largely of light-demanding species, was suppressed: the results thus tend to support those from Idanre F.R. During the T.S.S. operations an average of 38 square ft per acre B.A. was poisoned in the first poisoning, and a smaller amount in the second poisoning. After exploitation 60 square ft per acre were left, and shelterwood poisoning reduced this to 27 square ft per acre, of which 10 square ft were of economic species.

Shelterwood removal was studied in inv. 215 at Sapoba F.R., one plot of which provided the data shown in Figs 42 and 44. The area had been treated under T.S.S. since 1946, and was logged and the overwood poisoned in 1954. Five treatments were given: A, all uneconomic stems 6 ft girth (23 inches D.B.H.) and over poisoned; B, all uneconomic stems 1 ft girth (4 inches D.B.H.) and over poisoned; C, all shade-casting uneconomic 1 ft girth and over interfering with new crop poisoned; D, as for C, but repoisoning after one year any stems still living; E, unpoisoned control. In each block 90 saplings and poles of economic species were selected for growth studies, as far as possible stems of comparable size and species being chosen. The periodic annual growth over 4 years is shown in Table 36.

The study showed that the sodium arsenite poisoning was 100% successful within 2 years, and repoisoning in block D was not required. However, complete removal of the overstorey was found undesirable where the stand had been left open by exploitation, as it encouraged the further spread of Acacia and Calamus tangles. In addition the breakup of the dead trees caused considerable damage in the understorey (including economic regrowth), and the large fallen branches caused "craters" which acted as foci for new tangles. Additional damage to regeneration was produced when saplings, which had become etiolated under the shelterwood, were either unable to support the weight of the new crown which they formed or else developed a strong lean towards side light. The conclusion is obviously to remove the shelterwood cautiously, and not to poison more than is necessary for the satisfactory growth of the new crop.

TABLE 35

Development of Regeneration, Omo F.R.
(See text for treatment details)

	1952 Assessment					1960 Assessment				
	0'-3'H	3'-10'H	10' H-1' G	1' - 5'G	Total	0'-3'H	3'-10'H	10'H -1'G	1'-5'G	Total
A. Sterc. rhinopetala	-	-	-	3.6	3.6	3.6	19.1	73.4	11.7	107.8
Other "economics"	3.9	-	0.2	1.3	5.4	31.9	17.9	54.1	13.1	117.0
All economics	3.9	-	0.2	4.9	9.0	35.5	37.0	127.5	24.8	224.8
B. Sterc. rhinopetala	-	-	-	3.9	3.9	30.6	43.7	27.0	6.0	107.3
Other "economics"	0.7	0.1	1.1	1.3	3.2	44.4	6.2	13.7	6.0	70.3
All economics	0.7	0.1	1.1	5.2	7.1	75.0	49.9	40.7	12.0	177.6
C. Sterc. rhinopetala	-	1 -	-	-	-	1.9	3.2	4.4	0.5	10.0
Other "economics"	0.1	0.2	0.5	-	0.8	23.3	16.7	46.9	6.7	93.6
All economics	0.1	0.2	0.5	-	0.8	25.2	19.9	51.3	7.2	103.6

TABLE 36

Regeneration Growth After Shelterwood Removal (1954-58)
(See text for treatment details)

Treatment	P.A.I. - girth	P.A.I. - height	% lost or damaged
A	0.71"	1.2'	13
B	1.29	1.1	27
C	0.91	1.4	24
D	0.90	1.6	13
E	0.38	1.1	7

Other experiments dealing with aspects of silvicultural treatment are mostly more recent in origin and have not yet yielded their results. However, Table 37 summarises one of the most comprehensive experiments, involving 13 combinations of operations at Sapoba F.R. and gives some of the progress results. The treatments are quite distinct in the field, 2 being the most severe and 13 the least. As is typical in the Benin forests, Guarea spp. (mostly G. cedrata) constitute the larger part of the regeneration, these being least significant (although still plentiful) in treatment 2. The growth of the regeneration is closely related to the amount of canopy poisoning, only 25% of the stems being over 3 ft high where no poisoning had occurred (treatments 11-13), 32% where selective poisoning had occurred (treatments 6-10), and 36% where complete poisoning had taken place (treatments 1-5) by 1960. Logging occurred in all plots in 1961.

The possibility of exploiting before treatment has been examined in inv. 209 at Idanre F.R. and inv. 210 at Iguobazowa F.R., the latter being another forest in the Benin area. In both forests exploitation occurred in 1952-53, one plot in each area receiving no further treatment and two plots receiving a climber cutting after exploitation, followed about a year later by clearance poisoning; no overstorey poisoning has been given. The development of regeneration (3 ft high to 1 ft G.B.H.) has been:

	Treated		Untreated	
	1952	1958	1952	1958
Idanre F.R.	1.5 per acre	65.6 per acre	21.0 per acre	8.6 per acre
Iguobazowa F.R.	25,0 per acre	55.6 per acre	21.7 per acre	42.4 per acre

The effect of treatment has clearly been greater in the drier and generally more open stand at Idanre than at Iguobazowa, where Guarea spp. have constituted more than half the regeneration present at all stages. In discussing this study Lancaster (1960) concludes that such post-exploitation treatments may well be as effective as normal T.S.S., but that even at Benin some silvicultural operations are necessary to produce adequate regeneration: logging alone will not produce sufficient quantities. This of course, was an important consideration leading to the introduction of T.S.S. in 1944, while th first conclusion is only likely to hold good so long as logging does not remove all the seed bearers in forests such as Idanre or damage the bulk of existing regeneration in the moister Benin forests.

Swampy rainforests and other forests on poorly drained sites are not at present treated under T S.S., or indeed by any silvicultural operations. Yet these forests occupy a considerable area in the vicinity of the Niger River delta. particularly in the Eastern Region, and are important as the source of Mitragyna ciliata (Abura), Nigeria's second timber species in log volume exported (10% of total log exports in 1958-59). A number of experiments have been started in these forests with the aim of inducing regeneration of Mitragyna. Most have so far been inconclusive, but one (inv. 268), on Uwet Odot F.R., is of some interest. Here the forests occupy the gentle slope of a river levee, stands dominated by Oxystigma mannii occupying the lowest sites, but with more and more Mitragyna occurring as the levee is approached: the suggestion is of a true sere, with Oxystigma occurring at an early

TABLE 37

Investigation 273. Sapoba F.R., 1956-60

Treatment	Operations		Basal per Acre 1957		Stocking of Economics per Acre					
					1956			1960		
	1957	Subsequent	Total	% Poisoned	All Spp.	Less Guarea	% 3' +	All Spp.	Less Guarea	% 3' +
1	CC.CP	CC ann.	117 sq ft	84%	77	29	29	136	34	35
2	CC.CP	F ann.	129	85	114	37	29	124	63	33
3	CC.CP	CC in yr 4	134	84	97	35	28	123	38	35
4	CC.CP	As required	140	82	89	28	22	92	27	39
5	CC.CP	-	131	85	92	30	27	108	39	35
6	CC.SP	CC ann.	136	44	107	20	36	104	39	31
7	CC.SP	F. ann.	115	33	69	19	28	125	39	27
8	CC.SP	CC in yr 4	116	40	100	34	31	112	41	34
9	CC.SP	As required	130	33	101	32	28	128	49	32
10	CC.SP	-	107	37	62	28	28	91	31	35
11	CC	CC ann; SP year 6	118	0	127	52	23	113	44	24
12	CC	CC ann.	113	0	79	26	33	128	42	26
13	-	-	112	0	83	26	32	105	36	24
Mean	--	--	123	-	92	30	29	114	42	32

NOTE:

CC. Climber cutting.
ann. Annually, treatment repeated each year.
F. Freeing regeneration to below knee height.
In the "stocking of economics" details are given for all economic spp., and for all "less Guarea" spp. The "% 3' +" refers to the percentage of economics above 3 ft in height.

CP. Complete poisoning of all uneconomic stems to $2\frac{1}{2}$ inch D.B.H.
SP. Selective poisoning of uneconomics to $2\frac{1}{2}$ inch D.B.H. (in treatment 11 this operation is to be delayed to year 6, when uneconomics dominating regeneration will be poisoned).

stage and being replaced by Mitragyna as the silt deposits build up around the "islands" of Oxystigma breathing roots. The experiment was located in an almost pure Oxystigma stand, where 96% of the 250 stems per acre over 4 inches D.B.H. were of this one species. Clear cutting for pit props was carried out in one treatment in 1957, in another no treatment was given. The development of regeneration (milliacre quadrats stocked with stems up to 1 ft G.B.H.) has been:

	Untreated		Clear Cutting	
Species	1957	1960	1957	1960
Oxystigma	67.7%	78.9	65.3	47.3
Mitragyna	0.0	2.7	0.3	37.0
Others	2.4	1.3	3.0	1.0
TOTAL	70.1%	82.9%	68.7%	85.3%

The inducement of the more valuable Mitragyna has been most marked in the treated plots.

Other work, not strictly experimental, is likely to influence the future development of silviculture in Nigerian rainforests also. The early growth studies in the Okomu F.R. (Benin area), written up by Keay (1961) and discussed in Chapter 6, were partly responsible for the initial selection of 100 years as the rotation length under T.S.S. Keay's recent detailed analysis of the results have led him to believe that there are good grounds for allowing an intermediate cut halfway through this rotation, and that advanced fellings would seem desirable in areas not due for T.S.S. for 50 years or more. The study of logging damage in the Benin area, reported by Redhead (1960b), showed about a 10% destruction of regrowth for each stem extracted on an acre, the damage being widely dispersed, and mostly caused by tractors during snigging operations: Redhead considered that the damage was not sufficient to preclude management on a poly-cyclic system.

T.S.S. and the Future

Eighteen years after it was introduced in Nigeria, T.S.S. has been applied to over 600 square miles of forest reserve in the Western Region. During this period its basic features have been maintained, though it has undergone a number of important changes which appear to have made it into a generally more effective and efficient series of operations. In most areas adequate quantities of regeneration are being produced, either by actual inducement or by release of existing advance growth, and it seems probable that the volume of economic species in the new crop will greatly exceed the average of about 400 cubic ft Hoppus per acre now being obtained from the original forests in the Benin area. Climber tangles appear less of a threat than they did in the early days of T.S.S. The forests are being managed under working plans in an orderly fashion, though perhaps with less direct departmental control than some officers would fancy. The financial basis appears sound, so long as the demand for the forest products is maintained both on the local and on the export market: in 1958-59 total forest expenditure in the Western Region amounted to only 72% of the revenue, and the fear voiced in 1952, that working plans would collapse due to the physical and financial impossibility of keeping up with the prescribed operations, seems for the present remote.

What of the future? To a large extent this is veiled by political and technological uncertainties such as the pressure on the forest service to release reserves for agriculture, the long range export market for Nigerian timbers, the increase in the local per capita consumption of timber, and the speed with which species at present unused can be brought first on to the list of "economics", and then on to the list of obligatory species. At present the oldest coupes under T.S.S. have 80 years to go before they are due for further exploitation. Complementary to this is the fact that other coupes have as long to wait before they will belogged the first time. Such areas contain trees that are at present mature or overmature; under the present system many such trees will die before logging occurs, and in dying will cause damage to smaller trees in their vicinity. This has led to the suggestion (e.g. Keay, 1961) that where overmature trees are present, salvage logging on a relatively short cycle should be carried out to remove these stems before they die, the logging being associated with a climber cutting to enable the remaining smaller stems to benefit from the exploitation. The same considerations have suggested the desirability of an intermediate logging within the rotation of the treated coupes, in order to remove both the faster growing species, which have attained maturity long before the rotation is through, as well as those stems of somewhat slower growth which were just undersize at the time of initial exploitation, and which are likely to be overmature if left till the next. Within T.S.S. itself it would appear that a follow-up liberation treatment of the established regeneration would be beneficial some 10 to 15 years after exploitation, to ensure that the stems in the new pole crop are given the best possible conditions for maintaining vigorous growth. Although this suggestion does not appear to have been mentioned in print, it is not unlikely that the idea underlies the proposed sample enumeration (operation XIII) to be given in year 15 under the 1961 instructions: this could lead to a general liberation treatment similar to that carried out after the half chain square sampling at about age 10 years in Malaya+.

TRINIDAD *

The Environment

Trinidad, a former British colony, is a small, comma-shaped island lying just off the northern coast of South America at lat. 11°N and long. 61°W. It is separated from Venezuela by two narrow, romantically-named straits, and is believed to have been joined to the mainland during the late Pleistocene and early Recent. It has an area of 1,860 square miles and a population of about 800,000. The topography is marked by a mountain range along the north of the island, with isolated peaks up to 3,000 ft, and by a lower series of hills up to 1,000 ft extending down the centre of the island from north to south. Because of this topography climatic conditions vary considerably,

+ So much for silvicultural platitudes! It is understood that T.S.S. was abandoned in Nigeria in 1966.

* For much of the information in this section I am indebted to Mr David Moore, Conservator of Forests, Trinidad.

with consequent changes in the original vegetation. The island lies outside the Caribbean hurrican belt, but is subjected to fairly constant easterly trade winds on its windward side. The environmental factors and the vegetation have been discussed in detail by Beard (1946a), who recognises what are here regarded as three subformations of rainforest among the types of vegetation present. These are evergreen seasonal rainforest, submontane rainforest and montane rainforest, in each of which he distinguishes a single association, Carapa guianensis-Eschweilera subglandulosa, Byrsonima spicata-Licania ternatensis, and Richeria grandis-Eschweilera trinitensis respectively. The Mora excelsa communities, distinctive in physiognomy and composition, are regarded by Beard as being a faciation of the Carapa-Eschweilera association.

Indigenous forest still covers about 900 square miles on the island (Lamb, 1957), and of this about 500 square miles is reserved forest. Because of a relatively low population until quite recent times, much of the forest is undisturbed by man. The rainforest is found principally in the north and east. Evergreen seasonal rainforest occurs up to an altitude of about 800 ft in areas with an average annual rainfall of over 70 inches and with less than 3 dry months, each with under 4 inches of rain. Above 800 ft it is replaced by submontane rainforest which extends up to about 2,500 ft, with montane rainforest occupying the remaining higher land other than the most exposed ridges. In the submontane and montane rainforest zones there is virtually no dry season and the rainfall is itself higher. Details of composition and physiognomy are given by Beard (1946a) and his profile diagrams for these three main types and for the Mora forests have been reproduced by Richards (1952; Fig. 7a and b and 42a and b). Except for the Mora forests the communities are mixed in composition, though there is a reduction in the number of species present with altitude. In the faciation dominated by Mora up to 95% of the upper storey trees are of this one species: Beard (1946b) regards Mora as a recent arrival in Trinidad, having entered by the Pleistocene-Early Recent land bridge, and now tending to replace the more open Carapa-Eschweilera community.

Forest Development

As a small country with a high population density (about 450 per square mile), Trinidad is a nett importer of timber. In 1958 4.7 million cubic ft of timber were produced locally, 3.5 million cubic ft being sawlogs, and a substantial but unspecified volume was imported (Forest Department of Trinidad and Tobago, 1960): the following year 1.5 million cubic ft of coniferous timber alone were imported from (? British) Honduras (Lamb and others, 1960). Of the local production from crown forests (forest reserves and other forested crown land) over 50% came from 3 species, Mora (26%), Carapa (17%), and Terminalia amazonica (9%).

The general pattern of timber consumption has altered markedly since before the 1939-45 war. Timber imports have decreased from the pre-war levels and have been compensated for by increased use of local timbers, coupled with a widening range of acceptable species from the Trinidad forests. The local species are grouped into 4 classes for which differential stumpages are paid (Table 38): since 1940 the production of class I species has diminished, largely as a result of

TABLE 38

Royalty Classes and Values at Stump - Trinidad (1962)

Class I 24 cents per cubic ft	Class II 12 cents per cubic ft	Class III 5 cents per cubic ft	Class IV 2 cents per cubic ft
Manilkara bidentata	Carapa guianensis	Virola surinamensis	Pentaclethra macroloba
Tabebuia serratifolia	Vitex sp.	Symphonia globulifera	Spondias mombin
Cedrela mexicana	Ocotea sp.	Hernandia sonora	
	Mora excelsa	Laetia procera	
	Terminalia amazonica	Didymopanax morototoni	
	Eschweilera subglandulosa	Protium sp.	
	Hieronyma caribaea	Pithecellobium jupunba	
	Andira inermis	Hura crepitans	
	Byrsonima spicata		

NOTE: \$1 (B.W.I.) = 100 cents = 4/2 sterling; 1 cent (B.W.I.) = ½d. sterling past exploitation, while the output of class II and III species has been greatly increased. At the same time there has been a drop in per capita consumption due to the change from wooden to brick house construction (Moore, 1957). Another important change has been the diminishing demand for fuelwood (particularly charcoal), due to the increasing use of kerosene stoves: typical values for the production of fuelwood from crown forests are:

1949	2.06 million cubic ft
1954	1.58 " " "
1958	0.92 " " "

Because of the timber shortage, forest management tends to be intensive. 119,640 acres (312 square miles) of forest reserves are under working plans, 102,000 acres being reserved for plantations and 14,000 acres for natural regeneration under the Trinidad tropical shelterwood system (T.S.S.). The montane rainforests are regarded as serving primarily a protective function. In the submontane rainforests a start has been made towards conversion to *Pinus* spp., and a similar conversion is intended for the accessible areas of *Mora* forest: previously this latter type was treated under an extensive regeneration technique aimed at favouring the faster-growing species over *Mora*, but now operations in this type are what Moore terms "controlled exploitation", with the ultimate object of replacement by *P. caribaea*. The areas set aside for T.S.S. are essentially in the *Carapa-Eschweilera* association, on sandy soils.

Development of Silviculture: Arena F.R.

The tropical shelterwood system in Trinidad was developed on the Arena F.R. This reserve has an area of 3,800 acres and lies towards the centre of the island at an altitude of from 100 to 200 ft and with a mean annual rainfall of about 100 inches. The topography is gently undulating and drainage is mostly good, though there are small areas of seasonal swamp forest. The forest overlies Pliocene sands which have produced a white sandy soil of poor quality, deteriorating rapidly on exposure. There are also some areas with a very poor acidic red clay soil. On the well drained sites the forest is typical *Carapa-Eschweilera* seasonal evergreen rainforest (Brooks, 1941).

The area had been opened for agriculture settlement in 1890, but this proved unsuccessful. Most of the forest was subsequently logged and burnt, and where shifting cultivation was practised the forest deteriorated to a low, worthless scrub under 20 ft high, interlaced with vines and razor grass (*Scleria* spp.) (Beard, 1944b). Silvicultural work commenced in 1927 on the reserve and the following sequence of treatments then occurred (Ayliffe, 1952):

1927 Clear falling and burning, followed by the planting of *Carapa*, *Calophyllum braziliense*, and *Vitex divaricata*. Heavy grass infestation followed the burning and the results were unsatisfactory.

1928 Clear falling without burning, then planting with agricultural crops raised between the rows. Frequent clean weeding. Costs very high.

1929 Clean weeding abandoned and woody growth encouraged, with lowered costs and less grass invasion.

1930-31 Planting under shelterwood which was removed after one year, leading to deterioration of the crop.

1932-36 Working under shelterwood, mostly with artificial regeneration, but natural regeneration encouraged.

1937 Planting of Carapa ceased, Calophyllum favoured.

1939 High shade shelterwood system with natural regeneration (T.S.S.) evolved; planting decreased and ceased completely in 1945.

The evolution of T.S.S. thus followed the pattern of silviculture in many rainforest areas, with the initial emphasis of planting and a gradual change to the use of natural regeneration. In Trinidad the change was prompted by the discovery that natural regeneration was much more widespread than had been expected, largely owing to the efficient seed dispersal of certain species, e.g. Hieronyma caribaea, by birds and bats. At the same time it was determined that a high shade shelterwood was necessary if the dual objects of protecting the soil and permitting the new crop to develop were to be achieved.

As described by Brooks (1941) about this time, the main stages of T.S.S. were:-

1. Cut all vines.

2. Complete shelterwood formation within a year of initial vine cutting. Ideally the shelterwood should consist of evenly spaced upper storey trees giving a light, even canopy. However earlier exploitation and interference usually precluded such a shelterwood, and to avoid the occurrence of large gaps, light-crowned trees from the lower storeys were retained where the upper storey was lacking. Upper storey trees themselves were only removed in places where, once the lower storeys were removed, the canopy was still too dense, or where the upper storey trees were heavy-crowned and likely to cast too dense a shade: in such cases the larger trees were felled first so that any damage could be subsequently rectified by retaining some of the lower canopy trees. The marking of the shelterwood trees was done in stages to avoid errors from removing too much of the canopy. Virtually all produce from the operation was sold as timber, poles or fuelwood (charcoal).

3. Once felling and the formation of the shelterwood was complete no further trees were felled.

4. All palms were felled.

5. Subsequent tending was required to remove fast-growing weed trees which were interfering with desirable regeneration, but where these caused no interference they were retained to protect the soil.

6. Ultimately the shelterwood was removed by poisoning.

The results were considered highly satisfactory, though regeneration was lacking on the clay soils. Beard (1944b) believed the absence of regeneration on the clays was due to seed rotting on the heavily waterlogged upper clays during the wet season and to the subsequent drying out of the clays in the dry season. Where regeneration was absent, planting was carried out.

During and after the 1939-45 war the system became more standardized. Ayliffe gives the following time-table for operations:

Year 1 Climber cutting.

Year 1½ Allocation of areas to charcoal burners. Brushing of undergrowth. Branding of trees for felling. Formation of shelterwood.

Year 3 Complete shelterwood formation by start of wet season (May). Tending or cleaning towards end of year.

Year 4 Tending and climber cutting. Thinning desirable regeneration to 8 ft spacing. Second tending sometimes given.

Year 5 Tending and climber cutting.

Year 6 Start removal of shelterwood by poisoning any under-storey trees which had been retained. Tending.

Year 7 Climber cutting if necessary.

Year 8 Further poisoning of shelterwood. Tending, thinning and climber cutting.

Year 9, and subsequently.
Poison about every other year; climber cutting as necessary (Usually every year); occasional tending; thinning every 4-5 years.

Ayliffe notes that the success and cheapness of the system depended largely on the charcoal burners, who were each allocated one acre at a time, and who used all wood (even partly rotted trees on the ground) not sold for timber. However to take full advantage of the charcoal burners a good road system was needed, as the charcoal could not be carried more than about half a mile. The actual operations were similar to those described by Brooks. Shelterwood formation was carried out by the charcoal burners under the supervision of forestry department field staff, and the marking of trees to be removed was done in stages to allow for any felling damage. Three main stages in forming the shelterwood were recognized:

1. Removal of big, hollow trees and trees with dense crowns: both cause much damage in falling.
2. Sale of any timber trees, leaving an open canopy of upper storey trees and a denser canopy of understorey trees.
3. Removal of all low shade unless needed to form shelterwood in gaps, and the thinning of the upper canopy to the required density.

Although the shelterwood was preferably composed of small, desirable trees, these rarely escaped felling damage, and in practice only about half the stems retained were classed as desirables.

Regeneration was spectacular on the sandy soils, frequently with about 2,000 seedlings per acre becoming established after shelterwood formation. These were mostly fast-growing, light-demanding species with seeds distributed by wind, birds and bats. *Tabebuia serratifolia*, *Nectandra surinamensis*, *Terminalia amazonica*, *Hieronyma caribaea*, *Didymopanax morototoni* (favoured for matches), and *Byrsonima spicata* were the most common species in the regeneration, and averaged about 6 ft a year in height growth.

Tending was regularly carried out to prevent climbers damaging the new crop and to remove interfering weed trees. The first tending, about 6 months after the charcoal burners had finished, was considered the most important. With the associated thinnings, the tending could strongly influence the composition of the new crop by favouring the more desirable species.

Shelterwood removal was carried out by poisoning with sodium arsenite, starting three years after the shelterwood formation was completed with the removal of any low shade trees, and aiming to finish the poisoning within a further three years, though some trees had to be poisoned several times before they died. Once the crowns of the poisoned trees had been lost, the dead stems could be felled for timber or charcoal.

Profile diagrams showing the main stages of T. S. S. under this technique are given by Ayliffe.

Trinidad T. S. S. in Practice

With the changing pattern of timber consumption in Trinidad, and with the additional knowledge gained from the application of T. S. S. over 20 years, the silvicultural technique has undergone certain changes. Originally a 60 year rotation was fixed for T. S. S., and the annual coupe on the Arena F.R. limited to 63 acres. However when the regeneration was found to be better than had been expected, it was decided to forget sustained yield for the moment and to treat as much of the forest as the charcoal burners wanted: one reason for this was to treat the previously worked over forest as quickly as possible, and another was to make full use of the charcoal burners while a demand for charcoal still existed. For these reasons the coupe was increased to 100 acres in 1944 and to 165 acres in 1950 (Moore, 1957).

As more species became acceptable on the local market it was found that many of the species being favoured in the regeneration coupes were fast-growing, secondary species which attained their maximum economic size of 5 ft G.B.H. at about 30 years and then started to deteriorate. To take full advantage of these it became essential to reduce the rotation of 60 years to a felling cycle of 30 years, at which time the secondary species could be removed, leaving the pole-sized crop of slower species to form a shelterwood for a second generation of secondary species which could be harvested, with the slower-growing species, in another 30 years. With this development, ideas on the nature of the shelterwood changed. On the one hand there was little relationship between the trees left in the shelterwood and those forming the regeneration beneath, so that it was no longer regarded as essential to have the shelterwood composedof large upper storey trees producing seed. On the other hand, a shelterwood of smaller poles was now definitely preferred, since these could be retained as sound trees during the felling cycle of 30 years, yielding valuable timber when finally felled, and eliminating or reducing the need to poison the shelterwood at the end of the regeneration period. Tending was reduced in favour of a more restricted freeing operation*, and planting was

* A feat accompanied by some difficulty of an administrative nature, the field staff having to be convinced that less tending was not deleterious, and the trade unions that a doubling of the daily "task" did not mean increasing the amount of work (Moore, 1957).

reintroduced with the aim of inoculating the area with potential seed-bearers of species not native to the reserve: Simaruba amara, Chlorophora excelsa, Nauclea diderrichii, Terminalia superba and T. ivorensis are among the species used. Thus the timetable now used becomes:

Year 1 Climber cutting.

Year 2½ Exploit mature timber.

Year 3 Formation of shelterwood by charcoal burners or departmental labour. Planting of seedlings.

Year 4 Tending and cutlassing low to ground. Non-economic woody growth retained unless interfering with valuable regeneration.

Year 5 As for year 4, but no low cutlessing.

Year 6 Climber cutting. Reduction of woody weeds.

Year 7 As for year 6. Shelterwood trees not required in new crop poisoned.

Year 8 Thin out regeneration.

In forming the shelterwood the aim is now to leave 18 to 20 pole crop trees of economic species, per acre; where such trees are not available larger stems are left to give about the same degree of cover. When, as is now more commonly the case, the work has to be done without the aid of charcoal burners, the forest department staff carry ou out the brushing of the undergrowth and poison the stems not required for timber or as part of the shelterwood. Yields of produce obtained from typical annual coupes have been:

1950 coupe: 128 cubic ft of timber per acre (valued at B.W.I. $10.00 per acre).

13 cords (1 cord = 128 cubic ft stacked) of fuelwood per acre ($7.80 per acre).

1955 coupe: 150 cubic ft of timber per acre ($13.30 per acre) 16.5 cords of fuelwood per acre ($9.80 per acre).

After regeneration the coupes are essentially even-aged, the new crop having developed from seed as a result of the T.S.S. treatment. However, where it is possible to form the shelterwood of pole size trees these are retained as part of the new crop; other trees in the shelterwood are poisoned three years after the shelterwood has been formed. The new crop thus consists of fast-growing regeneration and the remaining shelterwood trees, both of which will be harvested in 30 years, and of slower-growing regeneration which will be harvested in 60 years.

The stocking attained following T.S.S. is indicated in Table 39, which shows the number of stems per acre present in the various treatments of a thinning experiment established in a stand in which shelterwood formation had been completed 14 years earlier. The five treatments applied at that time were:

A. Leaving 100 largest and most desirable stems per acre.

B. Leaving 60 largest and most desirable stems per acre.

C. Leaving 150 largest and most desirable stems per acre.

TABLE 39

Species Stocking and Growth After Thinning at Age 14 Years - Arena F.R.

(Growth figures refer to mean B.A. increase per tree, over 3 years after thinning.)

Group	Species	Stumpage Class	Stems per Acre — Treatments: A	B	C	D	E
Light-demanding	Byrsonima spicata	II	29	22	59	26	96
	Terminalia amazonica	II	19	6	11	7	42
	Hieromyma caribaea	II	4	3	10	7	28
	Nectandra surinamensis	II	9	8	16	21	23
	Didymopanax morototoni	III	27	16	32	22	42
	All light-demanding		88	55	128	83	231
	Mean growth, light-demanding (square ft)		0.104	0.148	0.087	0.106	0.047
Shade-tolerant	Carapa guianensis	II	2	1	0	6	4
	Manilkara bidentata	I	1	2	1	2	3
	Tabebuia serratifolia	I	5	0	16	63	64
	Eschweilera subglandulosa	II	1	0	3	7	12
	All shade-tolerant		9	3	20	78	83
	Mean growth, shade-tolerant (square ft)		0.101	0.160	0.060	0.030	0.020
TOTAL stocking			97	58	148	161	314
MEAN growth, all species (square feet)			0.104	0.149	0.084	0.070	0.040

D. As for A, but also leaving all shade tolerant species of any girth.

E. Unthinned control.

Nine economic species were present, the first 5 in the table being regarded as light-demanding and the last 4 as shade-tolerant: the latter tend to have the greater economic value and are the species expected to grow for 60 years. Treatment E can be regarded as representative of the species distribution after establishment and early tending, and C or D as representative of the stand after current first thinning.

The predominance of the faster-growing, light-demanding species in the regenerated stand is clearly shown by this data, the numerical superiority being maintained under all thinning regimes except D, where the shade-tolerant species were deliberately left. One interesting feature of the interim results of this experiment is that, while the B.A. increment per tree is closely correlated with stocking for the two tolerance groups (see Fig. 45), both groups appear to show much greater competition among their own species than among species of the other group. Thus the light-demanding species in treatments A and D show almost identical increments on a similar number of stems per acre within the group, even though the stems in treatment D are also in competition with 78 shade-tolerant stems per acre compared with only 9 such stems in treatment A. Similarly, the slower growth of shade tolerant species in treatment D, compared with treatment C, is much more marked than would be expected from the 9% increase in total stocking, but is what would be expected from the 290% increase in stocking of shade-tolerant trees: the very slow-growing <u>Tabebuia</u> is equally represented among the shade tolerant species in both C and D, so that the increments are not confounded by different proportions of

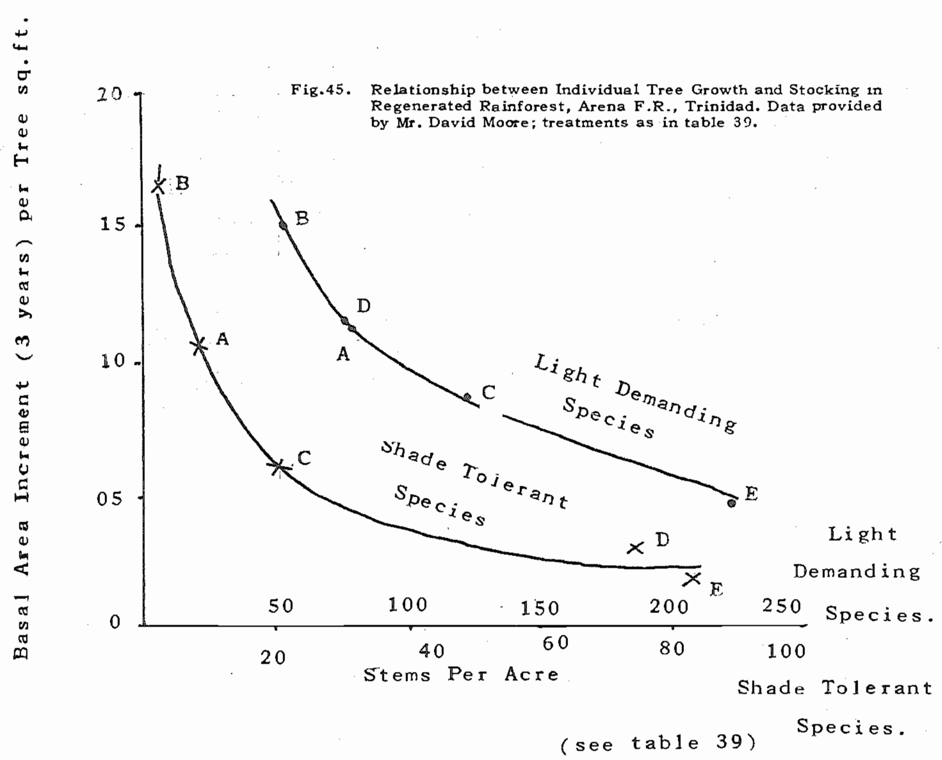

Fig.45. Relationship between Individual Tree Growth and Stocking in Regenerated Rainforest, Arena F.R., Trinidad. Data provided by Mr. David Moore; treatments as in table 39.

trees with different growth rates. If this trend is confirmed, it will add strong support to the feasibility of growing mixed crops of trees of differing silvicultural characteristics without causing too great a loss of increment within the different sections of the crop, and will also greatly ease the practice of thinning in such mixtures.

The experiment described is designed to throw light upon the type of thinning needed in the regenerated stands. It is expected (Moore, 1957) that thinning operations will take place at 15 and 25 years, Didymopanax being harvested at the second thinning when it should provide stems of about 17 inches D.B.H. desired by the matchwood market. The remaining crop will then have a further 5 years to develop before the end of the first felling cycle. Potential yields are not known, though Ayliffe (1952) records a sample plot with a volume mean annual increment of 60 cubic ft Hoppus (76 cubic ft true) per acre at age 14 years, and this had increased 70 cubic ft Hoppus (89 cubic ft true) 5 years later (Moore, 1957).

Regeneration is still difficult to obtain on the clay soils, economic species being very poorly represented and consisting largely of Pentaclethra macroloba (Class IV), which is used mainly for firewood. Any extensive areas of these acid clays are now being reserved for Pinus caribaea which, unlike Tectona grandis, appears promising on such soils.

T.S.S. has been applied to other forests than Arena F.R., and some 14,000 acres in all are earmarked for this treatment. The results have generally been similar to those obtained at Arena on sandy soils, though in areas of secondary forest, where a low shade shelter-wood has had to be used, the new crop tends to be shorter boled owing to to its soon over-topping the shade layer and branching out: Ayliffe records Didymopanax as forming a 50 ft bole at Arena, but only 30 ft in secondary forest at Longdenville.

The Trinidad method of T.S.S. appears to represent one of the most successful silvicultural treatments being applied to rainforest at the present time. As Moore (1957) states, "the modifications made in the technique have resulted in the T.S.S. becoming an economical method of silviculture, but it is doubtful if this would have been possible if market conditions had not so altered to favour the species which in 1940 were of little economic value". Because of its small size and high population, the "market conditions" necessary for success were encountered in Trinidad earlier than in most rainforest countries, but it appears to be only a matter of time before similar conditions reach many other countries.

PUERTO RICO.

The Environment

Puerto Rico is the easternmost island of the Greater Antilles, lying to the northeast of the Caribbean Sea between lat. 18° and 18°30'N and long. 65° 30' and 67° 15'W. It is roughly rectangular in shape, having as its greatest dimension a length of 113 miles and a width of 46 miles, with an area of 3,430 sq miles and a population of about 2.3 million. A Spanish colony from the early 16th century, the island was acquired by the United States of America in 1898 and, while still remaining a U.S. possession, now has considerable local autonomy with the status of a "commonwealth"*.

The island is composed mainly of Cretaceous volcanic material (andesite, tuff etc.), but with extensive Tertiary deposits of limestone along the north and, to a lesser extent, south coasts. A range of mountains, the Cordillera Central, extends along the length of the island from east to west, with altitudes exceeding 4,000 ft. The Cordillera lies somewhat closer to the south side of the island than to the north. A separate mountainous area, the Luquillo Mountains, occurs in the northeast of the island with peaks up to 3,500 ft. The limestone has produced low but very rugged hills along the north coast.

Rain-bearing winds are from the northeast, and on parts of the rain-shadowed south coast the annual rainfall drops below 40 inches and there is a protracted dry season each year. Most of the area north of the Cordillera has a rainfall of over 60 inches, rising to above 100 inches in parts of the Cordillera and Luquillo Mountains: La Mina, at an altitude of 2,350 ft in the central Luquillo Mountains, has a mean annual rainfall of 183 inches. Severe tropical cyclones (hurricanes) pass across the island on an average of once every 10 years (48 recorded in 450 years; Wadsworth, 1957).

In pre-Columbian times Puerto Rico was entirely forested or wooded, with little disturbance from the native Amerindians. Much of the northern coastal plains probably originally carried evergreen seasonal rainforest, which was replaced by submontane rainforest and montane rainforest as the mountains were ascended. Elsewhere the vegetation was mostly from the seasonal formation series of Beard (1955), passing from semi-evergreen seasonal forest (rainforest) in the somewhat drier areas and in the excessively drained limestone hills, to thorn woodland on the south coast (Gleason and Cook, 1926; Wadsworth, 1950). To-day, however, only about 5% of the island is forested, most of the destruction having occurred in the 19th century to make way for the coffee and sugar plantations, which remain the mainstay of the island's economy despite rapid industrial development in recent years. The most extensive remaining area of forest is in the Luquillo Mountains, where some 30,000 acres have been reserved as the Caribbean National Forest (Luquillo Experimental Forest). This is under the control of the U.S. Forest Service which manages it from the Institute of Tropical Forestry in Rio Piedras, some 20 to 30 miles distant. In addition to the Caribbean N.F. there are about 60,000 acres of forest in other parts of the island reserved as State Forest by the Commonwealth authorities.

The island's timber supply position is unusual in that at present hardly any local timber is used, other than as poles and, to a very slight extent, firewood. This appears due to the small area of forest on the island, and its relatively low volume per acre, having mitigated in the recent past against the establishment of a permanent sawmilling industry based on the local species, and equally to the island's U.S. - supported dollar economy finding it cheaper to import timber from the U.S.A. and elsewhere in tropical America than to produce it from the indigenous forests.

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*In Spanish, Estado Libre Associado; literally Associated Free State.

The Luquillo Mountains

The Luquillo Mountains occupy an area of about 50,000 acres, of which some 60% is under the control of the U.S. Forest Service. Only some 5,600 acres of this are regarded as virgin forest, most of the area having been logged over in the past and some sections being second growth forest following earlier clearing for agriculture. During the period 1932-51, 10.8 million cu ft of timber were obtained from the forest, 83% of this being for fuel and only 11% for saw timber. The forest carries about half the total saw timber remaining in Puerto Rico, provides excellent recreational facilities for the large nearby population centres, and from its streams produces water supplies for 50,000 people as well as 10% of the island's hydro-electric power. In addition to natural forest there are some 700 acres of plantation in the National Forest, mostly of indigenous species but also including Swietenia macrophylla, which is not native to the island, and Calophyllum antillanum, a species native to the lowland forests near the coast.

The mountains are composed of the Cretaceous volcanics and are of very broken relief; of the total area 25% lies between 400 and 1,000 ft altitude, 47% between 1,000 and 2,000 ft, 25% between 2,000 and 3,000 ft, and 3% above 3,000 ft. Mean annual temperature decreases by 1F° for every 250 ft rise in elevation from the mean temperature of 78°F experienced at the base of the mountains. Rainfall varies from about 70 inches per annum to over 180 inches, being lowest on the western side of the area and tending to increase with altitude. Cloud and fog are frequent in the higher parts.

Wadsworth (1951) recognizes four main types of forest vegetation in the mountains. Submontane rainforest occurs on the foothills and slopes below 2,000 ft on deep and moderately well-drained soils, and occupies about 70% of the area. Above 2,000 ft montane rainforest dominated by Cyrilla racemiflora occurs on the deep but usually poorly-drained soils (Wadsworth and Bonnet, 1951) on the valleys and gradual slopes, occupying 17% of the area. 11% of the area carries a palm brake dominated by Euterpe globosa: this is found on steep slopes and gullies with shallow, unstable soil above 1,500 ft. The remaining 2% occurs on the isolated peaks and ridges above 2,500 ft where conditions of extreme exposure have produced montane thicket (elfin woodland).

From the point of view of production forestry only the submontane rainforest is of importance; some timber could be produced from montane rainforest, but this is likely to remain of much greater importance for protection and recreation functions. The submontane rainforest is regarded as belonging to the Dacryodes excelsa association, sometimes known as the Dacryodes-Sloanea association, which occurs also in the islands of the Lesser Antilles, stretching south from Puerto Rico towards Trinidad (Beard, 1949). Wadsworth (1957) has observed that this may in fact be "two inseparable associations", one occurring on the upper slopes and ridges with Dacryodes, Tetragastris balsamifera and Buchenavia capitata common, the other in the lower slopes and valleys where most of the trees of Sloanea berteriana, Guarea trichilioides and Manilkara nitida grow. In all some 170 species of trees have been recorded from the Dacryodes association in Puerto Rico, and of these 25 species are regarded as economics for saw timber or pole production. The profile diagram (Fig. 20) was obtained from the ridge top facies and shows the characteristic physiognomy of this type. Dacryodes is by far the most common large tree in the type, comprising up to 35% of the basal area, and on small areas considerably more. The B.A. of virgin stands is normally about 180-200 sq ft per acre, but because of past exploitation the B.A. of most of the type now ranges between 70 and 140 sq ft per acre. Over large areas all the larger and more valuable trees have been removed. The palm Euterpe globosa forms dense glades in areas of impeded drainage, and at lower altitudes, along certain ridges and upper slopes, old clearings of up to half an acre in area have been covered with a very dense growth of a scrambling fern (Gleichenia sp.).

Development of Silviculture

The treatment of the natural, but cut-over, forests of the Luquillo Mountains started in 1943 following the success being obtained by such work in Trinidad (Wadsworth, 1947b). At that time market conditions for timber sales were good, enabling Wadsworth to liken the island to the environs of a large city where all accessible trees, regardless of size and species, were of sufficient value to warrant cutting and extraction. Under these conditions intensive management could be justified and early cutting operations could be directed towards the elimination of the inferior species in the stand.

In determining the form silvicultural treatment should take there were several factors which had to be taken into consideration:-

1. More than any other forest on Puerto Rico, the Luquillo Mountains were marked by the presence of cabinet and construction timbers. These were the groups in which disparity between local demand and supply was greatest, and for which the future demand was most certain. For these reasons it was considered that the aim of treatment should be directed towards the production of such saw and veneer timbers, even though at the time only 5% of the standing volume was suitable for this type of product.

2. Because of this low percentage of desirable volume it was essential that initial efforts should concentrate at improving the composition of the growing stock.

3. The importance of the mountains as a catchment area necessitated care being taken to protect the watershed, particularly by the avoidance of clear cutting.

4. Regeneration of the better species appeared to occur under continuous shade.

The last point suggested that either a shelterwood or selection system of obtaining regeneration should be used, and for a number of reasons the selection system was favoured. These included: 1. the better soil protection afforded; 2. the danger of greater cyclone damage to a shelterwood than to an all-aged stand, which would tend to be more windfirm; this fear was substantiated by the effects of the 1956 "Hurrican Betsy" (Wadsworth and Englerth, 1959); 3. the more uniform growth obtained and desirable for prime quality logs; 4. the co-ordinating of all cultural work with harvesting in a single operation; 5. the desirability, until proved otherwise, of retaining the general physiognomy of the virgin forests (Wadsworth, 1947b; 1952b). However one reason advanced against the use of a shelterwood, that it requires the cutting of all young trees without the knowledge of their replacement by better species, is in retrospect hardly valid: as has been shown, in the shelterwood system of Nigeria and in the clearcutting system of Malaya, such advance growth is relied upon to form the bulk of the new crop and is certainly not deliberately destroyed.

The method to be used in treating the forest should therefore be primarily a stand improvement operation, aimed at bringing the forest into a condition suitable for its ultimate management for sustained yield under a true selection system. This is achieved by harvesting over-mature trees before they are lost; thinning dense groups of poles; releasing smaller stems from suppression; avoiding the creation of large canopy gaps, in order to preclude soil deterioration and the invasion of herbaceous weeds or vines; leaving sufficient space around all trees of the upper canopy to enable light to reach the subordinate storeys; balancing the basal area representation so that all diameter classes are equally represented; maintaining a mixture of species for protection against epidemics and to provide flexibility to meet changing demands; eliminating tree species of no present or foreseeable economic value; and increasing the representation of the better sawtimber species.

In practice it is necessary to translate this policy into simple, clear, marking rules for the untrained field staff to understand and apply. The marking instructions for the Luquillo Mountains are as follows:

1. The forest should be cut to retain its future productivity at the highest level, with sufficient timber for a subsequent economic and selective cut after 5 years.
   - (a) Only cut where tree crowns are in contact.
   - (b) Remove only sufficient trees to provide adequate growing space for the remaining better trees. Adequate growing space means that the crowns of the larger trees should receive direct light from above and an average of 6 ft crown freedom on all sides.
   - (c) Openings in the canopy shall not exceed 25 ft in diameter except where the removal of a single tree creates a larger opening. No trees adjacent to such an opening shall be cut.

2. The reduction in stand density shall be accomplished by the elimination of the least productive trees in the order given:
   - (a) Dead, dying or seriously diseased or insect attacked.
   - (b) Inferior species, the largest trees first.
   - (c) Pole species of 10 inches D.B.H. or over.
   - (d) Second class sawtimber species of 16 inches D.B.H. or over.
   - (e) First class sawtimber species of 21 inches D.B.H. or over.
   - (f) Pole or sawtimber species without a sound, straight butt of at least $8\frac{1}{2}$ feet.
   - (g) Pole or sawtimber species with poor vigour or seriously broken crowns.
   - (h) Excess remaining trees, taking the smallest and poorest first in order from (i) pole species, (ii) second class sawtimber species, (iii) first class sawtimber species.

These rules have undergone only minor alterations since they were first introduced nearly 20 years ago, the main changes being a more clear statement of the type of trees to be removed and an increase in the permissible gap size from 20 to the present 25 ft diameter.

The Improvement Cutting/Selection System in Practice

Unfortunately for Puerto Rican silviculture, the post-war years saw the virtual disappearance of the local timber industry. The saw-milling industry, never very strong, found it difficult to cope in the face of cheap timber imports, while widespread electrification and the Caribbean-wide change to oil fuels (c.f. Trinidad) led to a sudden decrease in fuelwood demand. For this reason the silvicultural treatment could only rarely be applied in the form originally envisaged, i.e. as a harvest cutting-cum-improvement operation. However, since the Caribbean National Forest is also the Luquillo Experimental Forest, it was decided to proceed with treatment on a pilot scale over 6,700 acres, which were grouped into 6 working circles. The objects of this scheme were to obtain an economic basis for rainforest management, and also to provide demonstration areas which would enable private forest owners to follow suit and allow the re-establishment of a timber industry.

Initially it was proposed to work on a felling cycle of 5 years, 20% of each working circle being treated each year, but in future revisions of the pilot management plan it is expected to divide the area into accessible and relatively inaccessible sections, the former continuing to be worked on a 5 year cycle and the latter on a 10 year cycle. While all efforts were made to sell the produce of the treated forests, where this was not possible the marked stems were poison-girdled. The more accessible compartments in each working circle were left for treatment to towards the end of the first felling cycle, in the hope that better facilities for utilization might develop in the meantime: a hope that does not appear to have been realized.

As indicated in the treatment rules, the desirable species have been grouped into 3 classes, first and second class sawtimber species and pole species. These are shown in table 40. Two non-indigenous species are included in the first group: these are Swietenia and Calophyllum, which are now producing natural regeneration within parts of the forest from seed trees planted in other parts of the Luquillo Mountains. Of the native species, Dacryodes, Guarea and Ocotea moschata are the most highly prized.

The initial felling cycles are concerned more with stand improvement than with sustained yield; obviously it will be rare that a single treatment will be able to bring the stand to the desired state. The treatment applied varies considerably from acre to acre. Fig. 46 shows the results to be expected after treating the virgin stand illustrated in Fig. 20. Because of the heavy stocking in this previously unlogged stand the treatment appears more drastic than is the case in cut-over stands, but it must be appreciated that the soil is still well protected by the young trees and shrubs not shown on the profile diagram.

TABLE 40

Grouping of desirable species - Luquillo Mountains.

First Class Sawtimber Species	Second Class Sawtimber Species	Pole Species
Buchenavia capitata	Beilschmiedia pendula	Alchornea latifolia
*Calophyllum antillanum	Cecropia peltata	Byrsonima spicata
Cordia alliodora	Didymopanax morototoni	Linociera domingensis
Dacryodes excelsa	Inga Laurina	Matayba domingensis
Guarea trichilioides	Ormosia krugii	Meliosma herberti
Homalium racemosum	Sloanea berteriana	Nectandra coriacea
Manilkara nitida		N. sintenisii
Ocotea moschata		Ocotea Leucoxylon
Petitia domingensis		Zanthoxylum martinicensis
*Swietenia macrophylla		
Tabebuia pallida		
Tetragastris balsamifera		

Note: *Non-indigenous species.

Fig.46. Current Puerto Rican Treatment of Rainforest. Profile Diagram based on fig. 20. Transect after first felling cycle.

The B.A. remaining after treatment bears a close relationship to the initial stand B.A. Figures have been calculated to show this relationship (Tropical Forest Experiment Station, 1950), though it appears that in recently treated areas the reduction in B.A. has been more severe: table 41 compares the 1950 values with average values for two compartments treated in 1958, and it will be observed that the more heavily stocked areas in particular have been drastically reduced in B.A.

The ideal stand being aimed for in the treated forests is indicated in table 42. In this stand, which will only be approached after a number of felling cycles, the aim is to maintain a mixture of species and a balanced representation of the diameter classes. The B.A. of such a stand will be about 80 sq ft per acre, the level believed to give the best balance between the growth on individual stems and the total volume production per acre.

Because the treatment at this early stage places emphasis on improving the composition and structure of the stand, there has been relatively little study made on the obtaining of regeneration. However as the improvement operations are designed at bringing the forest to the stage where a true selection silvicultural treatment can be applied, it is obviously essential that adequate quantities of desirable regeneration be regularly obtained and be capable of making satisfactory growth. The writer carried out a survey of regeneration in two compartments, that had received treatment about $2\frac{1}{2}$ years earlier, in order to determine its distribution and composition. The compartments

TABLE 41

Basal Area per acre before and after Treatment, Luquillo Mountains.

Initial Basal Area	Residual Basal Area	
	1950 Values	1958 Values
40 sq ft per acre	33 sq ft per acre	21 sq ft per acre
60	46	30
80	60	38
100	72	44
120	84	48
160	102	56
200	116	63
240	138	69

TABLE 42

Ideal Stand to obtain following Treatment, Luquillo Mountains.

Diameter Class	Number of stems per acre			
	1st Class Saw. Spp.	2nd Class Saw. Spp.	Pole Spp.	Total
4.0 - 6.9 in	45	30	14	89
7.0 - 9.9	26	10	5	41
10.0 - 15.9	24	5	-	29
16.0 - 21.0	17	-	-	17
Total	112	45	19	176

had both been logged over previously and were in rather distant parts of the forest from each other. Only economic species (table 40) that appeared capable of ultimately producing merchantable stems were assessed, the stems being sampled in 3 size classes on plots of varying size; 0-1ft high on 1/1000 ac. plots, 1-5ft high on 1/125th ac. plots, and 5 ft high to 1 in D.B.H. on 1/40th ac. plots. The regeneration occurring on the two compartments is summarized in table 43.

Taken over the whole two compartments, regeneration of the economic species was generally plentiful and well distributed, though the first class sawtimber species were poorly represented in the two larger size classes assessed. Regeneration was much better on the ridges and upper slopes than in the gullies, where Sloanea berteriana formed a high proportion of what regeneration was present. Most of the species were most plentiful near parent trees, though some of the species with bird and bat distributed seeds were widespread throughout the area: such species include the valuable Dacryodes and Guarea. The conditions produced by stand treatment varied greatly, so that species of widely different tolerance levels, from the strongly light-demanding Tabebuia, Cecropia and Didymopanax to the very shade-tolerant Manilkara, Sloanea and various Lauraceae (Ocotea and Nectandra spp.) were able to find niches where they could regenerate and develop. However as the stands approach more towards a true selection forest it must be expected that the more tolerant and persistent species will be favoured over the light demanders. Regeneration was usually lacking in areas of palm glade and in the Gleichenia-covered clearings. It was concluded from the study that in most sites the current silvicultural treatment will produce adequate amounts of economic regeneration, but that special attention should be paid to liberating well established saplings of first class sawtimber species in future felling cycles, and that consideration might also be given to the enrichment planting of areas that are deficient in the more valuable species, particularly the heavy-seeded species of limited dispersal capacity such as Manilkara and Buchenavia. Enrichment planting has in fact always been regarded a means of establishing regeneration in difficult sites in the Luquillo Mountains (Wadsworth, 1952b, 1957) and has been employed over an area of some 500 acres, with Swietenia macrophylla the main species used. However much of this planting has been in second growth areas dominated by weeds, rather than in more typical rainforest stands after routine treatment.

The total volume (including small poles and branchwood) of virgin submontane rainforest in the Luquillo Mounains ranges from 3,000 to 6,000 cu ft per acre, about 30% of this being in sawtimber. In treated stands with fairly well balanced size class representation the volume has been reduced to about 2,000 cu ft per acre: such stands have shown a periodic annual increment of some 120 cu ft per acre, about half of which is in potential sawtimber (Wadsworth, 1957).

The Future of the Improvement Cutting/Selection System

In the long run silviculture cannot flourish without a market for the products of the forest. At the present time the "markets" in the Luquillo Mountains are for water and recreation, not for the timber that is being produced by the current silvicultural techniques, and the management of the water supply and recreation facilities has already been assured (Wadsworth, 1952a). Thus at the moment silvicultural work is an act of faith for the future, which is envisaged as needing

TABLE 43

Regeneration in Treated Forest, Luquillo Mountains.

Species	0-1ft. high		1-5ft high		5 ft high - 1 in D. B. H.		All Sizes
	Stems/ac.	% Plots stocked (1/1,000 ac.)	Stems/ac.	% Plots stocked (1/125 ac.)	Stems/ac.	% Plots stocked (1/40 ac.)	Stems/ac.
All economic species	3,300	76	520	81	190	91	4,010
1st Class Saw. Spp.	1,030	49	53	30	32	46	1,125

the cabinet timbers of the rainforest and as being able to afford the price that an intensive, true selection system must charge. In the meantime silvicultural treatment is being confined to the pilot areas as a research undertaking.

The treatment appears to be producing the results expected of it. In the first felling cycle considerable improvement in the composition of the stands is brought about, with the stands in the condition where growth is being largely limited to the more valuable species. At least in this initial, usually rather heavy cut, regeneration of a wide range of economic species is being obtained in most sites, though it is not unlikely that in subsequent, lighter fellings there will tend to be a greater representation of the more shade tolerant species: as these include some of the more valuable species in the area, the greater prevalence of such species should not matter in a selection forest, so long as the volume increment is not appreciably lowered as a result. Certainly the tentative sawtimber increment of about 60 cu ft per acre per annum gives little cause for alarm.

The originally suggested felling cycle of 5 years is now expected to be increased to 10 years in the less accessible areas. This is the inevitable result of the high cost of frequent, light harvesting operations compared with less frequent, heavier ones. It by no means upsets the general intention of a selection system, though it will probably mean a somewhat reduced yield on an annual basis since over thelonger period the stand density will have to range further from the optimum. It is likely also to result in a higher proportion of light demanding species regenerating after the heavier fellings. It is considered not impossible that, even if a reliable market for timber does develop, economic considerations may force the use of the longer felling cycle throughout the forest in due course.

A selection system is one of the most difficult forms of silviculture to apply properly. In developing such a system for Puerto Rico the forest authorities have had to take into consideration the need to protect the highly valuable watersheds and to guard as far as possible against the periodic cyclones. Because of these environmental conditions, a selection system was the obvious choice, and there is every indication of this system being applied most successfully in the Luquillo Mountains.

NORTH QUEENSLAND

Tne Environment

The State of Queensland occupies the northeastern fifth of the Commonwealth of Australia, lying between long. 138° and 153°E and lat. 10°30' and 28°S. It has an area of 670,000 sq miles and a population of about 1.5 million. Much of this area lies in the arid and semi-arid climatic zones, and it is only along the eastern fring of the State that conditions suitable for the development of rainforest are found. Even within this narrow eastern fringe the distribution of rainforest is discontinuous, its being found in scattered areas of varying size from the tip of Cape York in the extreme north to the New South Wales border in the south. The areas of rainforest mostly lie along the Great Divide that separates the westward flowing rivers from the short, fast flowing streams of the east, and to a lesser extent along the intervening coastal strip to the east of the Divide. The rainforest patches are separated from each other by extensive areas of sclerophyll forest and woodland, characteristically dominated by Eucalyptus spp.

South of the Tropic of Capricorn the rainforest can be regarded as belonging to the subtropical subformation, with small areas of both warm and cool temperature rainforest also occurring towards the extreme south (Webb, 1959; Herbert, 1951). The valuable conifers Araucaria cunninghamii, A. bidwillii and Agathis robusta are common constituents in various parts of these southern rainforests, and the policy of the Queensland Forestry Department has been to aim at the conversion of these rainforests to plantations of the conifers, particularly A. cunninghamii. North of the Tropic the rainforests become increasingly tropical in character, with evergreen seasonal rainforest at the lower altitudes and submontane rainforest at higher altitudes on the Divide. There are also small areas of semi-evergeen rainforest and of even drier vegetation types, still composed primarily of the Indo-Malaysian floristic element, in parts of the north, particularly north of 16°S: by Australian custom, even essentially deciduous types of such composition are still locally called "rainforest"

There were originally some 4,200 sq miles of rainforest present in this northern zone of Queensland, the largest part lying in a belt about 200 miles long and from 5 to 40 miles wide between lat. 15°13' and 18°30'S. About half of this area has been opened for settlement and now carries sugar cane farms on the coastal plain and maize growing and dairy farms on the tablelands of the Great Divide. However, about 2,300 sq miles of rainforest remain, of which some 300 sq miles have been permanently dedicated to forestry use and another 1,400 sq miles are under temporary forest reservation. The remainder is at present unclassified crown land. Of the total forest area about half is considered suitable for sustained yield timber production, the other half being either too steep or too inaccessible for timber production under current conditions (Haley, 1957).

The main area of productive forests is in the vicinity of the Atherton Tableland, south and west of Cairns (lat. 17°S), and it is in this region that most of the silvicultural treatment of the northern rainforests has occurred. The topography and geology of this area are rather varied. South of Cairns is a low corridor, now devoted almost entirely to cane growing, and separated from the coast by a granitic ridge running north-south and averaging about 1,000 ft in elevation but reaching an altitude of nearly 3,000 ft towards its northern end. This is paralleled by another much dissected granitic ridge to the west of the corridor. Many peaks along this ridge exceed 4,000 ft, the tallest being Mt Bartle Frere, at 5,287 ft. Queensland's highest mountain and the home of the only indigenous Rhododendron sp. in Australia. Lying between this ridge and the crest of the Great Divide, which rises to about 3,500 ft in the region, is the gently undulating Atherton Tableland, a basaltic plateau with an average altitude of about 2,500 ft. Beyond the Divide the land slopes gently towards the Gulf of Carpentaria in the west, and to the northwest of Cairns the altitudes are also generally lower. In addition to the granite and the basalt, there are extensive areas of metamorphosed shales which predate both series of igneous rocks and which outcrop through much of the highlands.

Temperatures along the coast are of the order normally expected in the lowland tropics, and there is a drop of about 1°F for every 300 ft in elevation. Thus Cairns, at sea level, has a mean annual temperature of 76°F while Atherton, at 2,470 ft elevation, has a mean temperature of 68°F. Occasional light winter frosts are experienced on the tablelands and adjacent higher country. Due to the marked topographic changes, rainfall varies greatly in the area, being generally high along the coast and ranges, but falling off rapidly to the west. Typical lowland values for mean annual rainfall are Cairns, 86 inches; Innisfail, 139 inches; and Babinda, 160 inches, while Atherton, in a rainshadow caused by the Bartle Frere ridge, has only 54 inches. The rainfall distribution is strongly seasonal, more than half the annual average falling in three summer months and even Cairns having 6 months (June to November) each with less than 4 inches of rain. Prevailing winds are from the southeast and are experienced along all the east-facing ridges, while tropical cyclones occur fairly frequently.

Vegetation

Rainforest is generally confined to the areas with more than 60 inches of rain, drier areas supporting a Eucalyptus-dominated woodland. At the lower altitudes the rainforest is of the seasonal evergreen type, and the relatively small remnants remaining are characterized by extensive vine tangles which Webb (1958) believes to be the result of the frequent tropical cyclones: the widespread occurrence of this and other signs of cyclone disturbance (form damage, Acacia stands, periodic leaf stripping, destruction of large stems) has led Webb to query whether forest management on a long rotation is feasible in these lowland stands.

In the main commercial rainforest belt, above about 1,500 ft, the rainforest is of the submontane type verging towards montane rainforest on the higher peaks. About 350 species are known to exceed 4 inches D.B.H. and about half of these exceed 16 inches. Stand composition is typically complex: Haley (1957) records a one acre plot containing 480 identified stems over 20 ft high from 100 species, with a further 380 stems unidentified. In general soils derived from basalt tend to support rainforest more mixed in composition than do the granite and shale soils. Small gregarious stands are occasionally encountered, Blepharocarya involucrigera being the commonest such species and sometimes forming almost pure stands on areas up to 100 acres. The conifer Agathis palmerstoni also dominates the rainforest in gregarious stands in some areas. Among the commoner groups of larger trees are various Flindersia spp. and several members of the Proteaceae, including Cardwellia sublimis, Musgravea stenostachya and Embothrium wickhami.

The height of the rainforest canopy is frequently only about 100 ft, and on slopes exposed to the southeasterly trade winds the crowns tend to be wind-shorn. The best stands occur on the protected western slopes of the higher ranges, and in the more sheltered gullies, where the height rises appreciably. Agathis, where it occurs, acts as a true emergent with its crown above the general canopy level, and the same appears to apply for certain more scattered species such as Toona australis and Endiandra palmerstoni. Basal areas in virgin stands are extremely high, being in the order of 350 sq ft per acre.

Scattered through the rainforest are enclaves, sometimes several hundred acres in extent, carrying eucalypts and usually occurring towards the ridge tops. Eucalyptus grandis and E. pellita* are the usual species present, the former being more common above 2,000 ft and the latter below this altitude. Tindale (1959) believes that these enclaves may be related to hunting activities by the early aboriginal inhabitants, though it is possible that cyclones may also be responsible, as Webb (1958) considers to be the case with the lowland enclaves dominated by Acacia spp.

Forest Economy

The rainforests of the Atherton region provide most of the timber requirements (chiefly from the heavier and more durable species) for an area with a population of about 100,000. More importantly, they are the source of much of the cabinet timber used in Australia. Before the 1939-45 war the annual cut averaged 2.0-2.5 million cu ft Hoppus, 90% of which was provided by the prime cabinet species such as Flindersia brayleyana, F. pimenteliana, Endiandra palmerstoni, Cardwellia sublimis and Agathis. Since the war the annual cut has been about 4.5-5.0 million cu ft, and the actual mill quotas from crown land have been fixed at 5.4 million cu ft. Some 160 species are now milled, the prime cabinet species making up about 45% of the total yield: in absolute volume, about the same as was being cut pre-war. Of this total volume Cardwellia provides about 22% and Flindersia brayleyana and F. pimenteliana (marketed jointly as Queensland Maple) about another 11%. Although providing only 45% of the total yield from the crown forests, the prime cabinet species have in recent years produced from 65 to 70% of the revenue from timber sales in the area (Volck, 1960).

For royalty purposes the rainforest species are grouped into 4 classes, the first being made up of a number of the more valuable timber species which themselves have differing stumpage rates. As well as the royalty varying between classes, it also varies with the size and with the quality of the log, large logs and those suitable for peeled or sliced veneer fetching premium rates. The basic prices are fixed at certain "keymarkets" (in the case of most of these northern rainforests, at Cairns) and the royalty of the logs in the forest is determined by subtracting from the keymarket price the costs of extraction and haulage to Cairns, the necessary calculations being made for each compartment logged. The effect is to increase the relative value of species in the better royalty classes over those in lower classes. Table 44 indicates typical keymarket prices prevailing at Cairns in 1959, the value referring to a volume of 100 superficial feet+ Hoppus (approximately 10 cubic feet true measure). The species listed in classes II, III and IV are shown in the species list that makes up part of appendix 3. For a moderately accessible compartment,

* Eucalyptus pellita, a large tree in north Queensland, also occurs as a small, rather scrubby tree in dry sclerophyll forest in southern New South Wales. The two areas of occurrence are separated by a gap of about 1,000 miles and it would appear that the occurrences may have originated independently, but produced trees giving similar herbarium material though having quite different growth habits and environmental requirements.

+ A superficial foot (or super foot) is 1/12th cubic foot; i.e. equivalent to the U.S. board foot. In Hoppus measure a super foot becomes 1/12th cubic ft Hoppus.

TABLE 44

Keymarket Log Prices at Cairns, 1959.

(Prices per 100 super ft Hoppus; A£1(20/-) = sterling 16/-).

Class	Species	14'+	8'-9'	7'-8'	6'-7'	5'-6'	4'-5'	Under 4'
		Centre Girth (feet)						
I	Endiandra palmerstoni	97/9	52/9	42/9	38/9	38/9	38/9	38/9
	Flindersia brayleyana) F. pimenteliana)	72/10	66/10	65/10	64/4	58/10	56/4	51/4
	Agathis palmerstoni - "A" quality	61/10	61/10	60/10	59/4	57/10	56/4	56/4
	Agathis palmerstoni - "B" quality	54/4	54/4	53/4	51/10	40/4	48/10	48/10
	Toona australia	71/10	71/10	50/10	69/4	65/10	64/4	59/4
II	---	61/10	61/10	60/10	59/4	55/10	54/4	49/4
III	---	51/10	51/10	50/10	49/4	45/10	44/4	39/4
IV	---	41/10	51/10	40/10	39/4	35/10	34/4	30/10

Ply (peeler) Quality Logs:-

Agathis palmerstoni - 11/- per 100 super ft in excess of "A" quality rate.

Toona australis, Flindersia brayleyana and F. pimenteliana - 8/6 per 100 super ft extra.

Flindersia bourjotiana (Class II) - 8/6 per 100 super ft extra.

Other species - 4/- per 100 super ft extra.

Sliced Veneer Logs:-

Flindersia brayleyana, F.pimenteliana, F. bourjotiana (Class II) & F. acuminata (Class II) - 20/- per 100 super ft extra.

distant about 20 miles from Cairns, the actual stump royalty would be about 30/-d. per hundred super ft below the keymarket price, and at a distance of some 40 miles about 35/-d less. As will be appreciated, small class IV logs become unsaleable at this distance, the cost of extraction being more than the value of the timber. The great difference between the value of large and small logs of Endiandra palmerstoni results firstly from this species being essentially a sliced veneer timber, with the consequent premium rates, and secondly from its having a particularly wide band of sapwood, so that small girth logs contain little heartwood suitable for producing veneers.

Development of Silviculture

The earliest silvicultural work in North Queensland occurred shortly before the 1914-18 war, when attempts were made near Atherton at inducing regeneration of Toona (Red Cedar) and at the enrichment planting of this same species, which has occupied a special niche in Australian forestry from the earliest days of European settlement when "Cedar-getters" were the first settlers to venture into many of the coastal river valleys of eastern Australia. During the war further work was carried out, and open plantations of Toona, Agathis palmerstoni and Araucaria cunninghamii (which is of limited natural occurrence in north Queensland) were commenced. During the period 1918-24 emphasis was placed on inducing regeneration of Toona, Flindersia brayleyana and Cardwellia, by felling and stacking all small growth (up to 4 inches D.B.H.) of useless species for a distance of 1 chain around the parent trees and, at the same time, releasing any existing regeneration of the merchantable species. E.H.F. Swain, the then Director of the Queensland Forest Service, considered at the time that, while the liberation of regeneration had been highly successful, the efforts at inducing fresh regeneration were a "costly failure". He proposed a system of opening the stands by removing useless stems 5 years before logging and then, if regeneration was still absent, to enrichment plant after logging: unfortunately this treatment was never applied in form suggested by Swain*.

From 1924-30 enrichment planting was in vogue once more, stands being logged as thoroughly as possible, useless undergrowth and small trees being brushed or felled, and then the more valuable Flindersia spp. planted beneath the remaining shade at about 10 ft by 10 ft spacing. Following planting both planted and useful natural stems were tended and the overwood was gradually removed. This was only applied to a small area (60 acres), but has produced an excellent stand. Table 45 shows the growth of a plot established in this enriched stand; in 1953 the plot carried a merchantable volume of 1725 cu ft per acre of Flindersia, and this increased to 2,300 cu ft in 1960 giving a P.A.I. of 82 cu ft per acre over the 7 years (Volck, 1960).

To this stage work had been largely experimental, but from 1930 until the war stopped treatment in 1942 the concentration of effort was on plantation establishment, the species used being chiefly Araucaria cunninghamii, Agathis and F. brayleyana, with the first making up about half the total area of 1,200 acres planted.

* In this proposal Swain would appear to have had in mind the success of the Malayan Regeneration Improvement Felling System (see section on Malaya), which was being formalized about this time.

TABLE 45

Growth in Enrichment Planted Stand of F.brayleyana.

(Planted 1925, some replanting, 1929).

Year	Stems/acre, 1 in.D.B.H.+		B.A./acre - sq ft	
	Flindersia	All Spp.	Flindersia	All Spp.
1930	19	102	1.8	20.6
1948	200	850	72.9	125.0
1953	206	1620	87.8	162.6
1960	197	-	102.9	-

In 1939-45 war altered conditions by providing a great increase in the number of rainforest species being utilized. Plantations were costly to establish and the clearing for plantations involved the destruction of many small, but now potentially valuable, stems of economic species. Large areas of the remaining forest reserves were too steep for plantation clearing to be safely carried out. At the same time the Australia-wide demand for the cabinet timbers from north Queensland continued: except for Toona these species were confined to the north. Pre-war treatments had shown that very fine stands of these timbers could be produced by natural regeneration, by enrichment planting, or by the release of existing advance growth, while it had also shown that, with species such as the Flindersia spp., stem form was much poorer on trees grown in open plantation than in those grown under rainforest conditions.

Consequently, when silvicultural work resumed after the war, interest swung back to the treatment of the natural forests, and in 1946 brief rules for the routine treatment of these stands were prepared. In drawing up these rules the lessons learnt in the earlier work were applied, but as there were still many gaps in the knowledge a comprehensive programme of silvicultural and forest products research was commenced at the same time.

Over the whole of this period logging in the rainforest had been carried out. Until the 1939-45 war only an extremely limited number of species were being extracted, and the only control was by the imposition of minimum girth limits. When silvicultural treatment commenced after the war, with markets available for a vastly increased number of species, these limits were:-

Endiandra palmerstoni	10ft G.B.H. (38 in D.B.H.).
Flindersia brayleyana, F. pimenteliana	9ft G.B.H. (34 in D.B.H.).
Toona, Cardwellia, Agathis	8ft G.B.H. (30 in D.B.H.).
Others	7ft G.B.H. (27 in D.B.H.).

The 1946 Treatment Rules

These first rules aimed essentially at a stand improvement treatment following logging. Useless stems were destroyed and the object was to leave a well-spaced stand of the best available species. Logging was carried out to the girth limits shown above, and then all undergrowth was brushed leaving only regeneration of useful species. Useless trees of desirable species, except those required for seed tree purposes, and all useless species were then destroyed either by ringbarking (girdling) or felling, whichever was the cheaper for each tree. Full stocking was regarded as 160 useful stems per acre 20ft high or larger, spaced at about 16 ft by 16 ft, and where an area was less than 80% stocked (visual estimate) useless stems of economic species were to be retained to provide seed. Where dense stands of advance growth over 20 ft high occurred, these were to be thinned to a spacing of about 12 ft by 12 ft if under 50 ft high, or about 16 ft by 16 ft if over 50 ft high.

The treatment was applied to unit areas of about 200 acres, but no treatment was carried out within 2 chains of a road or within 3 chains of the margin of the rainforest (owing to fires in the eucalypt woodlands and forests, the margin between rainforest and sclerophyll forest is usually very sharply defined). This restriction was a fire protection measure, for although the virgin rainforest is practically fire-proof, the stands immediately after treatment, with much debris on the ground, could readily burn during the first dry season.

These rules were applied until 1954 when, from the experience gained and from the results of research carried out since 1948, new and more detailed rules were introduced.

The 1954 Treatment Rules

The rules introduced in 1954 are considerably more detailed than the earlier ones, and in particular differ from the 1946 rules in that logging is carried out under tree marking, all stems to be extracted being branded beforehand by forest service staff. Girth limits are still retained, but provision is made for undersize trees to be thinned out in dense patches and for larger, healthy, well formed stems to be kept as seed trees for a later felling cycle. The exceptions to this retention of oversize trees are the heavier and slower-growing species of low commercial value (stumpage Class IV) and Endiandra palmerstoni, for which all merchantable stems down to the girth limit must be removed. In the case of Endiandra this action is due to the large size needed before the species attains commercial value, to its slow growth, and to its poor regeneration due largely to heavy seed loss by native mammals (mainly rats): in effect the forest service is prepared ultimately to lose this species in the treated forests, by preferring other more amenable and almost equally valuable cabinet timber species.

Another important change in the 1954 rules is that the commercial species are classed into 4 silvicultural groups in order of desirability, based on the timber value and silvicultural characteristics of the species concerned. The groups follow closely the stumpage groups; thus silvicultural group A, in which the individual species are listed in order of desirability, is composed mainly of species in stumpage groups I and II, stumpage group III species are mostly in silvicultural group B, while stumpage group IV is split into the generally lighter and faster-growing species (group C) and the heavier and slower-growing species (group D). However this division is not exact; group A contains one stumpage group III species (Flindersia ifflaiana), group B contains species from groups II, III and IV, while one group III species (Elaeocarpus grandis, which produces a very heavy, wide spreading crown) is relegated to group C.

Provision is also made in the rules for thinning in a wider range of advance growth size classes, for promoting regeneration in areas where it is inadequately present after logging, for enrichment planting in unregenerated areas remote from seed trees, for the subsequent tending of regeneration, and for controlling the virulent Stinger (Laportea moroides), a shrub or small tree nettle which regenerates very freely once the canopy is opened up.

The complete rules, covering tree marking, silvicultural groups, and subsequent treatment, are given in appendix 3. The last section (prescription for tending regeneration) was actually issued separately from the remainder of the rules, but forms part of the treatment schedule. The sequence of operations carried out is as follows:-

1. Operate on unit areas of about 200 acres, leaving firebreaks that will be logged, but not otherwise treated, for 3 chains inside rainforest margins and for 2 chains alongside roads.

2. Climber cutting, and cutting of all useless undergrowth, not more than 6 months before logging. Leave all stems of desirable species.

3. After climber cutting and undergrowth brushing, cut any stems of Laportea large enough to cut and swab the stumps weedicide, and spray any small stems of Laportea with weedicide.

4. Tree marking of stems for merchantable exploitation:-

   (a) Where areas will contain less than 30% of desirable stocking of A and B species after logging (regardless of the stocking of C and D species), seed trees of A and B species between 5 and 10 ft G.B.H. (19 and 38 in D.B.H.; preferably of the smaller sizes) should be retained at a spacing of about 120 ft by 120 ft. Group A should be preferred over group B, but Endiandra should not be left as a seed tree.

   (b) Mark all other merchantable stems, not required for seed, to the specified girth limits.

   (c) Mark any damaged trees unlikely to survive for 15 years.

   (d) Mark for merchantable thinning smaller stems down to 4 ft G.B.H. (15 in D.B.H.), unequivocally favouring group A species over all others, group B over C and D, etc., to leave a stocking ranging from about 48 to 90 stems per acre, depending upon the size of the retained stems.

   (e) Mark also any group D trees that are overtopping saplings of A or B species more than 10 ft high.

5. Logging of all marked stems, but no unmarked stems, followed immediately by the removal of germinating Laportea from along snig tracks and within the heads of fallen trees.

6. Silvicultural treatment to commence as soon as possible after logging:

   (a) Remove by ringbarking (or falling, if cheaper) all useless stems and species.

   (b) Provide reasonable growing space to the most desirable stems (key trees) by removing other well formed stems where necessary, provided no A species above 30 inches G.B.H. (9 in D.B.H.) or B and C species above 3 ft G.B.H. (11 in D.B.H.) are to be removed. D species under 4 ft G.B.H. (15 in D.B.H.) should be retained only where no alternative stem of A, B or C species is available.

   (c) Thin the remaining stand as follows:

      Where under 10 ft high - no treatment.

Where between 10 and 20 ft - no thinning, but clean around A and B species for a radius of 5 ft.

Where between 20 and 50 ft - space about 10 ft by 10.

Where stems are both above and below 50 ft - space about 12 ft by 12 ft.

In all cases adhere to the order of desirability, leave no stems closer than half the distance quoted.

(d) When the Laportea, germinated after treatment, reaches a height of 1 ft, give tending to remove this, and also any plants of Solanum auriculatum or other weeds interfering with desirable regeneration.

(e) On areas inadequately stocked with regeneration, but with seed trees of Flindersia brayleyana, F. pimenteliana, F. bourjotiana or Cardwellia present, treat to induce regeneration for no more than 6 months before seed fall (usually start of wet season, about January) by:-

(i) brushing down all undergrowth, except desirable regeneration, for 100 ft around seed trees;
(ii) raking debris into heaps to expose as much as possible of the soil;
(iii) if regeneration is obtained, subsequently tending as for young advance growth.

(f) Enrichment planting may be carried out in unregenerated areas remote from seed trees (more than 60 ft) or in the case of compartments with only C or D species seed trees, within 30 ft of the seed trees. Plant at 12 ft by 8 ft spacing.

(g) Inspect at 6 monthly intervals for the growth of Laportea and when necessary give tending to remove these, at the same time removing any competing useless or D species within 5 ft radius of key stems under 10 ft high.

7. Subsequent tending of regeneration to be carried out after about 3-4 years from initial treatment, and possibly also at later stages.

(a) No tending within 10 ft of A or B stems over 20 ft high except to remove climbers from the key tree.

(b) Regeneration 10 to 20 ft high - brush around key stem for 5 ft radius.

(c) Regeneration under 10 ft - brush around key stem for 5 ft radius, favouring species in order of desirability.

(d) Ringbark any D species overtopping regeneration of A or B species.

(e) Ringbark any C species under 3 ft G.B.H. (11 in D.B.H.) when within 10 ft of A or B species more than 10 ft high.

The treatment as prescribed has two main aims, the first being to obtain the full utilization of the merchantable timber while maintaining the forest in a healthy state, and the second to improve the composition and the silvicultural condition of the rainforest. Through the operation of the tree marking rules both logging and subsequent treatment are jointly directed at achieving these aims. Although the silvicultural treatment at this relatively early stage is primarily a timber stand improvement (T.S.I.) operation, since the stands being treated are either virgin or have been logged over in the past, efforts are being directed at ensuring the recruitment of regeneration, and the feeling among foresters in north Queensland is that it will ultimately develop into a true silvicultural system over subsequent felling cycles. In the better quality eucalypt forests of southern Queensland and N.S.W. a similar, though less involved, T.S.I. operation served as the link between early, almost uncontrolled, selective logging and the development of the Australian group selection system; it is thought by local workers that a similar evolution may occur in the north, also resulting in a form of group selection system.

The Treatment Rules in Operation

While the ideal is to combine treatment with logging under tree marking, this is not always possible. Some areas that have been treated had received heavy but incomplete logging in the past, so that the exploitable volume standing was insufficient to warrant a further economic harvesting; in such cases some larger trees than usual are retained in the treated stand. Elsewhere, on account of limited finance and manpower, logging under tree marking is proceeding well in advance of treatment. Nonetheless the combined operation is applied whenever possible.

In virgin rainforest the basal area normally averages about 350 sq ft per acre, though it may of course be much lower in previously logged stands. Haley (1957) quotes one plot where the B.A. of all stems over 2 inches D.B.H. was 350 sq ft per acre (equivalent to 328 sq ft in stems over 4 inches D.B.H.), and of this merchantable species (groups A, B, C and D) contributed 163 sq ft and the cabinet timber species (group A) 83 sq ft. About half the stems over 23 inches D.B.H. were of cabinet species, but the representation of these was much poorer in the smaller size classes.

Other plots, quoted by Volck (1960), show the B.A. of merchantable species to range from 108 to 164 sq ft per acre, and of cabinet species, from nil to 160 sq ft. On these plots the volume of standing timber larger than 8 inches D.B.H. ranged from 585 to 2,840 cu ft per acre for all merchantable species, and from nil to 1,470 cu ft for cabinet species. On another area, which had been selectively logged previously but which still carried sufficient timber to justify logging again ahead of treatment, the volume of the merchantable species over 8 inches D.B.H. was 1,460 cu ft per acre (of cabinet species, 620 cu ft), and for stems larger than 15 inches D.B.H. the volume was 880 cu ft per acre (cabinet species, 370 cu ft). Clearly the volume extracted after tree marking can be expected to vary greatly, even from virgin stands, and outturn figures known to the writer range from about 175 cu ft per acre in the cut-over stand mentioned above up to about 450 cu ft from a virgin stand.

After logging is completed in virgin areas, the composition of the remaining stand will be most variable. However Haley (1957) states that on the average the remaining B.A. is about 220 sq ft per acre, including some 74 sq ft of merchantable species and 13 sq ft of cabinet species. Comparable figures for stocking are: all species, 800 stems per acre 20 ft high and larger; merchantable species, 88, cabinet species, 21.

Tree marking is carried out by experienced subprofessional staff, under supervision of professional officers. The trees to be felled are marked by paint and close watch is kept that all marked trees, and only marked trees, are removed in logging. Maximum log lengths may be set to avoid damaging the remaining trees in snigging, and careless logging contractors and their staff may be prohibited from further operations in state forests.

At the start of the subsequent silvicultural treatment all stems to be retained after treatment (including saplings down to about 10 ft high) are marked with a paint ring at breast height. This marking is again done by subprofessional staff under professional supervision, and takes into account the thinning to be carried out during treatment. The unmarked stems are then removed. Normally sapringing is used to destroy trees too large to fell economically: sapringing is a form of ringbarking or girdling in which not only the bark, but also the sapwood, is removed from a 3 inch ring round the stem, and it is employed to give a fast kill and to avoid callus tissue forming across the wound. Even so some stems have been known to callus over such a gap. Poisoning is not usually used, but may be employed on very large stems and on trees with fluted stems: 10% arsenic pentoxide solutions and 1% to 5% 2,4,5T solutions have proved effective in such poisoning.

The cost of the main silvicultural operations (climber cutting, cutting uneconomic stems, marking trees for retention and removal of unwanted stems) averages about 35 man hours per acre (at a wage rate of about A£14 for a 40 hour week). As a result of the treatment the B.A. is usually reduced to within the range of 40 to 70 sq ft per acre, with an average standing volume of about 600 cu ft per acre over 8 inches D.B.H. Table 46 (from Haley) shows the stem distribution in one plot before and after treatment.

The stocking of cabinet species in this plot is higher than is usual. In other plots quoted by Haley (1957) and Volck (1960) the values after treatment for cabinet species are: stems per acre 48, 23, 50 and 62, and B.A. 10, 13, 34 and 33 sq ft per acre respectively, and as pointed out earlier the average B.A. from all plots established by the forest service after logging is only 13 sq ft per acre. These values are from areas treated under the 1946 rules, but in terms of stocking, particularly of the cabinet species, there is little difference in the results achieved by the two rules.

As a result of the stand improvement treatment, growth is concentrated on the more desirable stems remaining after logging. This is shown by the results in table 47 where a treated plot is compared with a logged, but untreated, plot close by. The B.A. of the treated plot is somewhat higher than usual here, and as a result the B.A. increment is also slightly higher: in plots reduced to about 55 sq ft B.A. per acre after treatment, the B.A. increment is normally in the order of 2 sq ft per acre per year (E. Volck, pers. comm.). Figures quoted by Volck (1960), comparing treated and untreated stands, show similar relative values to those in table 47.

The improved growth after treatment is shown also by the individual diameter increments of stems, particularly those under 11 inches. "This will result in more rapid recruitment into the merchantable sizes .... and this in turn will have a substantial effect

TABLE 46

Stem distribution in logged stand, before and after Silvicultural Treatment.

(Values per acre; diameter classes from quoted girth classes, to nearest inch).

	Diameter Classes							
	Under 4"	4-8"	8-11"	11-15"	15-19"	19-23"	Total Stems /acre	B.A. /acre
Before Treatment - all stems	558	210	86	44	16	8	922	189 sq ft
After Treatment - all stems	70	16	20	16	6	8	136	54
After Treatment - cabinet spp.	44	4	10	6	6	8	78	42

TABLE 47

Comparison of Growth in Treated and Untreated Logged Stand

Plot	B.A. /acre	Stems/ac.	B.A. P.A.I. (6 yr)			Vol. P.A.I. (6 yr)		
			All stems	Select Stems	Group A spp.	All stems	Select Stems	Group A spp.
Treated	91 sq ft	158	2.7 sq ft	2.7	0.9	48.0 cu ft	48.0	16.0
Untreated	246	820	2.0 sq ft	1.2	0.5	30.4 cu ft	10.3	3.7

on volume increments. Moreover most of these recruits will be members of groups A and B" (Volck, 1960). Some of Volck's increment figures are given in table 48.

From such data as this, Volck believes that the following increments can be attained in treated plots on stems below 30 inches D.B.H.:

0.5-1.0" diameter annual increment: Elaeocarpus grandis, Acacia aulacocarpa, Flindersia pimenteliana.

0.3-0.5": Fl. brayleyana, Toona australia, Agathis palmerstoni.

0.2-0.3": Cardwellia sublimis, Sloanea macbrydei, S.langii.

0.1-0.2": the other species, with the Eugenia spp., Ceratopetalum succirubrum and Blepharocarya involucrigera at the bottom of the list.

In most, though by no means all, cases the regeneration that responds to treatment is already present before treatment occurs. Regeneration established after treatment, except in those areas where special efforts are made to induce it, is usually likely to be suppressed by weed and coppice growth. However, one area known to the writer had been treated in November and subjected to a heavy seed fall of F.brayleyana and F. pimenteliana about a month and a half later: 7 years later it carried an extremely dense stand of Flindersia regrowth which had excluded virtually all weeds. Weed growth and especially coppice from the small, brushed stems, is usually vigorous and prolific and can attain a height of up to 10 ft within a year: for this reason the liberation treatment at age 3 or 4 years is required. The Flindersia spp. in group A are regarded as the most vigorous growers of the main cabinet species in the regeneration stand. Cardwellia also sometimes shows good growth, but at other times is very slow, possibly as a result of previous suppression in the untreated stand. Table 49 shows a comparison of F. brayleyana height growth in treated and untreated stands: the other Flindersia spp. show very similar rates (Volck, 1960).

The provision in the rules about inducing regeneration by brushing the undergrowth and heaping the resultant debris has only rarely been applied, though there are areas where it has been most successful. In practice enrichment planting is preferred as a means of regenerating understocked areas, being considered surer and more satisfactory generally. However in most areas the regeneration present at the time of treatment is sufficient so that special regeneration measures are not required.

Where enrichment planting is carried out F. brayleyana is the species generally used, as it has given excellent results, produces seed regularly, is easily raised and planted and provides a timber whose value is exceeded in North Queensland only by Endiandra palmerstoni. Table 50 shows the results obtained by some F. brayleyana enrichment plantings: the best growth, at R1073 Smithfield is in a reserve on metamorphic rocks. where the species does not occur naturally.

Among the weeds Laportea moroides is by no means the most serious in interfering with the growth of regeneration, but once

TABLE 48

Diameter Increments for Individual Species in Treated and Untreated Forest.

Species	Plot	Diameter Class (converted from Girth); Diameter P.A.I. 3 yrs.						
		Under 4"	4-8"	8-11"	11-15"	15-19"	19-23"	23-27"
Cardwellia sublima	Untreated	.03"	.08		.10	.18		
	Treated	.13		.17	.17			.19
Fl. pimenteliana	Untreated	.18	.24					
	Treated	.30		.80		.79		
Fl. bourjotiana	Untreated			.04	.05	.08	.10	
	Treated	.29		.22	.13	.10		

TABLE 49

Height Growth of Flindersia brayleyana Regeneration.

Plot	Height Class	0-1'	1-2	2-3	3-4	4-5	5-7.5	7.5-10	10-12.5	15-17.5	All classes
Untreated	P.A.I.	0.05'	0.05	0.3	0.04	0.1	0.9		1.1		0.3'
	No. stems	10	25	4	2	4	1		1		47
Treated	P.A.I.	1.3'	1.6	2.4	0.8	2.1	1.3	2.0	3.6	0.8	1.8'
	No. stems	13	49	11	7	5	17	5	3	2	112

TABLE 50

Growth of F. brayleyana in Enrichment Plantings.

Forest Reserve	Mean Ht. at Planting	Years to remeasurement	Survival	Mean Ht.	Ht. P.A.I.
R99 Western	1.0 ft	6 years	89%	19.3 ft	3.1 ft
R1073 Smithfield	0.3	5	82	30.3	6.0
R251 Ismailia	0.8	4	94	17.3	4.1

established in an area it can completely preclude entry for subsequent tending for 6 or 7 years. It is a fast-growing, short-lived shrub whose large leaves carry extremely virulent stinging hairs. In some parts of the Atherton Tablelands region it regenerates very plentifully once the stand is opened, and unless controlled at an early stage, it can make it impossible to work in the infested areas. Even after the plants die the spicules from the leaves can cause severe irritation to eyes, nose and throat for some years. For these reasons emphasis is now placed on controlling its development at all stages of treatment. It is readily controlled by various hormone sprays which, in the concentrations used, cause little damage to the regeneration of primary species: F. pimenteliana and Cardwellia occasionally suffer some die-back, and F. brayleyana some epinasty, but all soon recover. A 1% solution of the sodium salt of 2,4D has been found to cause the least damage to the primary species and to produce effective Laportea control, and this is now recommended for routine use.

Other weed control measures are largely aimed at assuring the early dominance of worthwhile regeneration. Once this dominance is achieved further tending is not required since it is costly and also since the growth of unwanted stems below the regeneration is believed to force the desirable stems to make vigorous upwards growth and to lose their lower branches at an early stage. Consequently the liberation treatment is carried out only around desirable plants in danger of being swamped by competing weed growth, by growth of less desirable economic species, or by climbers. Calamus spp., one of the worst of the climbers, is destroyed by cutting the stem just below ground level.

The Future of Treatment in North Queensland

As seen above, the treatment applied to the submontane rainforests of north Queensland is essentially one of stand improvement, in which the B.A. is reduced from an average of 350 sq ft per acre in virgin stands, to about 220 sq ft after logging, and to about 55 sq ft, all of economic species, after treatment. On the average about 13 sq ft in the treated stands is contributed by the cabinet timber species. Efforts are made to ensure the presence of regeneration in the treated stands either naturally or by enrichment, and the regeneration is tended to keep it growing vigorously. Figures available suggest that the treated stands can produce a B.A. P.A.I. in the order of 2 sq ft per acre and a merchantable volume P.A.I. of about 40 cubic ft per acre, all on stems of economic species.

During the 8 years (1947-1954 inclusive) that the first rules were in force, treatment was carried out on little more than a pilot scale, averaging about 50 acres a year. In the following $5\frac{1}{2}$ years, under the present rules, the treatment was applied more widely to some 2,000 acres, though it is still far from keeping pace with the rate of logging. However, with tree marking being much more widely used the logged stands are left in a moderately healthy condition, though, as the figures quoted previously show, the silvicultural treatment is needed for the site to approach its production potential. The areas that have been treated are mostly sites of reasonable accessibility with a good representation of cabinet species: in other words, those areas where the return on the money invested in treatment should be greatest.

Although the treatment rules sound involved they are applied most efficiently by the field staff, and it is primarily the limitations imposed by finance and manpower that prevent the wider application of the treatment to logged stands. The treatment at present prescribed is not regarded as static, and research is continuing into methods of improving the technique. Among the more important ideas under consideration are the possibility of ringbarking useless trees some years ahead of logging and the introduction of a pre-treatment regeneration assessment to use as the basis for enrichment planting. The early ringbarking would be intended both to speed up the growth rate of the standing trees and to help in promoting regeneration establishment, while the regeneration assessment would locate in advance those areas where primary species were deficient. Another suggestion that has been made is to provide special gangs of skilled workmen to carry out the liberation tending of regeneration: while the initial stand treatment depends for its success upon the ability of the man marking the stems for retention, the tending operation is virtually in the hands of the individual labourers, and with unskilled workmen the costs can become high through too much unnecessary, and indeed deleterious, cleaning.

Increment data is still insufficient to enable a definite statement on the length of the felling cycle to be made, but the local estimate is 15 to 20 years for the first cycle and probably a shorter period henceforth. Table 51 shows postulated stand values after these periods based on the limited data available. In an average stand even after 20 years the B.A. per acre is still well within the limits believed necessary for optimum growth (Dawkins, 1958), so there is every chance that the volume P.A.I. can be maintained throughout the cycle at close to the suggested rate of 40 cu ft per acre per year. Even if this rate were halved, the total increment over 15 years would well justify logging on economic grounds.

North Queensland is fortunate in having rainforests comparatively well stocked initially in highly valued primary species; in having markets available for most of the secondary species (about 160 millable species out of a total tree flora of some 360 species); in the vigorous growth shown by most of the primary cabinet species, especially after treatment; and in the prevalence of regeneration or advance growth present in most sites. The intensive silvicultural treatment carried out is a direct reflection on these favourable factors.

TABLE 51

Postulated Growth in "Average" Treated Stand

Value	P.A.I.	After Treatment	After 15 years	After 20 years
Basal Area	2 sq ft/ac.	55	85	95
Merch. Volume	40 cu ft/ac.	"X"	X + 600	X + 800

"X" probably lies at about 1,000 cu ft in stems above 8 inches D.B.H.

SILVICULTURAL TREATMENT IN OTHER AREAS.

Introduction

In the preceding sections of this chapter the silvicultural treatments being applied to rainforest in five countries - Malaya, Nigeria, Trinidad, Puerto Rico and Queensland - have been dealt with in some detail. The countries differ markedly in environmental conditions, in the markets available for the timber produced, in economic status and in the approach being taken in treating and managing their rainforest stands. In all cases, however, a system has evolved which, although far from being immutable, is regarded as serving the special local needs of the country well. In the case of the first three countries the treatments in their present or earlier forms have had important bearings on developments in other rainforest areas, while Puerto Rican influence can be expected to spread as a result of the special training courses in tropical forestry organized annually by the Institute of Tropical Forestry and the U.S. International Co-operation Agency (I.C.A.).

However, these countries are by no means the only ones engaged in managing their rainforest heritage, and in the remainder of this chapter it is proposed to examine more briefly the work being carried out in some other countries. For linguistic and other reasons the spread of information will be uneven and incomplete, but it should cover most of the major developments occurring around the world. The countries are dealt with in a rough geographical sequence from west (America) to east (Western Pacific).

British Guiana

This small colony on the northern coast of South America occupies a rather special place in the study of rainforest through the early ecological studies of Davis and Richards (1933-34). More recently its vegetation, which is largely rainforest as understood in this report, has been the subject of detailed classification by Fanshawe (1952a). To a greater extent than in most tropical countries, the rainforest lends itself to subdivision on floristic grounds, and the sequence of types discussed by Richards (1952) is typical of much of the main commercial rainforest zone on the lowlands. In Richards' sequence five communities were recognized, four of them with rather specific site requirements and strong tendencies to single species dominance, and the fifth occupying most of the intermediate and generally more favourable sites and possessing a very mixed composition. Table 52 summarizes some of the information about these five communities.

Of these types the one dominated by Ocotea rodiaei is by far the most important commercially. O. rodiaei (Greenheart) provides one of the most valuable export timbers occurring in British Guiana, and most of the silvicultural work in the country's rainforests has been concerned with this species. Seedlings of O. rodiaei are capable of existing in heavy shade for many years and then of responding rapidly when the canopy above is opened. Once released they can withstand almost full light intensity. Studies commenced by T.A.W. Davis in 1936 showed that in virgin forest openings were required in all storeys of the rainforest to induce regeneration and to promote its growth, the

TABLE 52

Summary of Data on the Moraballi Ck. Communitiies (ex Richards, 1952)

Richards' Name	Most Common Species	Percentage of Most Common species in stand (stems 16"DBH+)	Rainforest subformation	Site Requirements
Mora forest	*Mora excelsa*	67.2%	Equatorial	River flood plains with high water table.
Morabukea forest	*Mora gronggrijpii*	60.7%	Equatorial	On heavy red clay on slopes of lower hills.
Mixed forest	*Eschweilera sagotiana*	15.6%	Equatorial	On loams; over much of the lower hilly land.
Greenheart forest	*Ocotea rodiaei*	43.4%	Equatorial	On light, reddish-brown sands on ridge sides.
Wallaba forest	*Eperua falcata*	67.0%	Xeromorphic	On bleached sands (podsols) usually on ridge tops above Greenheart forest.

dense undergrowth layer being the most critical. Based on these findings the treatment applied to exploited stands of O. rodiaei is:

1. Remove all undergrowth except for young plants of O. rodiaei.

2. Thin out the lower tree layers, the intensity of thinning depending on local canopy conditions. Poles of O. rodiaei are retained.

3. Cut all vines.

4. Follow-up with one or two cleanings to cut back coppice growth and prevent the invasion by secondary species.

5. Once the regeneration is well established and growing, remove the larger remaining trees other than O. rodiaei by one or two poison girdling operations.

Clarke (1956) gives the values shown in table 53 as indicating the stocking of sound stems of O. rodiaei in virgin, logged and treated stands. The heavy degree of logging and the frequency of regrowth after treatment are apparent from these figures.

This treatment has also been discussed by Fanshawe (1952b), who points out that the marking of useless stems for removal is carried out by especially skilled workers who attempt to strike a balance between too little and too much opening in the upper canopy. The work is carried out after all exploitable stems have been removed: normally from 10 to 15 stems per acre are removed in logging. At the same time the treatment is applied to adjacent areas of mixed rainforest, in the hope of extending the O. rodiaei communities.

Some treatment has also been applied to Eperua falcata communities, whose timber is used for fuel and more recently for particle board production. In regenerating these stands it is essential that fire should have been excluded, and desirable that some canopy be retained after exploitation (Fanshawe, 1952b).

Whereas in the gregarious stands treatment aims at obtaining or assisting regeneration of the dominant heavy hardwoods, in the mixed stands the main object has been to foster the light, faster-growing hardwoods such as Carapa guianensis. These stands commonly only yield one merchantable stem to five acres, and silvicultural treatment is only considered justifiable in patches where seedlings of the economic species are fairly numerous. Early attempts at releasing the occasional groups of seedlings of Ocotea rodiaei in the mixed stands were unsuccessful, as the Ocotea plants below 6 ft in height invariably died though the sudden impact of extra light in these stands outside their optimum growing conditions; hence the present attempts to induce Ocotea regeneration more gradually around the edges of the O. rodiaei communities, thus narrowing the intervening belts of low production mixed rainforest.

Surinam

This Dutch colony on the north coast of South America has been the scene of some extremely detailed ecological studies in recent years (e.g. Schultz, 1960). The vegetation is broadly similar to that of neighbouring British Guiana, though Surinam lacks communities of the

TABLE 53

Stocking of Ocotea rodiaei in Treated and Untreated Stands.

Treatement	Stems per acre									
	Under 25' high	25'-2"DBH	2-4	4-8	8-12	12-16	16-20	20-24	24"+	Stumps
Virgin		4 (1)		0.5	1.5	3	10		5	
Exploited	242	5	8	5	3	3	-	-	-	20
"	150	15	3	3	-	-		3	-	23
"	617	5	8	3	3	3	-	-	-	15
Treated	513		14	3	1	3	2	1	2	9
"	556	10	23	-	-	8	5	3	3	13

Note (1): in the virgin plot there were 4 stems per acre in the 15 ft high to 4 inches D.B.H. class.

very valuable Ocotea rodiaei. Logging operations are carefully controlled and there is a well developed integrated timber industry dominated by a plywood and particle board plant (Lamb and others, 1960). Virola surinamensis is the main species used in this plant, waste from the plywood division providing the bulk of the raw material for particle board manfacture. One particularly interesting development likely to affect utilization has been the establishment of plantations of Pinus caribaea on the sandy savanna soils near the coast. These have been established by the forest service on behalf of a Dutch paper company, and it is hoped that they will ultimately provide the basis for a local pulp industry which will also utilize some of the rainforest species from the zone beyond the coastal savanna (C.B. Briscoe, pers. comm.).

Studied are being carried out on improving the composition of the rainforest and on obtaining natural regeneration. The treatment favoured at present is similar to "l'Uniformization par le haut" developed in the Belgian Congo (see below) (Schultz, 1960).

Brazilian Amazonia

The Amazon River, the largest river system in the world, flows across northern Brazil from its headwaters in central Brazil and in the Andes of Bolivia, Peru, Equador and Colombia, to enter the Atlantic Ocean practically on the equator. It is the centre of the world's largest continuous rainforest zone. Within northern Brazil this zone covers an area of about 1.3 million square miles, 40% of the country's total area, but with less than 4% of the total Brazilian population, a large proportion of which is confined to the two state capitals of Belem (State of Para) and Manaus (Amazonas). Despite its vast area, Brazilian Amazonia is a relatively minor producer of timber. Aubreville (1960) states that during the five years 1952-56, the average annual export of timber from the four river parts of Manaus, Itacoatiara, Belem and Macapa was only 1.1 million cu ft. Even when liberal allowance is made for the unrecorded volume of timber used locally within the region, the production from the Amazonian forests is only a fraction of that from certain much smaller territories such as Sarawak and North Borneo (Sabah) in south-east Asia or the Ivory Coast and Western Nigeria in West Africa. Since silviculture can only be expected to occur in the presence of a timber demand, it is not surprising that forest management in Amazonia is rudimentary in the extreme.

In an effort to develop the timber industry in Amazonia the Brazilian government in 1952 called in an F.A.O. team to advise on the measures needed to establish a permanent forest industry in the area. The team's report (Gachot, Gallant and McGrath, 1953) made a number of recommendations which led to the establishment of an F.A.O. Misson based at Belem and covering various aspects of forestry work. Among the Mission's main achievements have been the setting up of a sawmill training centre at Santarem, the carrying out of forest inventories of an exploratory nature over a belt of some 60,000 square miles extending for about 800 miles along the southern side of the River (Heinsdijk, 1960), the establishment of a centre for studying mechanical logging methods in the rainforest, and by no means least a most impressive start to developing silvicultural techniques for application to the rainforests over part of this vast area.

As can be imagined the rainforest over such a large area varies considerably in its physiognomy and composition, and some information on these variations have been given in earlier chapters. On structural classification alone areas of equatorial, evergreen seasonal, semi-evergreen, swampy and xeromorphic rainforest are known from parts of Brazilian Amazonia. Silvicultural studies have been commenced by F.A.O. in a number of sites but the most important work has been carried out in two areas, one in the grounds of the Commissao Brasiliera - Americano (CBA) about 8 miles south of Santarem, and the other at the site of the F.A.O. logging study and training centre of the Curua Una River (Curua) about 65 miles east of Santarem. Santarem itself, the third largest city of Amazonia, lies on the junction of the Tapajos and the Amazon Rivers about midway between Belem (near the mouth of the River) and Manaus (970 miles upstream).

CBA and Curua are similar in many respects. In both areas there is a strip of rather low land stretching back from above the seasonal flood level for some miles. This is known as the "flanco" and consists of very sandy soils supporting, in its undisturbed state, semi-evergreen rainforest (fig. 17): between Santarem and CBA much of this has been converted to savanna by repeated cultivation and burning. The end of the flanco is marked by a surprisingly abrupt escarpment averaging about 200 ft in height. This forms the edge of the "planalto", an almost perfectly flat plateau surface which continues for considerable distances to the south without any apparent features of relief. The soils of the planalto are high in clay and support evergreen seasonal rainforest (fig. 12). Rainfall in both areas is unusually low: 11 years' record at CBA gives a mean annual rainfall of only 34 inches, with 7 months having less than 4 inches, while 2 years' record at Curua gives a mean of 67 inches with 6 months under 4 inches (Pitt, 1961). Some planting studies have been made on the flanco at Curua, but all treatment studies in the natural forest have been carried out on the planalto, which supports one of the highest volume yielding rainforest types encountered in Amazonia by the forest inventory team (an average volume of 3,300 cu ft per acre for the Curua area in stems over 10 inches D.B.H., rising in some $2\frac{1}{2}$ acre plots to 4,500 cu ft per acre; (Heinsdijk, 1957; Pitt, 1961).

The small area used at CBA had been subject to some past disturbance by man, but the more extensive site at Curua was free from any past logging, though not entirely without signs of man's earlier presence*. Both areas carried rainforest of the usual mixed composition (an average of 37 species over 10inches D.B.H. per $2\frac{1}{2}$ acre plot at Curua, and 110 species on 33 acres; an average of 43 species per plot at CBA and 98 on 30 acres). Most of these species had unknown timber qualities when work commenced in 1956, though studies have since then been made on many of these enabling a tentative list of the 50 most important timber species from the lower Amazon to be prepared (C.H. Holmes pers, comm.). This list is given in Appendix 4.

The silvicultural studies in these areas commenced in 1956

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* Although the planalto at Curua was, until very recently, quite remote from any habitation, and at its nearest point is 3 miles from the river "highway", barely a tree of Bertholletia excelsa was seen without at its base a heap of decaying fruit from which the "Brazil Nuts" had been extracted, nor a tree of Manilkara huberi without the scars of past chicle-tapping operations on its trunk.

and 1957, and the results have been reported, briefly in 1960 and in considerable detail in 1961, by C.J.W. Pitt, the first silviculturist with the F.A.O. Mission. Apart from planting studies, both in open plantations and for enrichment, Pitt concentrated on treatments aimed at inducing and encouraging regeneration ahead of logging. In these treatments an initial climber cutting was followed by selective poisoning to open the canopy to various degrees. The climber cutting was more necessary in the somewhat disturbed forest at CBA than in the virgin forest at Curua. Canopy opening was was carried out from above: in light openings only useless stems in the overstorey were poisoned, whereas in heavier treatments some removal of lower storey trees was also carried out. The heaviest treatments reduced the basal area of stems over 10 inches D.B.H. from 90 sq ft per acre in untreated stands to about 50 sq ft per acre after poisoning. In addition, some cutting back of undesirable undergrowth up to 2 inches D.B.H. was carried out, the actual prescriptions varying somewhat from plot to plot. (The prescription in some plots to "cut back those undesirable species with opposite leaves" (Pitt, 1961, p.57) is a reflection of the frequency of Melastomaceae in the undergrowth of these rainforests). Some details of the treatments carried out and of the results in regeneration of desirable species are given in table 54. The increase in regeneration with the degree of opening is clearly shown, this coming largely from such light-demanding species as Goupia glabra, Didymopanax morototoni and Jacaranda copaia. The growth rate is also better in the more open plots. Pitt, who considered that in an area such as Curua it is better to aim at obtaining regeneration of the less valuable but still acceptable species like Goupia, rather than the more valuable but generally slower-growing and less amenable species such as Manilkara huberi, Cordia goeldiana and Cedrela odorata, concluded that in pre-exploitation treatment the canopy should be heavily opened, by poisoning in the lower storeys and cutting the undergrowth.

Attempts were also made to induce regeneration of Cedrela odorata around a number of seed trees. Various degrees of canopy opening were tried, coupled with varying seed bed preparations such as cleaning to expose the mineral soil, cultivation, and burning the slash and undergrowth. No seed was produced until the third year after initial treatment, when excellent establishment was obtained in a plot where undergrowth cleaning had occurred shortly before seed fall. In other plots, where the undergrowth was denser, heavy mortality occurred at the start of the dry season, even when the undergrowth had been cleared subsequent to the seed fall.

Pitt also examined the possibility of obtaining regeneration by treatment after logging. At CBA exploitation over 7½ acres yielded an average outturn of 580 cu ft per acre (70 cu ft of which was from species not currently acceptable as economics) from 5 stems per acre, and the remaining stand was further opened by poisoning and undergrowth clearing. Regeneration was prolific, the most common species being Ocotea sp., Jacaranda copaia and Virola sp., though 15 desirable species in all were recorded as regeneration. Jacaranda appeared in the more open patches, with Virola where there was still some shade retained. At Curua a small area was completely cleared and the debris burnt. Within 18 months there was sufficient regeneration to warrant a cleaning. Goupia glabra was the most frequently occurring desirable species, and in tending operations other desirable species were favoured

TABLE 54

Pre-Exploitation Treatments in Amazonian Rainforests

Location	Curua						C.B.A.					
Canopy Opening	Control		Light		Heavy		Light		Medium		Heavy	
Trees/acre poisoned:												
Overstorey	-		7		10		16		16		19	
Understorey	-		-		19		-		10		27	
Regeneration:	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
At Treatment	38	3	26	3	22	4	62	8	36	6	60	9
After 2 years	50	9	63	12	77	18	70	8	79	8	92	9

Note: For results of regeneration, (1) is the percentage of milliacre quadrants stocked with desirable species under 5 ft high; (2) is the number of desirable species present in the regeneration.

in preference to this. Table 55 shows the stocking and growth $1\frac{1}{2}$ and $2\frac{1}{2}$ years after burning: the unstocked milliacre plots are mostly in patches where the initial fire was very intense; these remained almost free of any plants even after 3 years.

In summing up the results of the experiences at Curua, Pitt concluded that the following stages were probably necessary in regenerating these forests:

1. Climber cutting, to let in more light, destroy one of the worst group of weeds, and reduce subsequent logging damage.

2. Freeing young plants of desirable species and thinning out groups of such species.

3. Possibly poisoning large undesirable stems. This operation is however regarded askance by members of the F.A.O. logging team, who point out that the dead trees constitute a very real hazard at exploitation: such stems are more liable than living trees to break up during the disturbance of the forest in logging, and despite the impression sometimes gained from the literature the large limbs and dead trunks are still very heavy and fall under the same pull of gravity as any other object.

4. Possibly soil treatment around valuable trees to promote their regeneration.

5. An inventory of larger stems prior to logging to indicate which trees should be removed and which, for seed supply purposes, should be retained.

6. After logging, the freeing of advance growth, the destruction of large undesirables, the burning of heaps of branch wood and the poisoning of understorey trees in dense patches.

7. In the second year after logging, an assessment of regeneration to serve as a guide for further tending such as weeding, cleaning or thinning.

8. Enrichment planting, particularly in burnt patches where a very fierce fire has prevented the establishment of natural regeneration.

9. Periodic operations of a "refining" nature, part of the aim of which should be to keep the B.A. of the treated forest in the range of about 65 to 80 sq ft per acre, compared with the 105 to 120 sq ft of the natural forest.

Pitt also accumulated much valuable information on the silvicultural characteristics of many of the most important Amazonian species. His studies are unlikely to be surpassed for a long time in the amount of detailed and practical information which was gathered in 5 years from a virtually scratch start.

Other Rainforest Areas in America

America, as was shown in Chapter 1, has the largest area of rainforest in the world, much of it still undisturbed by man. Probably

TABLE 55

Development of Regeneration after Clearing and Burning, Curua.

Time after Burning	1 Yr 7 Months	2 Yrs 7 Months
% milliacre quadrats stocked	59%	79
% with Goupia	55%	49
% with other desirable spp.	4%	30
No. of other desirable spp.	3	11
Mean Height Goupia	3.0 ft	8.2
Mean Height all spp.	-	8.2

because of these large areas of virgin forest, the management of rainforest is generally less developed in the Americas than elsewhere, though as has been discussed there are notable exceptions to this statement. However, over much of the region the position today is little different from that of 30 years ago, when Gill (1931) drew a somewhat gloomy picture of forestry developments in the Caribbean basin. Recently Lamb and others (1960) have reported on forestry activities through part of this area, and it is apparent that most of the countries concerned have preferred to concentrate their efforts in plantations rather than in the management of natural rainforest stands. Countries where rainforest has been replaced by woodlands and savannas dominated by Pinus spp. have similarly preferred to emphasise the management of these softwood stands rather than devote too much attention to the hardwood-dominated rainforests: British Honduras and, within the last few years, Nicaragua provide examples of this policy.

A change in this attitude is nonetheless occurring, largely prompted by the two professional forestry schools in tropical America, the Inter-American Institute of Agricultural Sciences at Turrialba, Costa Rica and the University of the Andes at Merida, Venezuela. Holdridge (1957) has discussed the work being carried out by the first school in the rainforests of Costa Rica, and concludes that it should be possible to develop suitable silvicultural techniques, provided work is restricted to areas where economics enable considerable cultural work to be carried out or where local species, such as Cordia alliodora in some second growth stands, can be produced with a minimum of silvicultural effort. From Venezuela Lamprecht (1954) has published an account of the montane rainforests in the Mucuy Valley, at an altitude of from 7,200 to 10,500 ft. Lamprecht has proposed the introduction of a selection system for these forests, in which regeneration of the main species (including Podocarpus spp. above about 8,500 ft) can become established beneath the undisturbed forest canopy. A selection system is preferred to guard against damaging the protective functions of these high altitude forests and to avoid the entry of bamboos and undesirable secondary species, which appear following heavy logging.

Ghana

The Republic of Ghana (formerly the British Colony and Protectorate of the Gold Coast) lies at the eastern end of the disjunct western belt of rainforest in tropical Africa. The vegetation has recently been described by Taylor (1960) and, as might be expected from Ghana's geographic location, it shows many close similarities with the vegetation of Nigeria. In the sense used in this report the commercial forests of Ghana can be classed as evergreen seasonal and and semi-evergreen rainforests, and these still cover about 15,000 sq miles, of which 5,800 sq miles have been dedicated as forest reserves. Logging in the past has tended to be highly selective. Foggie (1953) notes that of 190 species known to exceed 12 inches D.B.H., from 95 to 120 are normally encountered in forest enumerations, but of these only 10 are certain to be marketed and, under the best marketing conditions, only 25 species can be expected to be removed in exploitation. For this reason logging has been highly selective, though Foggie observes that many of the trees remaining cannot be classed as weeds, even though they are not commercial species at the present time.

Silvicultural treatment has been carried out in the natural rainforests, along with the establishment of open and enrichment plantations. Two main approaches have been taken in the natural stands: (1) the conversion to a uniform forest by the tropical shelterwood system (T.S.S.), and (2) improvement by cyclical fellings and treatment on a selection system (Foggie and others, 1952).

T.S.S. was first tried in 1945. It was adopted in the original form used in Nigeria and has continued more or less in that form since then. Taylor (1954a) studied various modifications in the techniques, noting that where the forest canopy was opened to medium density initially the desirable regeneration of Meliaceae (Khaya, Entandrophragma and Guarea) appeared and was able to make good growth for several years, whereas with heavier initial opening of the canopy these species were less common and were replaced by Chlorophora, Nauclea, Terminalia and Triplochiton. As a result of these findings the following timetable of operations was adopted.

Year 1	Climber cutting, then poison or cut all useless stems up to 4 inches D.B.H. to open canopy to medium density.
Year 2	Poison all large crowned trees in lower storeys to open canopy to light density.
Years 3, 4 and 5	Annual cleanings to free desirable regeneration from weeds.
Year 6	Exploitation.
Year 7	Cleaning and coppicing damaged regeneration.
Year 10	Climber cutting.

Taylor believed that a regeneration assessment should be carried out in year 5 or 7 to indicate areas where, on account of poor regeneration stocking, enrichment planting would be required.

T.S.S. has only been applied to those forests with a moderately normal structure and sufficient seed trees to provide the regeneration. The cost of treatment (about 20 man days per acre) is high compared with the revenue (equivalent to 3 to 12 man days per acre) obtained from exploitation, and as a result only part of the forest reserves are treated in this manner in Conversion Working Circles (Foggie, 1960). A post-exploitation system has also been tried experimentally. In this the coupe was given a climber cutting and the canopy was opened to medium density immediately after logging, and further opened the following year. In areas unaffected by logging the effect was similar to the routine T.S.S., but more reliance was placed in regeneration already established on the ground when treatment started (Foggie and others, 1952).

The other, and more widely used, form of treatment in Ghana has been that of cyclical fellings. This has appealed because forest assessments in the country have indicated that with most species, including the valuable Meliaceae, there are ample smaller stems present to replace the large ones removed in logging (see for examples the forest enumerations given in detail by Taylor, 1960). At the same time there is an admittedly irregular, but nonetheless existent, series of age/size classes present and "deep consideration should be given to the possibilities of using this before abandoning it and trying to create a wholly new system of age class distribution" (Foggie and others, 1952) - particularly when even-aged rainforest regeneration produces a crop that is barely uniform in any other respect (Foggie, 1960). It is appreciated that such a system must be accompanied by treatment to favour the commercial species, promote their regeneration and remove the useless competitors, but despite the reversion to this system in Ghana the form that such treatment should take is still not clear (Foggie, 1960).

The Former Belgian Congo

The great central zone of rainforest in Africa occurs in the basin of the Congo River, a basin that is largely occupied by the former Belgian colony of the Congo. About 45% (400,000 sq miles) of this large territory is covered by rainforest of various types, among which equatorial, evergreen seasonal, semi-evergreen, swampy and, in the extreme east, montane rainforest can be recognized. Timber production from these forests has been estimated at about 25 million cubic feet per annum (Forestry Service, Belgian Congo, 1958), with the average yield obtained being about 300 cu ft per acre but rising to nearly 1,500 cu ft per acre under the most favourable conditions (Donis, 1958).

Silvicultural emphasis in the Congo has been on artificial regeneration, and wherever possible open plantations have been created. Humblet (1958) states that an annual area of nearly 20,000 acres was being regenerated in this way, in conjunction either with clear felling operations to provide fuel for the railway and river transport services, or with a form of taungya farming associated with the commercial cultivation of bananas in the Mayumbe district near the mouth of the Congo River. Where conditions did not permit such intensive treatment enrichment planting in lines was carried out; this proved highly succesful in secondary forests and in areas with rather open stands of small trees, but was abandoned after trial in the denser stands (Forestry Service, Belgian Congo, 1958).

Treatment involving natural regeneration was barely applied in the Congo as a routine operation, but was the subject of considerable study by the agricultural research organization (INEAC) at their forest experiment station at Luki, in the Mayumbe District. At this station Donis and Maudoux (1951) developed the technique known as l'uniformization par le haut*, which in 1955 was being applied on a pilot scale at the rate of about one square mile a year (Dawkins, 1955a). Mayumbe is a hilly district with a mean annual rainfall of about 50 inches and a dry season of 5 months, but the long dry season is greatly modified by almost incessant fogs coming in off the ocean. The rainforest (probably evergreen seasonal) is marked by the presence of much Gossweilerodendron balsamiferum in undisturbed stands, while Terminalia superba tends to dominate the more extensive secondary forests in the district (Wilten, 1957).

The aim of l'uniformization par le haut is to convert the mixed, all-aged rainforest to stands that are much more uniform in condition. Treatment is preceded by an intensive enumeration of the stand, and

* I am unable to suggest a snappy English translation for this phrase.

the results of the enumeration are then used to determine the precise form of the treatment to be applied. In its basic form the treatment removes the useless overstorey trees and vines and reduces the differences in size classes by selective poisoning in the smaller stems: Dawkins (1955a) considers it to be essentially a weeding operation on a grand scale.

The initial enumeration is carried out at a 10% intensity for all stems over 2.5 inches D.B.H. (20 cm. G.B.H.), on transects of half chain square (10 meters by 10 meters) quadrats. On every tenth quadrat (1% intensity) regeneration under 2.5 inches D.B.H. and all lianes (heavy vines) are also assessed. From the enumeration results a stand table is prepared: table 56 shows the summary of such a stand table for a 44 acre block assessed in 1948 (from Donis and Maudoux, 1951). In practice individual species are shown in the table, in order to determine which species should be eliminated from the stand during treatment.

Once the sizes and species of stems to be eliminated from the stand have been determined from the stand table, treatment is carried out. All climbers are destroyed and all useless stems and species over 20 inches D.B.H. are poisoned, along with certain smaller species with characteristic bad form or heavy crowns. In addition a proportion of other understorey stems are cut or poisoned these being determined by an examination of their size frequency distribution in the stand table. Of these various operations the first and most important is invariably the heavy opening in the upper storey canopy. As a result of treatment Donis and Maudoux estimate that light intensity at ground level is increased to 30-40% of full daylight (Richards, 1952, quotes 1% of full daylight as being an average value in undisturbed rainforest). Table 57 (from Donis and Maudoux) shows the effect of l'uniformization par le haut on the stand considered previously.

After treatment the remaining upper storey trees are virtually in the open while the understorey trees have much reduced competition and the regeneration present at the time of treatment is left in good condition to make further growths. Dawkins, who visited Luki in 1954 stated that in the blocks treated 6 years earlier the absence of large climbers and the crown freedom of the large and medium sized trees was most striking. He noted that some development of undergrowth and climbers had followed the opening of the canopy but this was insufficient to prevent abundant recruitment of desirable seedlings. Donis and Maudoux felt that further treatment would be needed to repoison any resistent trees, to make further openings in the under-storeys and to free the regeneration from climbers. Although at Luki l'uniformization par le haut was being applied to virgin forests ahead of logging, they believed it would be equally suited to forests exploited in the past. At Luki it was expected that logging would follow treatment in 10 to 20 years when the stand would be suitable for a near selection system of management, the smaller size classes having benefited greatly from the initial operation.

Donis and Maudoux claimed this treatment to be a cheap method of improving extensive areas, well suited to the silvicultural conditions and type of exploitation in tropical forests, requiring no special knowledge other than that obtained from the enumeration, and capable of being applied throughout the year. However, it should be

TABLE 56

Stand Table for 44 acre block prior to Treatment, Luki, Belg, Congo.

(Stems per acre shown)

Diameter Class - inches

Final Canopy Storey of Species	2.5-5	5-7.5	7.5-10	10-12.5	12.5-15	15-17.5	17.5-20	20-22.5	22.5-25	25+	Total
Upper Storey	61.4	26.9	16.9	9.7	6.7	3.7	2.3	1.7	1.3	3.9	134.5
Middle Storey	93.5	36.2	14.2	6.4	2.6	1.5	.6	.2	.1	.1	155.4
Lower Storey	14.5	4.8	1.5	.3	.1 (12.5-17.5 combined)		-	-	-	-	21.2
Others	6.9	1.3	.5	.2	.1	.1	-	.1 (20-25 combined)		-	9.2

TABLE 57

Effect of l'uniformization par le Haut on Stand, Luki, Belg. Congo.

	Present initially	Stems per acre		Stems of Economic spp. retained.
		Eliminated	Retained	
Upper Storey spp. 20" D.B.H.+	7	5	2	2
10-20" D.B.H.	22	-	22	5
2.5-10" D.B.H.	104	-	104	27
Regeneration (-2.5" D.B.H.)	6,000	-	-	4,600
Middle Storey Spp.	155	55	100	-
Lower Storey Spp.	21	17	4	-
Middle & Lower Storey spp. - Regeneration	5,200	-	-	-
Lianes - Developed	98	98	-	-
Regeneration	9,000	-	-	-

noted that the treatment makes no provision for inducing regeneration: as Donis and Maudoux acknowledge, at Luki they were fortunate in having dense regeneration of certain high-value species. Maudoux (quoted by Donis, 1958), in a study of 572 half chain square quadrats, found an average stocking of 3,500 stems per acre of regeneration of upper and middle storey species in undisturbed forest; 85% of this was less than 3 ft high but 34% (1,180 stems per acre) was of Gossweilerodendron alone, and other valuable species were also well represented and had high frequencies in all quadrats examined. Where regeneration is less plentiful the long term effects of l'uniformization par le haut might well be less satisfactory, unless special provision is made to induce regeneration either naturally or artificially.

Former French African Territories

Until the winds of change blew with gale-like force across Africa, more than half the rainforest belt extending west from the Congo was under French administration. Although these former French possessions are now split into a number of independent republics, it is convenient to deal with them together.

Throughout these territories, which include considerable variations both structural and floristic in their rainforest communities, the silvicultural emphasis has been on artificial regeneration, particularly by enrichment planting. Indeed some of the world's finest examples of enrichment planting are to be seen in these areas (Dawkins, 1961). With this concentration of effort on the artificial, relatively little attention was paid to the use of natural regeneration, and indeed Aubreville (1953a), while admitting that natural regeneration could give excellent results in certain circumstances, has recorded his scepticism of the wisdom of spending too much time or money on the use of natural regeneration in West Africa. Aubreville divided systems using natural regeneration into two types, those aiming at inducing fresh regeneration and those where existing advance growth was tended, and it was the former that he doubted most - thus prompting a defence of practices in the former British West African territories by Taylor (1954b). The tending of advance growth has, however, been the subject of more than a little effort by the French. Aubreville (1957) mentions that good results were obtained in the Ivory Coast by releasing advance growth of Tarrietia utilis, while the growing and tending of stands of Aucoumea klaineana has largely dominated forestry activity in Gabon (Gauchotte, 1957).

Aucoumea klaineana (Okoumé) is a fast-growing, secondary rainforest species confined to Gabon and the neighbouring territories of Rio Muni and the coastal area of the former French Congo. It is believed to be a native of swampy forests, but it rapidly colonizes unburnt land after clearing. It is extremely intolerant of shade and is succeeded in the secondary succession by such species as Khaya ivorensis, Terminalia ivorensis and T. superba (Becking, 1960). While enrichment has been the main method used to regenerate this species, existing stands have been sought out, small stems freed of competition to speed up their growth, and older stands thinned out to optimum stocking. Over the period of 5 years, 1949-53, some 17,000 acres of Aucoumea were liberated in this way (Gauchotte, 1957).

From Cameroun Morellet (1958) has reported work being undertaken in the Mbalmayo Forest, where Triplochiton scleroxylon

TABLE 58

Development of Stand after Treatment, Mbalmayo Forest, Camaroun.

		After Initial Treatment	3 years later
Desirable Stems/acre:	Seedlings (under 5 ft high)	5.1	14.4
	Saplings (5 ft high - 4 in D.B.H.)	3.7	10.5
	Trees (4 in D.B.H.+)	3.3	3.8
	All sizes	12.1	28.7
% Blocks	(2½ acres) stocked with:		
	40+ all sizes per acre	8%	46%
	20+ trees per acre	4%	30%

and Terminalia superba predominate on abandoned farm land, with the West African Meliaceae frequent in the older secondary forest. The forest is divided into $2\frac{1}{2}$ acre (1 hectare) blocks and a general liberation treatment is carried out with climber cutting, clearing of competing herbaceous growth, and the girdling of useless species overtopping desirable advance growth (except if overtopping Chlorophora excelsa). Ten species are listed as desirable: 6 Meliaceae, Triplochiton, Terminalia, Chlorophora and Erythroxylum mannii. After treatment a tally is made of the desirable stems remaining on each block, and the treatment is repeated after 3 years. Originally the operation was designed only to favour the growth of existing stems, but a reassessment of the first area treated (770 acres), following retreatment, showed a considerable increase in desirable stocking (table 58). Morellet considered that further treatment should be abandoned in those blocks with neither 40 desirable stems per acre of all sizes nor 20 trees per acre larger than 4 inches D.B.H., but blocks with over 20 trees per acre should be given further climber cuttings and girdlings of competing stems, while blocks with less than 20 trees per acre, but more than 40 stems of all sizes, should receive more intensive cleanings until 20 of the stems per acre reach 4 inches in diameter.

On this same forest a combination of agriculture and natural regeneration was tried, $2\frac{1}{2}$ acre blocks being let out for farming, but with all desirable stems being retained during the period of clearing and farming. The results were apparently successful, but Aubreville (1957) remarks that its need for a consenting population of farmers and for a strong forester rather limits its field of application.

Finally from these former French territories, Foggie (1960, in welcome English for a change) states that recently a system resembling l'uniformization par le haut has been commenced in the Ivory Coast. Here climber cutting is followed in turn by the removal of unwanted upper storey trees, thinning in the middle storey and finally careful openings in the lower storey, avoiding conditions likely to cause a resurgence of climbers. The emphasis is clearly on opening the canopy from above. If 40 saplings or poles per acre are established in this stand it is regarded as stocked; if less than 40, enrichment planting is carried out. Cleanings are carried out every 3 years for 10 years to prevent the understorey swamping the valuable regrowth.

Uganda

Uganda lies on the uplands of East Africa, sandwiched between the former Belgian Congo on the west and Lake Victoria in the southeast. The vegetation is mostly savanna woodland and steppe, but towards the west there are some small, isolated areas of rainforest which are remnants of a larger rainforest belt now converted to savanna by pressure of fires and farming. These patches form the eastern limit of the great rainforest zone in the Congo basin. Although occurring at relatively high altitude (in vicinity of 3,000 ft), the rainforest is probably best regarded as of the evergreen seasonal type. Eggeling (1947) has given a detailed description of the ecology of one of these patches.

Up until 1952 silvicultural work in Uganda was concerned chiefly with artificial regeneration, both in plantations and as enrichment planting, the latter being applied to the rainforest areas. However since then there has been a change to the use of natural regeneration.

Dawkins (1957a) has given the reasons for this change in policy as the rise in costs (especially of labour), labour shortages at the time of planting, heavy losses due to game, stagnation of the seedlings due to constant shading in of the lines, and chagrin at finding natural regeneration to be more plentiful than the artificial, and frequently also more healthy.

The treatment now applied relies on the removal of the original crop in one operation. Prior to this logging a refining operation (Dawkins, 1955b) is carried out, aimed largely at getting the existing regeneration on the ground firmly established before the economic stems are removed. While it is financially more desirable to carry out the refining at or about the same time as logging, it appears that the regeneration is in better condition to respond after logging if the refining is carried out several years beforehand, and this problem is under study (H.C. Dawkins, pers. comm.). The form of the refining treatment depends on the results of a regeneration sampling closely derived from the linear sampling techniques of Malaya. Unproductive gaps and thickets receive no attention, scattered regeneration is freed from vines and interfering stems, while in areas of abundant regeneration all undesirable stems over a minimum size are removed. A 3% solution of mixed butyl esters of 2,4D and 2,4,5T in diesel oil, applied as a basal bark spray, is used to remove unwanted stems, arsenic being barred on health grounds (Dawkins, 1953; 1957b, 1958). Subsequent tending treatments to the new crop are similarly based on the results of linear sampling.

Reunion

The French island of La Reunion lies in the Indian Ocean about 400 miles east of Madagascar, at about lat. 20°S. With the British island of Mauritius and some smaller islands in the vicinity, it forms part of the Mascarene Islands. Its vegetation is of rainforest and can probably be compared fairly closely with the communities studied by Vaughan and Wiehe (1937, 1941) on the neighbouring island of Mauritius.

Silvicultural work in these rainforests has been undertaken since 1950 and has been recorded by Miguet (1955). The aim is to replace the natural mixed stands by simpler communities with only a few dominant species. The choice of these species has been dictated by local tradition in the use of timber, and the main desirable species are *Imbricaria maxima*, *Mimusops calophylloides*, *Terminalia benzoin*, *Diospyros melanida*, *Ocotea cupularis*, *Calophyllum inophyllum* and *Elaeodendron orientale*. To these are added a few other rarer endemic species and also several exotic species (including *Cinnamomum camphora*, *Swietenia macrophylla* and *Grevillea robusta*) which are being introduced into the stands to provide seed for future crops.

Some 11,000 acres of forest are to be treated, and the rotation has been set at 150 years: this requires an annual coupe of 75 acres, but as a safety precaution only 60 acres are being treated each year. The sequence of treatment operations is as follows:

1. August: Mark all dead trees for sale. The buyer is then responsible for clearing all undergrowth and stacking the debris at the time of exploitation. As a result of the clearing the forest can be viewed more easily, and usually reveals much advance growth from 6 to 20 ft high.

2. October: Brand living trees for sale. Miguet states that the stand density after these trees are removed should be as for regenerating Oak, presumably in the seeding felling of the uniform system. A shelterbelt ½ chain wide is left around the coupe, but within the coupe all stems of undesirable species are branded, while retaining for seed trees as many well formed stems of desirable species as possible. Where well formed stems are scarse any stems are retained, and where there is an overabundance of suitable seed trees the rarer species are preferred.

3. Exploitation is carried out normally from November to April, and must be completed by July. While mechanical logging would be preferred this is economically impossible and the logs are squared and pitsawn on the site. Refuse and tree tops are roughly heaped, there being little market for this material as fuel.

4. After exploitation there is a very open stand with an open cover of sparse crowned seed trees, large gaps, some dense patches of advance growth, and a lighter scattering of advance growth over the whole area.

5. November - January: Broadcast sowing of seed in situ. Most of the species ripen their seed at this time, and the choice of species sown depends largely on the availability of seed at the time. However these normally include Imbricaria, Mimusops and Terminalia. The seed is cheap and is shown at the rate of about 4,000 to 6,000 seeds per acre, with resowing being carried out if necessary in March and April. The sowing is carried out throughout the exploited stand, except under the dense clumps of advance growth where a local palm, Acantophoenix rubra, is sown. This species grows well under heavy shade and is of considerable local value.

6. Regeneration is normally completely established in the year following sowing, and any poor formed or old seed trees are then removed.

7. Tendings appear necessary at intervals of 3 to 4 years.

The stand after treatment contains a mixture of regeneration, poles and larger stems, and it is expected that in future the treated forest will be managed by volume control, presumably on a selection system. One interesting feature of the treatment is the use of in situ sowing. Miguet states that experiments have proved that nursery work is injurious to seedlings on the island, and that much better results are obtained by sowing in the field, preferably under open conditions.

India and Pakistan

Rainforest in the Indian subcontinent (excluding the Andaman Islands: see below) is confined to two areas, one along the Western Ghats in the south Indian peninsula and the other lying northeast of the Bay of Bengal, in Assam and East Pakistan. In both areas the rainforest is mostly of the evergreen seasonal type, with some submontane and montane rainforest occurring at higher altitudes. Usually, though not invariably, the Dipterocarpaceae are well represented in the rainforests, most commonly by Dipterocarpus spp. (Champion, 1936a; F.A.O. 1960b).

Griffith (1947) has summarized the experience gained in treating Indian rainforests prior to 1939 in four main points:

1. Where regeneration is absent it is usually not possible to induce it.

2. Where regeneration is present it can be brought to pole size by tending.

3. General workings should be of the selection type, with more concentrated fellings where regeneration is present followed by a fairly quick lightening of the canopy from below upwards.

4. Compensatory plantings should be made in suitable areas to allow for those areas without natural regeneration.

Based on these principles the emphasis in treating Indian rainforests has for a long time been on the use of a selection system, coupled with improvement operations to promote the development of advance growth. In some areas, including East Pakistan, conversion to plantation has been favoured over treating the natural stands (Krishnaswamy, 1952; Ghani, 1957), but for the most part some variation of a selection system is used, despite the doubts that have been cast on the general suitability of selection management for Indian conditions (Champion, 1929; 1936b).

The usual form is for a fairly long felling cycle (25 to 45 years) and the avoidance of excessive canopy openings by imposing girth limits and restrictions on the number of trees per acre removed and on the proximity of felled trees. Artificial regeneration may be employed after logging, though in most areas adequate advance growth is already present. Following logging, tending operations are carried out by cleaning the established regeneration and by gradually raising the canopy level (Stracey, 1959). The actual details vary in different parts of India. Thus in the forests in Assam dominated by Dipterocarpus spp. and Mesua ferrea, which regenerate well, the selection felling is followed by three years of tending which involves climber cutting, weeding to free the regeneration, and girdling or felling in the understorey to raise the height of the lower canopy to about 30 ft, followed by selective girdling of unwanted stems in the middle storey. However, in the Assam forests dominated by Phoebe goalparensis and Amoora wallichii, regeneration is usually very scarse; here heavier fellings are carried out leaving a fairly open canopy, and enrichment planting of Phoebe is then performed beneath this remaining shelterwood (Kadambi, 1957). Seth and Dabral (1960) have given figures to show the response by the regeneration to tending in the Dipterocarpus - Mesua association: in unexploited forest the advance growth averaged about 1 ft in height; from 5-10 years after logging, but without any tending, it averaged about 2.5 ft; whereas in logged and treated forest of the same age it averaged about 7.5 ft in height. It was considered that the upper canopy was insignificant in its effect on the growth of the regeneration, the lower and middle storeys being much more important.

In Coorg (south India) treatment varies with the state of the forest. Where there is a preponderance of larger stems a low girth limit (4 ft 6 inches = 17 inches diameter) is applied, resulting in heavy canopy opening. Many secondary weed species invade the stands after logging, but these are controlled by intensive tending to favour the desirable regeneration. This treatment is regarded as an irregular shelterwood system. Where the size class distribution is more normal, a higher girth limit is imposed (6 ft = 23 inches diameter) and treatment resembles that in a true selection system, with relatively little opening being made in the canopy (Krishnaswamy, 1952).

Nair (1952, 1957) has given general reviews of silviculture in the rainforests of the Western Ghats. Of some 50 species reaching timber size normally only about a dozen are exploited, and these include both shade bearers (Palaquium ellipticum, Poeciloneuron indicum, Hopea parviflora) and strong light demanders (Dysoxylum malabaricum, Calophyllum elatum, Vateria indica). Logging under the selection system removes from 3 to 5 large trees per acre and these, in falling, may create gaps of up to 3 square chains in area, the gaps being rapidly invaded by worthless secondary species (Elateria cardamomi, Laportea crenulata, Macaranga peltata). Clearing the undergrowth is carried out several months ahead of the usual period of seedfall and, for certain species which it is hoped to regenerate, soil raking may also be performed. Weeding operations to favour the young regeneration are performed three times in the first year, roughly 3, 6 and 9 months after seedfall. In the large gaps caused during logging, direct sowing may be used to supplement natural regeneration. When the seedlings reach 2 or 3 inches in height they are thinned to a spacing of 3 ft. Weedings are subsequently carried out twice a year, and when the regeneration reaches the sapling stage the lower and middle storeys are progressively opened to admit more light. At the same time advance growth of the valuable species is also favoured in tending.

Andaman Islands

These Indian islands stretch in a north-south chain through the southeastern Bay of Bengal between lats. 10°30' and 13°40'N. There are four main islands with an area of about 2,500 square miles. Topography is generally hilly, rising to 2,400 ft. A somewhat deciduous type of forest occupies the foothills up to about 300 ft, and above this it is replaced by rainforest (probably evergreen seasonal) in which Dipterocarpus griffithii, D. turbinatus and Planchonia adamanica are the largest trees, with D. kerrii forming almost gregarious stands in some areas.

Logging commenced in the Andamans in 1857 and continued as uncontrolled selective exploitation up to 1906 when improvement fellings were introduced, but this early silvicultural work was considered unsuccessful. During the 1920's the apparently inevitable phase of trying artificial regeneration was passed through, also unsuccessfully, and in 1929 the selection type fellings were replaced by more concentrated logging, leading to the introduction of definite regeneration treatment in 1931. This treatment is based on the fact that seed years of the main economic species occur every 2-3 years, producing abundant regeneration which will persist on the floor of undisturbed forest for several years before it finally dies. Heavy canopy openings also cause the loss of this unestablished regeneration, but with a gradual raising of the level of the understorey the regeneration can be made to respond (Chengapa, 1944; Griffith, 1947). The current form of this treatment is discussed by Banerji (1957), who states that since 1933 it has been applied to over 30 sq miles and is proceeding at the rate of 3,000 acres (4.7 square miles) a year.

In the good seed years of Dipterocarpus spp., cutting of the undergrowth up to 25 ft high is carried out over all areas that are deficient in advance growth and that are scheduled for logging within the next 4 years. This ensures a reservoir of regeneration on the ground when the area is finally exploited. In the year preceding exploitation climber cutting is carried out. At exploitation all merchantable stems are removed, normally yielding 500 to 750 cu ft of timber per acre. Initial canopy lifting then occurs, being finished by March. In this operation the degree of opening is regulated by the nature of the regeneration, being heavier above the more light demanding species and those stems that are already well established. The canopy lifting is done by felling the smaller undesirable stems and by girdling the larger ones. The general result is to produce the highest possible, more or less continuous canopy, beneath which the coupe can be viewed from one side to the other. Weeding is carried out about August in the year following exploitation, and at the same time any previously girdled trees still living are regirdled and, if the development of the regeneration permits, the remaining canopy is removed, leaving the regeneration fully exposed. If the regeneration will not permit this early opening, the final removal of the shelterwood may be delayed until the third year. Tending, cleaning and climber cutting are repeated in August of the second year, and again in the third and, if necessary, fourth years. At each tending preference is given to the more valuable species present. Thinning is carried out in the sixth year after exploitation.

The schedule of operations in this treatment, which Banerji calls the "canopy-lifting shelterwood system", thus is:

At seedfall within 4 years of exploitation: Cutting of undergrowth

Year 1	Climber cutting
2	Exploitation
	Formation of high canopy
3	Tending, cleaning and climber cutting
	Removal of shelterwood (usually)
4	Tending, cleaning and climber cutting
	Final girdling of shelterwood if necessary
5	Tending and climber cutting if necessary
8	Thinning

Ceylon

Rainforest in Ceylon occurs towards the southwest of the island, giving way to more deciduous forest types in the north and east. Various associations have been recognized within the rainforest zone, these being determined largely by soil differences and past history (de Rosayro, 1942; 1957). Various species of the Dipterocarpaceae (Dipterocarpus zeylanicus, Doona spp., Shorea spp.) are the most important commercial species present (F.A.O. 1960b).

Research on methods of regenerating these forests commenced in 1938 after the failure of earlier shelterwood and improvement fellings to produce regenerated stands. It was found that regeneration was normally plentiful in undisturbed rainforest and could be increased in quantity by suitable pre-logging treatment. However, advanced saplings of some species (e.g. Doona gardneri, Vitex pinnata) failed to respond to canopy opening after long periods of suppression, though other species such as Dipterocarpus zeylanicus could withstand suppression for a number of years and still make good growth when conditions improved. Climbers were found to contribute appreciably to the density of the main middle storey (ecodominant) canopy. Weeds occurred prolifically in gaps, and had caused the earlier regeneration failures when too heavy early cleanings defeated their own purpose by encouraging even more vigorous weed growth. Various experimental treatments were tried, ranging from canopy lifting to removal of the overwood while retaining as much as possible of the lower storey and undergrowth. Based on the results of these experiments Holmes (1956-57) recommended that treatment should be:

Year 1	Climber cutting.
2	Reduce density of middle storey canopy to half by removing the large-and low-crowned stems (suitable for fuel) evenly through the stand.
4	Remove all overwood, leaving the undergrowth and lower storey trees.
7 or 8	Cleaning in regeneration, repeated at two-yearly intervals.

On the other hand, de Rosayro (1957) has recommended that in most forests a selection system should be employed, using a 10 year felling cycle with a minimum felling diameter of 20 inches. Intensive tending should be carried out during the felling cycle and yield control would be determined by regularly repeated 10% stand enumerations. For the forests dominated by D. zeylanicus, and also for secondary forests dominated by Vitex - Wormia - Chaetocarpus, he suggests the use of an irregular shelterwood system, removing the larger overstorey stems and building up the stocking of pole size trees which will then be permitted to reach maturity. Subsequently, he suggests, even-aged stands should be aimed at on these sites.

British Borneo Territories*

The two former British territories on the island of Borneo, Sarawak and North Borneo (now Sabah), have forests that are very similar to those of Malaya, though in most cases the actual species present are different. In both cases the timber industry is of considerable importance to the local economy, but whereas in Sarawak 90% of the export timber (16 million cu ft in 1959) comes from the peat swamp forests, in North Borneo 90% of the exports (43 million cu ft in 1959) are dipterocarps from the dry land rainforests (Forest Department, North Borneo, 1959; Forest Department, Sarawak, 1959).

The extensive Sarawak swampy rainforests have developed on deep peats that have accumulated to depths of up to 60 ft over the past 5,000 years (Forest Dept., Sarawak, 1960). The swamps typically show a concentric zonation of communities, from one dominated by

* Since 1963 these two territories have been joined with Malaya in the Federation of Malaysia.

Shorea albida in the centre to a mixed community rich in Gonystylus bancanus, the main export species, near the swamp edge. The forests are being worked on a 60 year rotation and exploitation is by means of railways constructed into the swamps, areas adjacent to the lines being logged. Strict departmental control over logging operations ensures the removal of all merchantable timber. Silvicultural treatment must follow immediately behind exploitation, as once the railway lines are removed for use elsewhere there is no access into the area. In the mixed communities selective poisoning of useless species is carried out, favouring the advance growth of Gonystylus and avoiding excessive canopy opening. In areas where abundant stems of Gonystylus under 20 inches D.B.H. remain after logging, only trees interfering with the development of these are poisoned. If possible it is intended to give a freeing treatment after 10 years. In the Shorea albida communities this type of treatment is successful if performed during a seed year, but these occur only at intervals of 5-8 years. Consequently planting is being attempted in these areas (Brunig, 1957; Forest Dept., Sarawak, 1960).

In North Borneo the commercial forests are very similar to the equatorial rainforests in Malaya, but are characterized by a smaller number of non-dipterocarps and by the presence of generally larger trees, heights of 240 ft and girths of 20 to 25 ft (75 to 90 inches diameter) being not uncommon. The most common commercial species is Parashorea malaanon which, over large areas, makes up 80% of all the timber trees, and in parts up to 98% (Walton, 1955). Plot figures for virgin rainforest in North Borneo quoted by F.A.O. (1960b) show an average stocking of 194 stems per acre, and a B.A. of about 172 sq ft per acre, over a total area of 19 acres: of these values 32% of the stems and 60% of the B.A. are represented by dipterocarps, and of the 21 trees per acre over 20 inches D.B.H., 15 are dipterocarps. Burgess (1961) has examined the structure and floristic composition of several stands of equatorial rainforest in the territory; the physiognomy illustrated in his profile diagrams is very similar to that discussed earlier in this report from the Malayan forests.

With this extremely close similarity between the lowland dipterocarp rainforests of North Borneo and Malaya, and in view of the close liaison that has always existed between forest services in the two areas, it is little wonder that the methods of silvicultural treatment developed in Malaya have been applied with equal success in North Borneo. Despite spasmodic fruiting by the dipterocarps, there is almost invariably a big reservoir of seedling regeneration present beneath the virgin forest; Nicholson (1958a) estimates an average stocking of 10,000 seedlings per acre. These are mostly virtually dormant, though certain more tolerant species, such as Dryobalanops lanceolata and Dipterocarpus spp., are able to make slow growth. However they respond rapidly to increase in light; 19 months after logging, 100 seedlings of Parashorea malaanon are recorded by Nicholson as having attained a mean height of 4.8 ft, with the 20 best at 7.8 ft and the tallest at 11.3 ft. The current treatment is:

1. Start treatment as soon as possible after logging is complete.
2. Girdle and poison (solution of 2 lb sodium arsenite per 1 gallon of water):

   (a) all non-commercial species over 2 inches D.B.H.

(b) all defective or malformed commercial species over 2 inches D.B.H.

(c) all commercial species over 23 inches D.B.H. (6 ft girth).

3. Cut climbers only when on economic trees.

4. Do not slash the undergrowth.

This is of course very much like the existing Malayan practice. The only forests where it has not proved satisfactory are stands that had been selectively logged in the past, followed by the current heavy logging of all economic stems above 6 ft girth. Such stands frequently have an abundance of climbing bamboos and sometimes also a lack of seedling regeneration, but these areas are not extensive.

Nicholson considers that it might be silviculturally desirable to delay poisoning for 5 years after logging, when the climber tangles are less dense and a thinning operation could also be carried out. However access to logged areas is usually difficult at this stage. In any case treatment should not be delayed much longer than 5 years, as it has been found that seedling suppression and mortality commences about that time: by 8 years after logging there is a 50% mortality of seedlings in untreated areas, compared with areas treated a year after logging.

The Forest Department, North Borneo (1959) gives a slightly different treatment prescription from that outlined above. Girdling is listed for stems down only to 6 inches D.B.H. in areas that have been heavily logged, and the more drastic canopy opening recorded by Nicholson is only applied in "islands" where there has been little or no timber removed and conditions are less open. This form of treatment corresponds closely with current practice in Malaya (Wyatt-Smith, 1961a; see also section on Malaya).

Growth of the regeneration after treatment is rapid, the best 40 stems per acre averaging about 0.6 inches diameter growth over the first few years, with mean D's.B.H. of 3.3 inches recorded at age 5 years and 3.7 inches at 6 years (Anon., 1961).

Up to 1959 treatment had been carried out over 265 sq miles, about 7% of the total forest under working plan.

Logging in North Borneo is normally by tractor, though in steep and mountainous country high lead logging has also been practised successfully (Walton, 1954). Nicholson (1958b) has studied an area of 108 acres, logged by tractor, where an average outturn of 4.7 trees per acre, with a B.A. of 30 sq ft and a volume of 1,300 cu ft, was removed. 53% of the remaining stems over 4 inches D.B.H. were damaged during logging, but there remained an average of 8 undamaged commercial stems per acre between 4 and 23 inches D.B.H., and Nicholson believed these should be retained until the evidence definitely showed they were moribund and unable to respond to the increased light. If they made satisfactory growth he felt they should be extracted during the regeneration rotation. Present policy is indeed to retain these advanced stems in the regenerated stand, at least for the time being. Walton examined an area after high lead logging, and concluded that even without any treatment a stocking of about 20 dipterocarps per acre could be expected to develop, and that with suitable treatment better results could be achieved.

One worry in regenerating North Borneo rainforests has been the presence of a convolvulaceous climber, Merremia borneensis. This can smother regeneration in a mat of twisted stems up to an inch thick and can climb 60 ft up into trees, persisting in old openings for many years. Walton (1955) felt that one of the most urgent needs in the territory's silviculture was to find a suitable method of controlling this climber. However he noted that in areas after mechanical logging it appeared to lose its vigour after a couple of years, and it seems as though the valuable dipterocarp regeneration is being obtained despite this weed.

The Philippines

In the Philippines dipterocarps again are the most important group of timber trees present, and are estimated to make up 75% of the standing timber volume in the islands in all types of forest. In the typical dipterocarp rainforest the dipterocarps may make up 95% of the stand (Mabesa, 1958). Walton (1954), who visited Basilan Is. (south-west of Mindanao), felt that the dipterocarps most nearly approached their optimum conditions here, with few other species present in the upper and middle storeys, and with a good representation of middle size classes, which are usually deficient in the dipterocarp forests of Malaya and North Borneo.

Past silvicultural work in the Philippines rainforests appears to to have been limited, and recent ideas are on a selection system relying on the stocking of intermediate size classes to provide the timber for subsequent fellings without silvicultural assistance (Walton, 1954). Walton examined several areas on Basilan Is. where high lead logging had been carried out, and he found abundant regeneration in the small sizes, as well as about 20 stems per acre over 4 inches D.B.H., of which 6 or 7 stems were over 16 inches D.B.H. He believed that careful tractor logging might enable these forests to be worked successfully on a felling cycle of about 30 years, but if high leads were to be re-used it would be necessary to restrict logging to once in each rotation of 80 to 100 years. The present policy is to aim at a felling cycle of about 40 years, with the retention of 60% of the trees up to 30 inches D.B.H. (F.A.O., 1960b).

Indonesia

The main commercial rainforest stands in Indonesia are in Sumatra and Kalimantan (Indonesian Borneo), and as elsewhere in Southeast Asia the forests show a dominance of dipterocarps which in both provinces provide the main timber species. Silvicultural work in Indonesia has been limited in the rainforest areas, the main emphasis having always been upon the management of the very fine and extensive Tectona grandis forests in the more seasonal parts of the country, particularly in Java. Recently however the Indonesian forestry authorities have shown an increased interest in the management of the rainforests (G.G.K. Setten, pers. comm.), and it seems that a method of treatment similar to that used in Malaya could ultimately be applied to these rainforest communities.

Papua - New Guinea

The eastern half of the island of New Guinea, and the adjacent islands of the Bismarck Archipelago, are under Australian administration. Apart from areas of eucalypt-dominated woodland in the drier and more seasonal parts of Papua, the territory was originally covered by rainforest or, in the extensive areas of poor drainage, by various types of swamp communities (see Chapter 5). This rainforest ranged from equatorial in the humid lowlands, to montane in the high ranges, though under pressure from farming large areas have been converted to grassland characteristically dominated by Imperata cylindrica ("kunai") and Miscanthus floridulus (Robbins, 1961).

Dipterocarps are present, but not common, in the lowland rainforests of eastern New Guinea. Two other types of rainforest communities have however strongly influenced silvicultural thinking in the territory. One is the submontane rainforest community which in local areas (notably in the Bulolo - Wau district)is dominated by the conifers Araucaria klinkii or A. cunninghamii; the second is the Eucalyptus deglupta community which occurs at an early stage in the succession of vegetation on to alluvial deposits, landslips and volcanic blast areas in New Britain, at maturity forming an overstorey of tall eucalypts above the developing rainforest.

In the submontane Araucaria stands, which are the territory's most valuable forests under management at present, the policy is one of direct conversion, after logging, to plantations of the two conifers. Planting commenced in 1950 and initially A. cunninghamii was planted almost exclusively, owing to difficulties in raising A. klinkii in the nursery. These difficulties have now been overcome and the aim is to plant equal areas of both species each year at an annual rate of 1,000 acres. Up to 1960 some 5,000 acres had been planted (Anon., 1960). In the lowlands planting is also well established, with Tectona grandis the main species used and with E. deglupta on the wetter sites unsuitable Tectona.

Relatively little work has been carried out with natural regeneration in the lowland rainforests, it being believed that nearly all this land will be required for agricultural development (F.A.O., 1960b). However recently treatment has started in New Britain, adjacent to one of the plantation areas. After logging all economic stems, a climber cutting is carried out, the undergrowth is removed, and useless small stems up to 12 inches D.B.H. are felled. Where the upper canopy was not sufficiently opened in logging large, undesirable stems are ringbarked or poisoned. The main species in these stands is Pometia tomentosa and there is usually abundant seedling growth of this present on the ground, responding vigorously to increased light. Other commercial species, including Dracontomelum mangiferum and Calophyllum spp., also appear plentifully in the regenerated stand. After canopy opening two annual tendings are given to free the regeneration, particularly from wild gingers (Zingiberaceae). In a 6 year old regenerated stand there were 350 stems per acre with a B.A. of 51 sq ft per acre; the 160 best stems per acre had a mean D.B.H. of 5.4 inches and the taller stems were over 60 ft high. This treatment has been applied to 800 acres, but because of diminishing forest resources close to Rabaul (the main town on New Britain) and the increasing number of commercial species it is thought that the present system may be altered to some form of selection system (Territory of Papua and New Guinea, 1959; Anon., 1960). Research is also being started on regenerating some of the territory's dipterocarp forests.

New South Wales

Unlike the countries and territories dealt with previously, the Australian state of New South Wales (N.S.W.) lies wholly without the tropics between lats. 28° and 37°S. Rainfall shows a general steady decrease from the eastern coast and nearby ranges to the state's western limits, where Broken Hill has a mean annual rainfall of 8 inches. The commercial forest belt is mainly restricted to the eastern section where rainfall is above 30 inches, though there are some important riverine eucalypt forests and mixed eucalypt - Callitris woodlands in the drier western regions. The forests in the east are chiefly composed of Eucalyptus spp., but it is estimated that at the time of European settlement (1788) there were about 1,500 sq miles of rainforest within the present boundaries of N.S.W. Agricultural development has however so destroyed these rainforests that probably little more than 500 sq miles remain at the present; these remnants are mostly included within the state's 10,000 sq miles of state forest (permanent forest reserves) (Forestry Commission of N.S.W., 1957).

The rainforests have a discontinuous distribution along the coast and highlands, occurring in areas with a rainfall exceeding about 60 inches a year. In addition there are numerous smaller patches occurring in drier areas where there are locally favourable topographic or soil conditions. Three main types of rainforest can be recognized in N.S.W., subtropical, warm temperate and cool temperate*.

Subtropical rainforest is found on soils derived from alluvium or basalt and occurs from sea level up to about 3,000 ft. Because of the fertile soils on which it develops it has been subject to greater destruction than the other types, but still makes up about half the total area of rainforest in N.S.W. It is more mixed in composition than the other types, with about 30 species of trees present to the acre and with a B.A. in the order of 200-250 sq ft per acre. One, other or both of the local Tarrietia spp. (T. actinophylla and T. trifoliolata) are normally the most common species present, though at high altitudes Sloanea woollsii may become dominant, while some of the state's most valuable timber species, including Toona australia, Gmelina leichhardtii and Flindersia spp., are also found in this type.

Warm temperature rainforest is usually marked by a dominance of the Cunoniaceae, especially Ceratopetalum apetalum which frequently makes up half or more of the trees in the type. In northern N.S.W.

* The synonymy of names used previously for the N.S.W. rainforests is:

This report	Baur, 1962b	Baur, 1957	Webb, 1959
Subtropical	Subtropical	Tropical	Notophyll Vine Forest
Warm temperature	Submontane	Subtropical	Simple Notophyll Vine Forest
Cool temperature	Temperate	Temperate	Microphyll Mossy Forest

The "dry rainforests" also found in N.S.W. fall outside the definition of rainforest used in this report (see Chapter 5).

it is found in the same general climatic regions as subtropical rainforest, but is confined to poorer soils derived from shales and acid igneous rocks; however in the south of the state it occurs also on basalt, but with strong floristic affinities to, and some structural characters of, subtropical rainforest. B.A. varies from 220 to over 300 sq ft per acre, usually being higher at the higher altitudes. About 20 tree species occur to the acre. In the northern part of the state Araucaria cunninghamii was formerly common as a scattered overstorey, regenerating within the forest: by comparison in the subtropical rainforests Araucaria normally regenerated on the margin between rainforest and eucalypt forest and was present above mature rainforest only as large, overmature veterans.

The third type of rainforest, cool temperate, is found above about 3,000 ft in northern N.S.W. in areas of high rainfall, frequent mist and cool temperatures; B.A. is in the order of 300-350 sq ft per acre, normally half of this being contributed by Nothofagus moorei. Ceratopetalum apetalum is often, though not invariably, associated as smaller stems. There are rarely over 10 tree species present on an acre.

The rainforests in N.S.W. were exploited from the earliest days of settlement and despite their much reduced extent still yield about 4 million cu ft of timber a year, much of this going into the manufacture of veneer. They also attracted some of the earliest silvicultural attention in the state, experimental plantations of Toona being started about 1890. Little serious work however was carried out until 1938, when the policy of conversion to plantations of Araucaria spp. was implemented. This continued to 1954 when rising plantation costs brought about a re-examination of this policy, leading to a cessation of open Araucaria plantations, more intensive research into the silviculture of the natural rainforests, and, in 1956, the introduction of the first working plans aimed at managing certain natural warm temperate rainforest stands.

The warm temperate rainforests, with their tendency towards single species dominance by the valuable Ceratopetalum, lend themselves to sustained yield management to a greater extent than either of the other types. Cool temperate rainforest is dominated by a species of considerably less value* and in any case is believed to be of greater importance for its protective functions than for timber production, while long past highly selective working in much of the subtropical rainforest has left these stands, always dominated by species in the lowest stumpage class, even poorer in worthwhile species.

In the Ceratopetalum stands there is usually a moderately good distribution of size classes, while regeneration is normally present on the forest floor and appears to become more densely established after logging. All but the lightest degrees of logging however lead to crown die-back developing in the remaining stems, presumably as an exposure reaction in these more climatically extreme rainforest communities. The die-back manifests itself as a gradual loss of crown starting from the tips of the twigs; its intensity increases with the

*Royalties in N.S.W. are determined in a manner very similar to that described earlier for North Queensland. While virtually any stem of suitable size and form can be used, species in low stumpage classes bring only minimum returns to the forest service, often barely covering the cost of measuring.

degree of canopy opening, and in areas of heavy logging it may lead to the death of most of the remaining trees, though in lightly logged areas the affected trees usually recover. The growth rate of Ceratopetalum has been under study for a relatively short time, but it is clear that it is slow: the oldest plot, in a selectively logged stand, suggests an average period of over 200 years for a stem to grow from 2 to 20 inches D.B.H., but with odd select stems showing up to double this rate (Baur, 1959).

For several reasons it has been decided to manage these warm temperate rainforests on a selection system. The existing size class distribution and the regular recruitment of regeneration, even in virgin stands, suggest that these forests are suited to such a system. Complete removal of the crop in one operation means selling a lot of small, but potentially valuable stems, at minimum rates. A given volume of Ceratopetalum logs over 17 inches centre diameter is worth roughly 10 times as much in royalty as the same volume in logs under 13 inches centre diameter. At the same time such heavy removal leads to severe die-back, so that there is little chance of being able to retain any undersize stems for a later cut, while with more frequent, relatively light fellings this advance growth can be relied upon to continue growing. There is also a further advantage to a selection system in this instance; with past Australian experience of fast-growing eucalypts and faster-growing Pinus radiata, there is a definite psychological barrier against taking more than 100 years to grow any tree crop, and Ceratopetalum would need at least this under a uniform system. However with a selection system one talks of felling cycles, and the rotation length, which has little meaning in this context anyway, need not be considered.

It has been found that the B.A. of a virgin Ceratopetalum stand can be reduced by about 40% without die-back becoming critical: thus a stand with an initial B.A. of 230 sq ft per acre can be reduced to about 140 sq ft with reasonable safety - provided the canopy is opened more or less evenly and extensive gaps are avoided. In practice a sample enumeration of all stems over 4 inches D.B.H. is normally carried out and the results used to determine both the existing B.A. and the size of stems to be removed on a straight diameter limit basis: thus in a given stand it might be found that, if all stems over 18 inches D.B.H. were removed, the B.A. would be reduced to 60% of the total. This diameter limit is used only as a guide in tree marking for removal; adjacent large stems are usually not both removed in order to avoid large gaps, while to compensate for these thinning is carried out among the smaller stems. Marking is done by subprofessional staff who have an extraordinary skill in balancing out the B.A., the final stand rarely being more than 10 sq ft outside the required level. In the initial cycle on virgin stands there is usually an appreciable B.A. held in large useless stems: allowance is made for these in tree marking, and after logging they should be girdled and poisoned.

In the growth plot referred to above, the stand had been reduced to about 160 sq ft per acre B.A. after light selective logging and the removal of useless stems: 12 years later the B.A. had increased to 200 sq ft, while the merchantable volume of stems over 10 inches D.B.H. had increased from 2,900 cu ft per acre to 3,800 cu ft, a volume P.A.I. of 75 cu ft per acre. On the basis of this strictly limited data it is believed that a felling cycle of about 25 years would be required for the B.A. to be kept in the range of 130 to 210 sq ft per acre. A shorter cycle could be used, but yields would be correspondingly decreased at each cut.

It is believed that a similar system may be suitable for cool temperate rainforest, with the aim to convert gradually from Nothofagus to Ceratopetalum dominance. In the subtropical rainforest, with its preponderance of low value species, thoughts still lie towards conversion, but with the interest now on eucalypts rather than conifers: very good results have been achieved with sowing the seed in situ after burning the logging débris, and this has become standard practice in the narrow stands of subtropical rainforest found along gullies in eucalypt forest. Eucalyptus grandis, which occurs naturally in such sites following fire, storm or logging damage to the rainforest, is the species used (see Chapter 9). Elsewhere the more extensive subtropical stands appear to need a steady process of improvement fellings and refining to favour what valuable stems are present: this however still lies in the future.

New Zealand

The original vegetation of New Zealand was to a very large extent rainforest, ranging from the Nothofagus - dominated cool temperate rainforest of South Island's "Westland" to subtropical rainforest with Agathis australis in the north of North Island. However 5 centuries of Maori occupation resulted in half these ancient forests being destroyed and incinerated, and 120 years of European settlement have seen half the residue treated similarly, so that today only about one fifth of the country remains under natural forest, most of this being either protection forest or non-merchantable because of the very low timber volumes carried (Cameron, 1960a; 1960b). This deliberate destruction of forest has on the one hand been largely compensated for by what must rank as one of the world's greatest artificial reforestation schemes, based on the fast-growing exotic Pinus radiata. On the other hand the destruction has been aggravated by the introduction of certain mammal pests: especially in areas where the remaining forest serves primarily a protective function on steep slopes, deer and other hooved browsing animals from the Northern Hemisphere have modified the undergrowth, prevented regeneration of the canopy trees, destroyed the thick absorbent covering of the forest floor and compacted the mineral soil, while arboreal possums from Australia have ravaged the crowns of the living canopy trees, debilitating and even killing them (McKelvey, 1960).

Species of Podocarpaceae (Dacrydium cupressimum, Podocarpus spp., Phyllocladus spp.) have been the most important commercial trees in the temperate rainforests and have dominated the stands over wide areas, particularly on the central plateau of North Island. However their very slow rate of growth and the difficulties in attempting to regenerate these conifers have made their silviculture an unattractive economic proposition: Cameron (1960a) has shown that on abandoned farm land some 50 years must elapse before podocarps even appear as seedlings in the secondary succession, and another 50 years before they attain small pole size.

In discussing the management of these remnant natural rainforests Cameron (1960b) has concluded that intensive management is only possible in the accessible forests with few species and relatively high yields. Such conditions apply to some of the Nothofagus and Agathis communities where either even-aged (e.g. by planting with Agathis or by use of a uniform system with Nothofagus) or uneven-aged management could be applied: uneven-aged management by a true selection system is suggested for Nothofagus in accessible forests of high protective or scenic value and for Agathis on a few particularly fertile sites where it is able to regenerate beneath its own shade. However for the bulk of the forests only a very extensive form of management appears practicable.

Where intensive management has been applied to Nothofagus spp., it has usually been by means of what is locally known as a uniform system which, according to Kirkland (1961), is in reality a system of clear felling with seed trees. Kirkland has studied the regeneration in stands dominated by Nothofagus fusca and N. truncata and the results of his work can be summarized as follows:

1. Heavy flowering occurs on the average of once every 5 years, in the spring of a year in which the preceding spring-summer-autumn had been hotter and drier than usual.

2. Seed fall occurs the following autumn and the seed germinates in the spring, producing over 100,000 seedlinings per acre (equivalent to a germination of from 2-3% of the seeds).

3. The seeds germinate in the thick litter (duff) which dries out rapidly in the summer, so that seedling stocking by mid-summer is greatly reduced. Survival is greatest under dense shade, least in open patches.

4. The species are light demanding and only produce pole crops in gaps. On the other hand they are extremely shade persistent, and the relatively few seedlings that survive from each seed year can hold on for a lengthy period in the undergrowth, forming a rich reservoir of advance growth.

5. In regenerated stands the regeneration is mostly from this advance growth, which can respond vigorously to release; in one pole stand examined by ring counts 69% of the stems came from advance growth, less than half of these had been under 10 years of age when released by logging. The oldest stem was over 100 years when released, having at that stage a stump diameter of 3.2 inches. During its long period of suppression this stem had grown at the rate of 62 rings per inch; in the first 12 years after release it produced 4.4 rings per inch.

6. The Nothofagus must be grown in a tight stand, otherwise the stems are "short-boled, heavily branched, dead-spiked and barely merchantable".

7. With the existing seed tree method of regeneration the new crop tends to be clumped, the isolated seed trees are highly susceptible to wind-throw and post-logging deterioration*, and any fresh regeneration faces heavy mortality in the open conditions as well as strong competition from weeds.

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* Post-logging deterioration is probably identical with the crown die-back referred to previously in the warm temperate rainforests of N.S.W.

The forests are such that repeated light loggings, as under a true selection system, are uneconomic, and Kirkland believe that management should aim at converting the virgin forests to even-aged Nothofagus, at the same time fostering any podocarp regeneration that may appear. He points out that the control of light and insolation, which are the main features of a true uniform system, can be achieved by manipulating the usually dense understorey of Weinmannia racemosa and Quintinia acutifolia. Based on these considerations he recommends using a small bulldozer to remove the surface litter some years ahead of logging. This operation should be as light as possible and should expose the somewhat scarified mineral soil over about half the area treated. Such exposed soil is also believed suitable for the regeneration of the valuable Dacrydium cupressinum. Regeneration of Nothofagus should then appear, and when this is sufficiently plentiful the understorey should be removed by poisoning and the new crop allowed to develop for several years before the overstorey is removed.

In earlier work on regenerated Nothofagus stands, Conway (1952) has suggested a rotation length of 120 years for stands carrying 80 to 100 stems per acre. He estimates a final yield of about 8000 c. ft. per acre from such stands in logs with a minimum diameter of 18 inches and a length of 45 ft., plus a further 1500-2000 c. ft. per acre from intermediate thinnings: the volume M. A. I. over the rotation is thus in the order of 80 c. ft. per acre. By comparison, virgin forest typically carries 30 to 75 stems per acre in trees over 6 inches D. B. H., with merchantable volumes of only about 3000 c. ft. per acre and with stems aged up to 450 years.

CHAPTER 11

THE PRINCIPLES OF SILVICULTURAL TREATMENT.

> "However management is introduced, the first consideration of silviculture must be Regeneration or Establishment to ensure that the exploited or senescent trees are replaced, in greater quantity and quality to the limit of full stocking, or to establish a fully stocked crop of desirable species."
>
> Dawkins (1958; p. 78)

> "The principles governing the choice of a system of silviculture should on the one hand be adopted to environmental conditions and on the other hand answer the requirements of good management. They are, therefore, of two kinds: biological or cultural principles on the one hand, and economic principles on the other hand."
>
> Schaeffer (1951)

Types of Silvicultural Treatment

In the preceding chapter the types of silvicultural treatment which have been applied to natural rainforest in various parts of the world have been reviewed, and in the case of five countries the silvicultural operations have been considered in some detail. In most countries efforts at rainforest treatment have followed a similar pattern; firstly highly selective and barely controlled logging of a few species; then a growing interest in plantations as a means of compensating for the growing stock lost from the natural forests; then, as markets improve and more species are utilised, the development of some series of operations aimed at bringing the natural rainforest towards the state where sustained yield management is possible; and finally a second wave of interest in plantations as a means of maintaining local timber supplies. The significance of these stages will be considered further in chapter 13: in this chapter it is proposed to examine somewhat more critically the different types of silvicultural treatment which have been or are being applied to areas of natural forest.

These treatments have two distinct aims in their application. One aim is that of improvement of the usually mixed and apparently uneven-aged (and certainly uneven-sized) virgin forest, by removing the overmature and useless stems and thus allowing the remaining potentially useful stems adequate space for their further growth. The second aim is to establish regeneration (by inducement, artificial introduction, or release of existing dormant regeneration) to replace the stems which have been removed in logging or in subsequent treatment.

The distinction between these aims is important. The development of a series of treatments to obtain regeneration, maintain it in a vigorous and healthy condition, and bring it through to maturity is the foundation for a silvicultural system, which in turn is one of the main bases for sustained yield management. Such a system, once developed,is continuously being applied to part of the forest by removing the mature stems or stands and replacing them by some type of regeneration. By contrast improvement treatments are required when previously unmanaged forest is being brought under management for the first time: such forest invariably contains a large proportion of useless growing stock, nowhere moreso than in rainforest, and this must be removed if the useful stems in the stand are to be permitted their optimum development. Once the stand is brought under management most useless trees should not be permitted to develop as such stems will be eradicated during one or other of the various tending operations which the new crop will receive. Thus treatments aimed primarily at improvement are but a passing phase in the introduction of organised forest management to areas of virgin or near virgin forest, whilst treatments aimed at obtaining regeneration can, if successful, be expected to form the basis of a silvicultural system which may become a permanent feature of the management of the forest.

In the various treatments discussed in Chapter 10 a few have improvement as their sole immediate aim: l'uniformisation par le haut in the Belgian Congo is outstanding in this regard. Others have the establishment of regeneration as their primary aim, though improvement is effected at the same time by removing the unwanted stems as part of the regeneration process: in this category come the Malayan uniform system and the tropical shelterwood systems of Nigeria and Trinidad. Still others make deliberate attempts at realising both aims concomitantly by an improvement treatment which at the same time fosters the development of regeneration wherever it is needed: most of the treatments with the general appearance of some form of selection system, such as those applied in Queensland and Puerto Rico, fall into this category. Although in most cases there is indeed an effort to improve the forest and to establish regeneration as joint aims of the one treatment sequence, in several areas independent suggestions have been advanced that, where exploitation of a stand is not expected for some considerable period, improvement treatments should be applied so that, when the stand is finally due for logging, most of the useless stems will have been removed and the desirable stems will have made correspondingly increased growth. Suggestions of this type have been made by Wyatt-Smith (1961a) in Malaya and by Dawkins (1958, p. 111) in his general review of tropical forest management. In such cases the initial treatment would be essentially improvement, while the later treatment, at the time of exploitation, would be essentially regeneration.

Of these two aims, improvement of the rainforest is in most cases the more important initially: with improvement the forest is brought to the condition where sound management and a reliable system of silviculture can subsequently be introduced; without improvement even the most successful treatment to induce regeneration comes to nought as the regrowth will be indefinitely suppressed and retarded by the useless trees.

Evidence of this is plentiful in the early attempts at enrichment planting, particularly where enrichment was carried out in conjunction with little-controlled selective logging. As Begue (1960) states, "the maintenance of forest resources through forest improvement work must be the goal of the tropical countries in the immediate future, taking the place of sustained yield from the forests, the goal in temperate countries *." First things must come first, and in unmanaged forest improvement must occur ahead of, or at least concurrently with, regeneration establishment.

The treatments where the main aim is to establish regeneration can be divided into two major classes, those aiming at establishing essentially even-aged regeneration and those where the object is to maintain a relatively all-aged, all-sized forest. In practice the distinction between these two classes is not always as marked as theoretical considerations might suggest, but nonetheless there are basic differences which make it desirable to consider the two types of systems separately.

Essentially Even-aged Systems

In most areas where serious efforts are being made to introduce sustained yield management to rainforest, the emphasis is upon establishing what is essentially even-aged regeneration over extensive areas by some form of clear-cutting or shelterwood system. Various reasons have contributed to this, including the lack of success obtained under the early selective logging, which frequently masqueraded as the very different selection system; the relatively low merchantable volumes of economic stems per acre, necessitating the removal of most merchantable timber in a single operation (particularly in the past three decades, as mechanical logging has become widely established); the greater ease of management in even-aged stands, especially where the local labour sources are not the most reliable; the damage occurring during logging to potentially useful stems which are intended for a later felling cycle under selection systems; the rising standards of utilisation, enabling most stems of suitable form and size to be logged, rather than either destroyed subsequently as useless or else held over for a subsequent felling cycle in the hope that by then the species would be "economic"; and the growing realisation that most of the more desirable species are those which respond most vigorously to ample light and growing space. Gordon (1957), in discussing these systems aimed at obtaining even-aged regrowth, stresses that two conditions must be fulfilled before they can succeed:

1. the unmerchantable proportion of the crop must be small.
2. adequate regeneration must follow at a cost bearing some relation to the revenue obtained from the old crop.

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* Begue however apparently fails to realise that improvement is equally important in many temperate countries where, unlike his native France, the forest services have inherited virgin forest and not a forest estate with a long history of sound management behind it.

Where the first condition does not apply, usually due to inaccessibility, then Gordon believes that management of the forest is premature and the area should be sealed off and protected till its economic position improves. For the second condition, complete logging naturally provides greater revenue, so that the scope for silvicultural treatment is increased.

In table 59 ten different sequences of treatment operations are summarised. Two of these (Malayan R.I.F. and the Nigerian 1944 T.S.S.) are now of historical interest only, having been replaced by other sequences, but the remaining eight are systems in current use or which have been applied quite recently. All these sequences are discussed in greater detail in Chapter 10, and in all cases there is a fairly well defined timetable for the operations, though some operations are optional and dependent upon the individual condition of the forest. Table 60 gives four other sequences which are also aimed at producing a more or less even-aged regrowth crop, but which are less specific about the time each operation is to be given.

The effects of these various operations can probably be better indicated visually, and in fig. 47 a profile diagram is given of a

Fig.47. Profile Diagram of hypothetical rainforest stand (based on fig.12), used in subsequent figures to illustrate effects of various silvicultural treatments. Numbers indicate stem D.B.H. in inches (stems under 2 inches D.B.H. not numbered). Four classes of trees shown, in descending order of desirability: class 1, close double hatching; class 2, wide double hatching; class 3, single hatching; class 4, (mostly useless), not hatched. General level of undergrowth indicated.

hypothetical rainforest stand (actually based on the evergreen seasonal rainforest at Curua; see fig. 12). In this diagram the diameter of the various trees larger than 2 inches D.B.H. is shown, and the general level of the shrubby undergrowth and associated suppressed useful regeneration is indicated. The trees are classed in four groups of diminishing economic value, class 1 being the most important and

TABLE 59

Timetables for Treatment Sequences – Even-aged Rainforest Regeneration.

Year	Malaya (R.I.F.)	Malaya (Uniform System)	Nigeria T.S.S. (1944)	Nigeria T.S.S. (1961)	Trinidad (T.S.S.)	Ghana (T.S.S.)	Uganda	Reunion	Andamans	New Zealand (Uniform)
n – 7	Ro*, Ru*, C									
n – 5		(Ru)		S, CC, Ru		CC, Ru*				
n – 4	(Ro*, Ru*) C		CC, C, Ru*			Ru*				
n – 3		(C)	S, CC, Ru*			C*			C, Ru*	I
n – 2	(C)	(CC)	C (twice)			C*	S (L, CC, T Ru*, Ro*)			Ru
n – 1			C (twice)		CC	C*			CC	
n	F	S, F, Ro, Ru	F	F	F	F, S, (P)	F	C, Ru, F, P	F, Ru*	F
n + 1			C		Ru*, Ro* (P)			Ro	L, C, CC	
n + 2		(C)		CC, L, Ro	L	C, L			L, C, CC	
n + 3			C		L			L	L, C, CC, Ro	
n + 4					CC, L					
n + 5		S (CC, L, T, Ru)			CC, L, Ro	CC				
n + 6					T			L	T	
n + 8			C							
n + 9				S				L		
n + 10		S (CC, L, T, Ru)								

Notes: (1) Further details of all treatments will be found in chapter 10.

(2) In a number of cases the pre-felling treatments are determined not by year, but by the time of heavy seeding of the more important species; in such cases an average time for the operation is shown in the table.

(3) Where several alternative sequences exist, what appears to be the more usual one is given.

Symbols: C, cleaning of undergrowth; CC, climber cutting; F, main felling of merchantable trees; I, soil treatment to induce regeneration; L, liberation of regeneration, weed removal etc.; P, enrichment planting or sowing; Ro, removal of unwanted overstorey trees; Ru, removal of unwanted lower storey trees; S, sampling of regeneration; T, thinning of regeneration; *—operation of a selective or partial nature only; ( )—operation given in selected sites only, or if shown (usually by S) to be necessary.

TABLE 60

Other Treatment Sequences for Even-aged Rainforest Regeneration

Operation Sequence	British Guiana (for *Ocotea rodiaei*)	Amazonia	North Borneo	East New Guinea
1	F	CC	F	F
2	C, Ru	L, T	Ru, Ro	CC, Ru
3	CC	(Ro)	(CC)	Ro *
4	L (twice)	(I)		L, C (twice yearly)
5	Ro	F		
6		L, Ro, Ru *		
7		S, (P)		
8		(L, CC, C, T)		

Notes and symbols: as for Table 59

roughly equivalent to the Class B species in Malaya, the Class I & II species in Trinidad, the first class sawtimber species of Puerto Rico, or the group A and B species of north Queensland (see respectively Wyatt-Smith, 1960b; table 38; table 40; and appendix 3); class 4 trees are those which, due to species or defectiveness, can be regarded as lacking economic value other than possibly for fuel. In subsequent figures the appearance of this stand is indicated at various stages in the course of silvicultural treatment under different schedules, neglecting any possible damage to the remaining stems through felling and assuming that poisoned or girdled stems have disappeared.

Outlines of these various sequences are as follows:

1. Malaya (Regeneration Improvement Fellings). This system is apparently the oldest system aiming at producing essentially even-aged regeneration from the natural rainforest. Its parentage seems to lie in the classical uniform system of Europe, the stand being opened up in one or two operations ahead of the main logging to promote the establishment of regeneration which is subsequently rather intensively cleaned. Although in its early years the trees removed in the initial openings were, where possible, sold as mining timber or fuel, in most cases these stems were poisoned. Felling usually followed about 7 years after the initial opening, and subsequently the remaining useless overwood was removed, part of the more useful overwood was salvaged, and the regeneration was kept well tended.

2. Malaya. (Uniform System) (fig. 48). This system, with some later modifications, replaced R.I.F. in 1950, when it was determined that adequate regeneration was usually present before any treatment, and in order to make use of a single, heavy, logging operation. Pre-felling treatments are strictly limited, though some canopy opening may be carried out during good seed-years in areas that are deficient in regeneration and seed trees from 3 to 7 years ahead of logging, and operations to eliminate bamboos, *Eugeissona* (stemless palm) and climbers in heavily infested stands may be given from 2 to 5 years ahead of logging. Excepting these atypical operations, the first scheduled task is milliacre regeneration sampling to ensure that sufficient regeneration is present, followed by the logging of all merchantable trees (usually down to 17 inches D.B.H.; fig 48a). Immediately after logging all remaining useless stems are poisoned down to either a 2 inch or 6 inch D.B.H. limit, dependent upon the species in the regeneration (2 inches for the light-demanding *Shorea* spp., 6 inches for the more shade tolerant species such as *Dryobalanops* and *Shorea curtisii*) and the heaviness of the main logging. Any potentially useful stems between the logging diameter limit and the poisoning limit are retained, providing an open, pole-size overstorey (fig. 48b). Areas rich in the slow-growing heavy hardwoods are given a regeneration cleaning about 2 years after logging, but other treatment is dependent upon diagnostic sampling of the regeneration at about 5 and 10 years after logging, when any operations indicated as being necessary are given: these may include climber cutting, eradication of weed trees; general liberation of regeneration, enrichment planting, etc. In the meranti-type (*Shorea* spp.) stands, the rotation of the regenerated rainforest is expected to be 70 years.

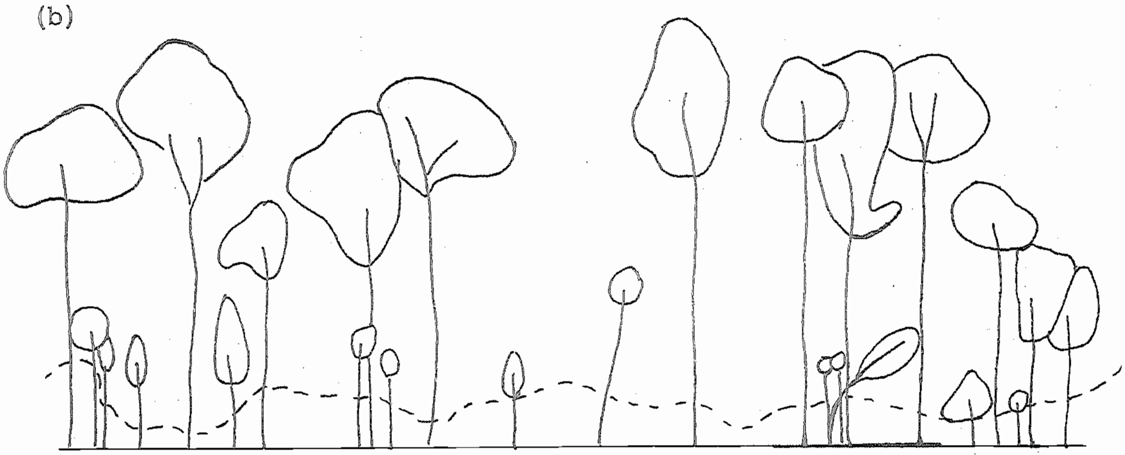
3. North Borneo. This system is modelled directly on the Malayan uniform system, but due to access difficulties is less intensive in its follow-up treatments. Complete felling of all merchantable trees is followed by poisoning all useless stems larger than 2 inches D. B. H., the retention of small, potentially useful stems, and the cutting of climbers away from these. The girdling and climber cutting is usually given soon after logging, but may be delayed up to 5 years when some tending of the regeneration is also given.

4. New Guinea. The system developed in Eastern New Guinea is similar to the Malayan uniform system in that logging of all merchantable stems is the first major operation, but subsequently greater undergrowth cleaning is carried out, all unwanted stems up to 12 inches D. B. H. being removed, along with the smaller undergrowth and climbers, whilst the larger useless stems are only poisoned where the canopy is dense. The regeneration is subsequently tended and cleaned twice a year for a number of years.

Fig.48. Effect of Malayan Uniform System (c.f. fig. 47): (a) after exploitation, (b) after poison - girdling.

(a)

(b)



5. British Guiana. The system used in the stands of Ocotea rodiaei in British Guiana also commences with the complete logging of all merchantable trees, but the removal of the remaining overstorey is carried out more gradually than in Malaya. First the undergrowth is cleaned and the lower tree storey is thinned out, retaining any stems of Ocotea, and climbers are destroyed.
Several cleanings of the regeneration follows, and when the regeneration is well established the remaining overstorey of stems other than Ocotea is removed in one or two poisoning treatments.

6. Nigeria. (Tropical Shelterwood System, 1944). This system which has now been considerably altered, was based fairly closely on the Malayan R. I. F. treatments. Operations commenced four years ahead of anticipated logging, when climber cutting, poisoning of the middle tree storey, coppicing of mis-shapen but useful regeneration and some undergrowth cleaning were carried out. This was followed a year later by further climber cutting and more poisoning of the tree understoreys. During the next two years the regeneration was cleaned twice to favour its development and induce further regeneration, and after exploitation of the merchantable timber the regrowth received further cleanings at regular intervals. Initially no thought was given to removing the unwanted overstorey remaining.

7. Nigeria. (T. S. S., 1961) (fig. 49). Subsequent alterations to the Nigerian T. S. S. have resulted in the current treatment becoming more flexible, less intensive, and more efficient. Operations start 5 years ahead of logging with a sampling of the regeneration already present. Climber cutting follows the same year and, if the sampling shows adequate regeneration to be present, unwanted stems in the middle storey are poisoned (clearance poisoning, fig. 49a). If insufficient regeneration is present, the clearance poisoning is delayed a year and, instead, all unwanted undergrowth is removed to promote seedling establishment. Logging takes all merchantable trees (fig. 49b) and several years later any damage due to logging is repaired, the regeneration is cleaned, the useless overstorey is removed, and a further climber cutting is given (fig. 49c). As can be seen, the end result is not dissimilar to the Malayan uniform system. Ten years or so after logging some type of liberation treatment, determined by diagnostic sampling, is expected to be given. The rotation is estimated at 100 years.

8. Ghana (T. S. S.). The system used in Ghana to produce even-aged regeneration is modelled on the first form of T. S. S. in Nigeria. Operations commence 5 years ahead of logging, with climber cutting and a light opening of the canopy by poisoning the smaller useless trees under 4 inches D. B. H. The following year further canopy opening is carried out by poisoning the larger, dense crowned, understorey trees, and for the next 3 years annual cleanings of the regeneration are given. Following logging a regeneration sampling is carried out to indicate those areas where enrichment planting is needed, and further cleaning operations are given in the second and fifth years after logging. Rotation length is expected to be 80 to 100 years.

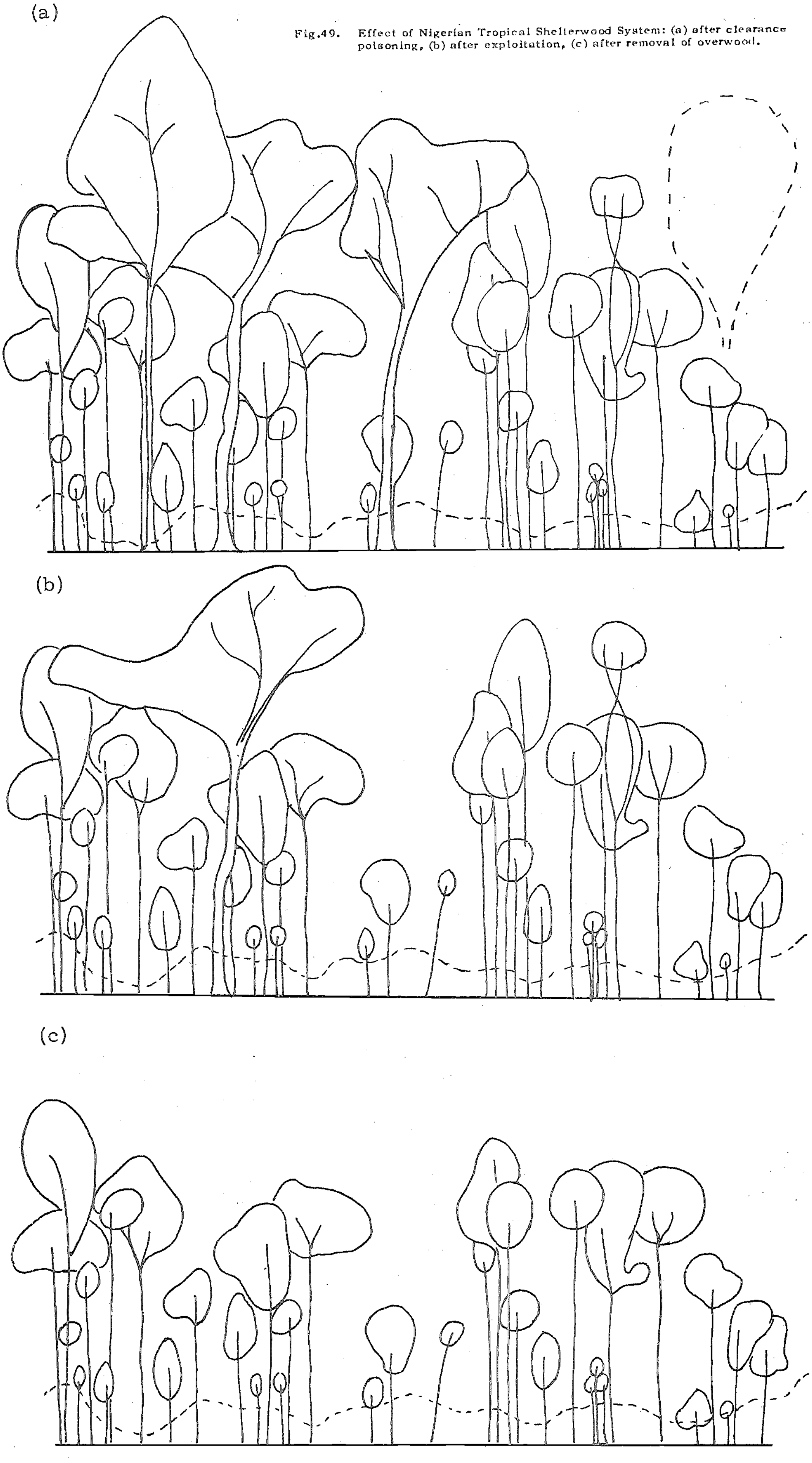
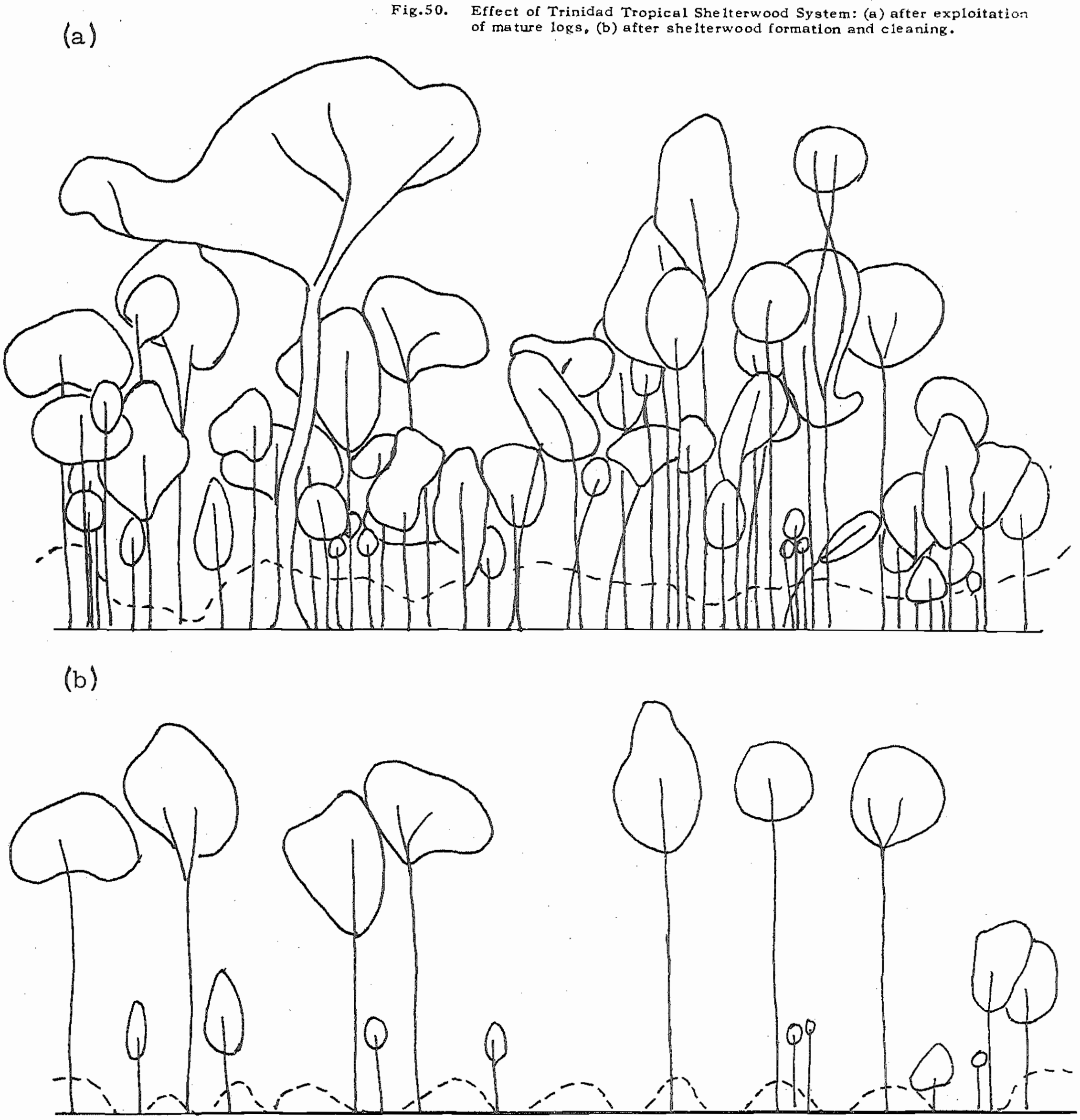


Fig.49. Effect of Nigerian Tropical Shelterwood System: (a) after clearance poisoning, (b) after exploitation, (c) after removal of overwood.

Fig.50. Effect of Trinidad Tropical Shelterwood System: (a) after exploitation of mature logs, (b) after shelterwood formation and cleaning.



9. Trinidad (T. S. S.) (fig. 50). Though now known by the same name as the Nigerian system, this older system (1939) differs in important respects from the African sequence of treatments by having exploitation of the merchantable stems as one of the initial operations, and by retaining the shelterwood purely to foster the regeneration which becomes established, not as a source of seed trees to produce the regeneration. In this it is very similar to the system used for Ocotea rodiaei in British Guiana, and it is indeed probable that the latter has been based upon the treatment developed in nearby Trinidad. In the Trinidad T. S. S. climber cutting is carried out a year ahead of logging, and then all merchantable stems are exploited (fig. 50a). The following year the remaining stand is opened out to leave a scattered shelterwood, preferably of about 18 to 20 pole-sized economic stems per acre.

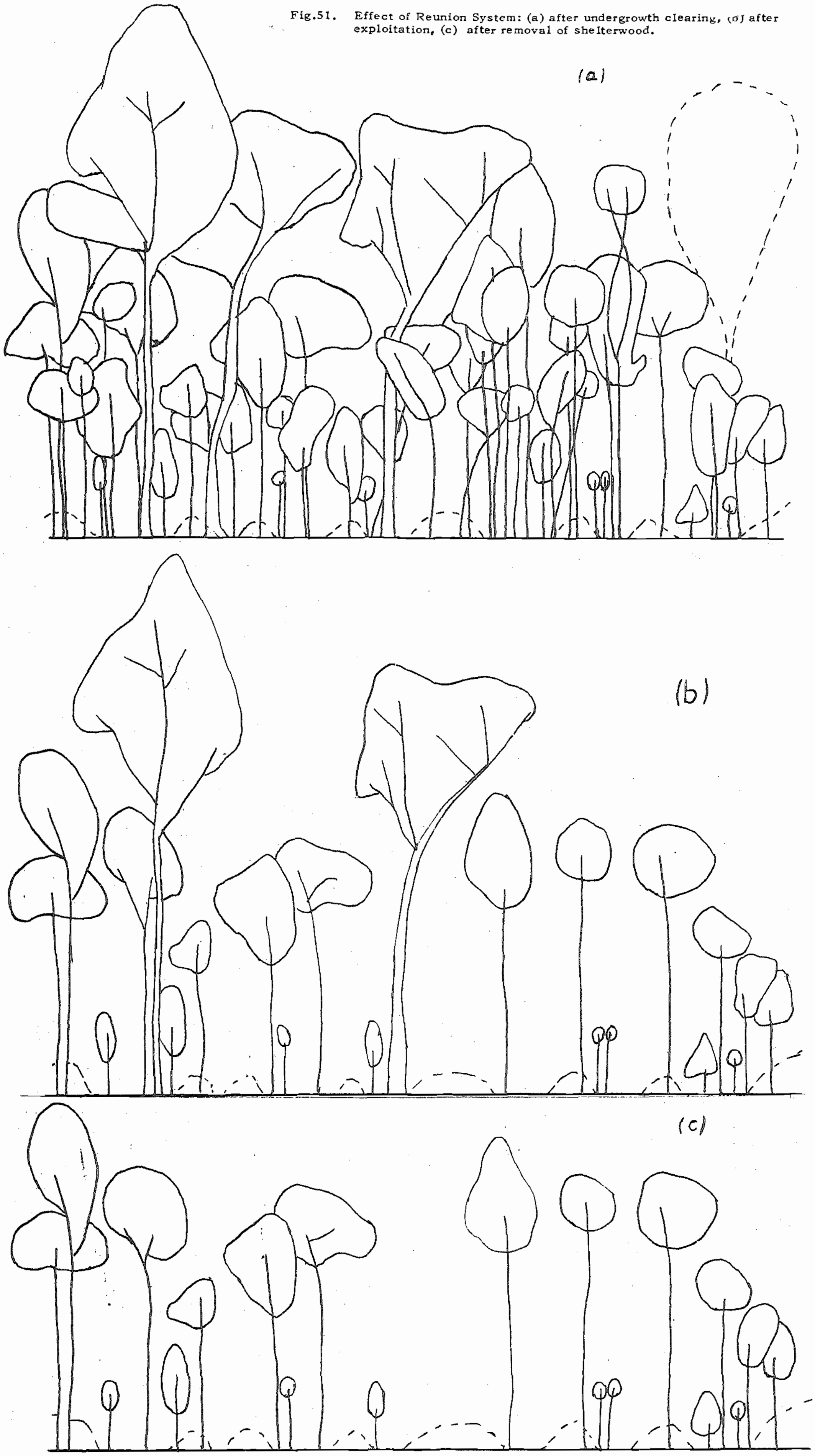
Where such stems are not available other trees are left to form an equivalent degree of canopy shelter. If possible the stems removed during shelterwood formation are used for charcoal, otherwise they are poisoned. Planting may be carried out at the same time to inoculate the area with species not naturally present. Over the next four years the regeneration is tended annually by cleaning, climber cutting and the removal of weed species (fig. 50b), and in the last of these years any shelterwood trees not required in the new crop are removed: in the figure, all shelterwood trees would probably be retained. During the year after shelterwood removal the regeneration is thinned, and later thinnings are expected at age 15 and 25. At age 30 years the stand is logged to remove the retained shelterwood trees and any faster-growing regrowth stems, while the slower-growing stems will be kept for the full rotation of 60 years.

10. Reunion (fig. 51). The system developed in Reunion has much in common with that of Trinidad, with an early logging and the subsequent retention of a shelterwood. The first operation is to sell any dead trees (for charcoal?) and to clear the undergrowth (fig. 51a), followed a few months later by logging in which any well formed seed trees are retained for shelter (fig. 51b). At the same time seed is broadcast to provide regeneration, which is usually well established by the following year when any old or poor seed trees are removed (fig. 51c). The rotation is estimated as 150 years, and some effort is made to maintain a mixture of sizes in the shelterwood, possibly as a form of protection against cyclone damage, for the full rotation.

11. Uganda. Influenced by the local work and strong beliefs of H. C. Dawkins, this country has adopted a system in which a general refining treatment, based on a previous diagnostic sampling, precedes complete exploitation by several years. In the refining any regeneration present is freed of vines and competitors, and in dense thickets useless stems are removed: the object is to have the regeneration firmly established by the time of logging. After exploitation further liberation treatments are given to the new crop, again based on the results of diagnostic sampling.

12. Amazonia. (fig. 52). The suggested system for the Amazon rainforests of Brazil has also been influenced strongly by the ideas of Dawkins. Initial treatments ahead of logging include climber cutting, the freeing and thinning of existing regeneration, the possible poisoning of large useless trees, and possibly some soil treatment around seed trees to induce regeneration. The appearance of the stand after these pre-felling operations is shown in fig. 52a. Exploitation of the merchantable trees follows (fig. 52b). Subsequent treatments include freeing the regeneration, poisoning any remaining large useless trees and any dense patches of understorey, and enrichment planting where this is needed (fig. 52c). Diagnostic sampling is recommended as a guide to further treatment, which should aim at maintaining the stand basal area at between 65 and 80 sq. ft. per acre.

Fig.51. Effect of Reunion System: (a) after undergrowth clearing, (b) after exploitation, (c) after removal of shelterwood.



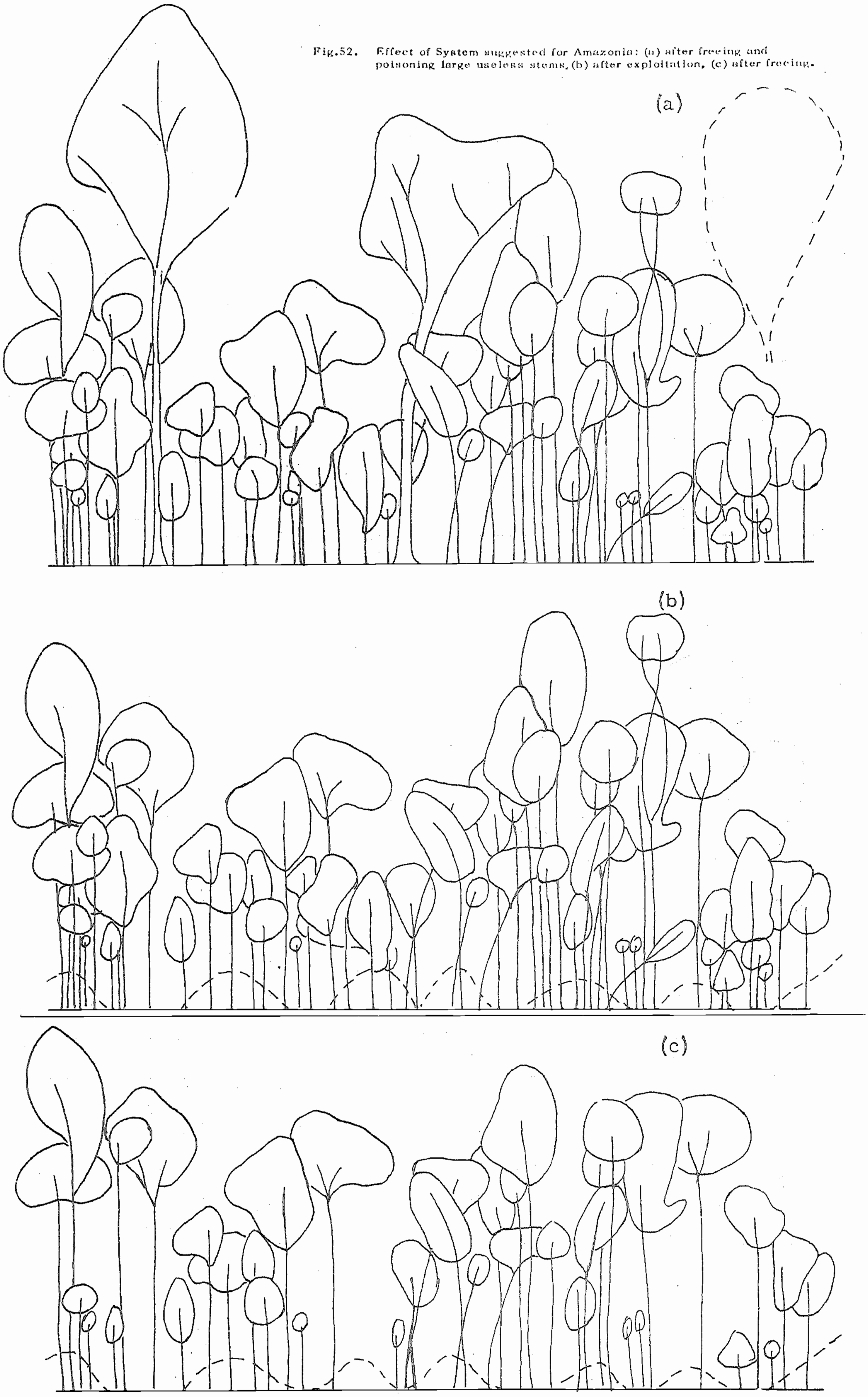


Fig.52. Effect of System suggested for Amazonia: (a) after freeing and poisoning large useless stems, (b) after exploitation, (c) after freeing.

13. Andamans. (Canopy-lifting Shelterwood System) (fig. 53). This system, one of the older treatment sequences still in use, shows some similarity to other shelterwood systems (e.g. Trinidad), but in particular the Indian emphasis on "canopy lifting" is strongly marked. The first operation occurs up to 4 years ahead of logging when, at the time of a good seed fall, undergrowth up to a height of 25 ft. is removed: the first raising of the general canopy level (fig. 53a). Climber cutting occurs a year ahead of logging, and at exploitation all merchantable stems are removed (fig. 53b). This is followed by a further lifting of the canopy by felling the smaller useless stems and girdling the larger ones, to leave a fairly continuous high canopy (fig. 53c). Over the next three years the regeneration is regularly tended, and when it appears well established the remaining unwanted stems in the shelterwood are removed (fig. 53d).

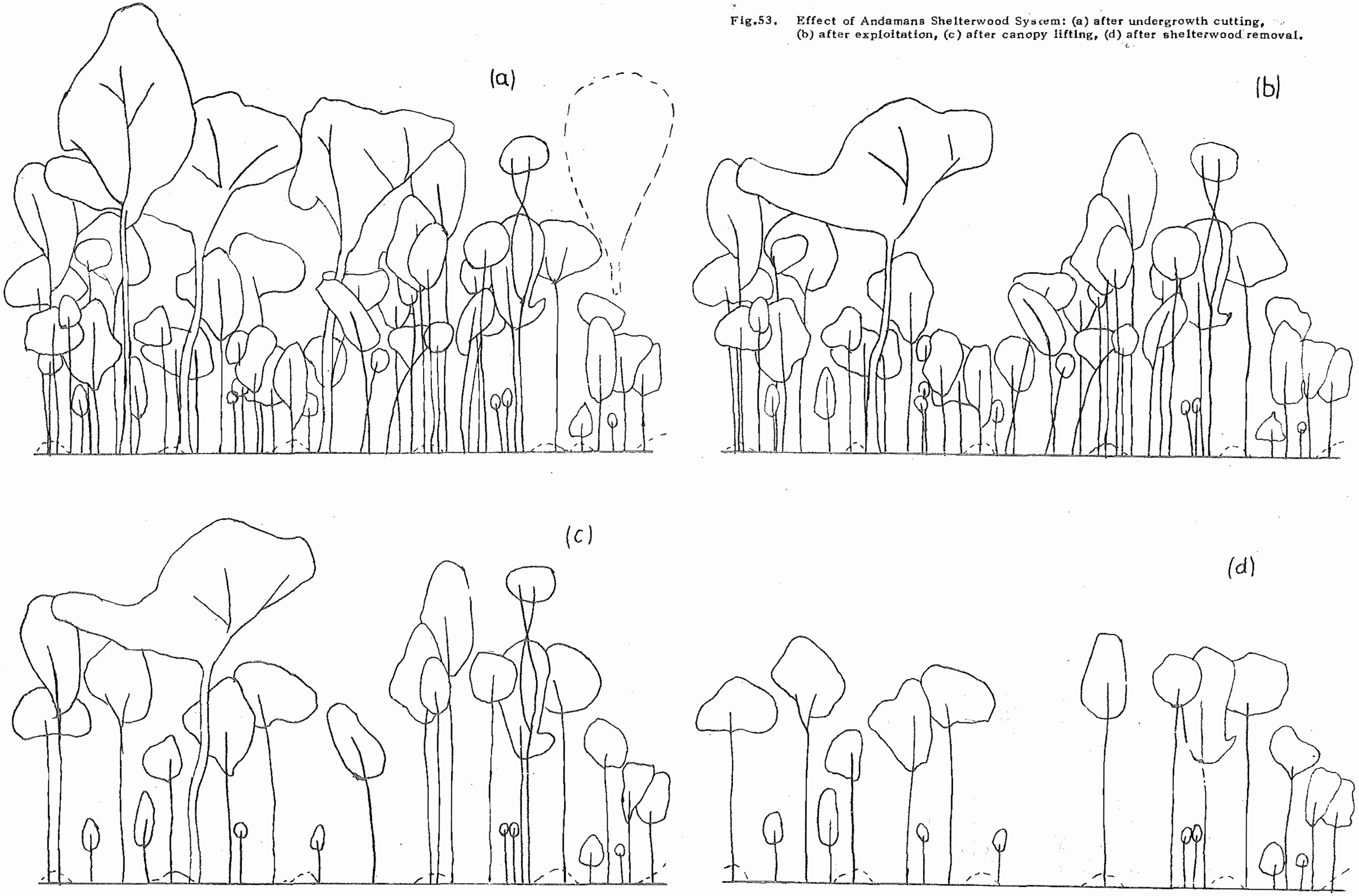
14. New Zealand (Uniform System). The system suggested for the *Nothofagus* rainforests is based fairly closely on the European uniform system. The first operation is a bulldozer treatment to remove the surface litter over about half the soil surface ahead of a heavy seed fall. When the regeneration from this seed fall appears the canopy is opened by removing entirely the useless understorey layer. The regeneration can become well established and exist for considerable periods beneath this reduced canopy, and the final regeneration operation, the removal of the overstorey as a commercial logging operation, can occur at any convenient time after the regeneration has become established.

The fourteen treatment sequences outlined above all aim at producing a more or less even-aged crop of regeneration to replace the original unmanaged rainforest. It is however important to note that, except in the suggested New Zealand system and in some cases in the Trinidad T.S.S., the result is never truly an even-aged or even-sized crop. In very few if any natural rainforests is there a complete absence of under-sized poles and saplings of desirable species, and in all treatments these are retained, if at all possible, so that the treated stands usually have a somewhat two-layered appearance, though the upper layer tends to be scattered and open.

The treatments described fall into four broad classes, differentiated by the time of opening the canopy in relation to commercial exploitation and by the purpose for which the shelterwood, if any, is retained.

The first of these classes takes in the direct adaptations of the classical uniform system, where the old stand is opened ahead of major exploitation in an effort to induce regeneration and aid its establishment. Systems here include the pre-war Malayan R.I.F., the Nigerian and Ghanaian T.S. Systems and the New Zealand uniform system. Unlike the uniform system in Europe, however, all of these achieve the initial canopy opening not by selective felling in the upper storey, but by reduction of the lower storeys and the removal of climbers: as Lancaster (1961a) observes, climber cutting alone under West African conditions produces a very marked lightening of the canopy. Here we see an old established silvicultural system having its main principles applied to rainforest in a form modified to suit the characteristic structure of rainforest with its dense and heavy shade-casting lower storeys: as can be seen from Figs. 32 and 33,

Fig.53. Effect of Andamans Shelterwood System: (a) after undergrowth cutting, (b) after exploitation, (c) after canopy lifting, (d) after shelterwood removal.



this structure is likely to be present just as characteristically in the regrowth stands resulting from such treatment. The main purpose in this type of treatment is to induce regeneration to become established before the better seed trees are removed in logging. If adequate regeneration is already present on the ground, then the formation of a shelterwood ahead of exploitation is unnecessary: the realisation that this was usually the case in Malaya led to the abandonment of R.I.F. in 1950 in favour of the much simpler, so-called "uniform system", while Lancaster (1960) has shown that this is apparently also the case in some (but certainly not all) of the Nigerian rainforests. On the other hand, where regeneration is scarce, some treatment to open the canopy ahead of exploitation may be well justified, as stressed by Wyatt-Smith (1961a, 1962) in his review of current Malayan silviculture.

In the second class of regeneration treatments are those where shelterwood formation is again a deliberate part of the regeneration sequence, but this is intended primarily to foster and protect regeneration already present, rather than to provide the source of the seed. Treatments of this type are to be found in Trinidad, British Guiana, New Guinea, and Reunion. In these the commercial logging of the main crop occurs as one of the first major treatment operations, and this is followed by the formation of a shelterwood from the remaining undersized and useless stems to protect the regeneration for some years, when those shelterwood trees which are not required in, or suitable for, the final stand are removed. Since the shelterwood is composed of trees which are either probably too small to produce seed or else of species or phenotypes too poor to be wanted as regeneration, the regeneration in these treatments must come from other sources. In British Guiana, and apparently New Guinea, it is already present in the natural rainforest (this is to some extent probably true in the other areas as well), in Reunion it is supplemented by broadcast sowing, and in Trinidad it reputedly mostly arises from seed brought in by birds and bats at the time of, or shortly after, logging.

The third class of regeneration treatments links the two. Here a shelterwood is formed ahead of logging, at the time of a seed year, in order to induce seedling establishment. Logging follows in due course, as in the first class, but the shelterwood is then preserved for some years after logging in order to foster the development of the regeneration still further. This type of treatment is seen in the Andamans.

The fourth and final class of treatments is the simplest. These treatments rely upon regeneration being already established (though some pre-felling treatment may be given to assist it) and being able to respond to what is virtually complete exposure: they bear much the same relationship to the European clear-cutting system as the first class does to the uniform system. In this category are the systems used in Malaya, North Borneo and Uganda, and suggested for Amazonia. Pre-felling treatments are restricted to the minimum necessary to ensure that regeneration is indeed present and capable of responding, and then the merchantable trees are removed in a single and usually heavy operation, and as soon as practicable afterwards the remaining unwanted stems are destroyed.

In practice this is not quite as drastic as it sounds: potentially useful poles are retained while understorey species below a certain size are also retained, at least until a subsequent liberation treatment is required. With this undergrowth the degree of shelter can to some extent be manipulated, and thus in Malaya the undergrowth is kept more dense in areas where such species predominate as Dryobalanops aromatica, which is prone to damage by sudden exposure, than where light-demanders, such as many Shorea spp., are plentiful.

The four classes of treatment sequences to obtain even-aged regeneration can thus be termed:

1. Pre-felling inducement - a close relative of the European uniform system.

2. Post-felling protection - a more distant relative of the uniform system.

3. Extended inducement and protection - a combination of the previous two.

4. Immediate exposure - a relative of the clear-cutting system.

The first and third are probably the most costly, since they require access into stands well in advance of logging and the nowadays usual roading system. This is however probably essential if even-aged regeneration is required in areas where there is rarely an adequate stocking of desirable regeneration present naturally. Post-felling protection systems can utilize the access prepared for logging. These systems necessitate an origin of regeneration from some source other than the shelterwood, and their value lies probably less in protecting the regeneration from exposure (Malayan experience shows that this is still possible under a clear-cutting system) than in guarding against a sudden upsurge of fast-growing, short-lived weed species which might otherwise swamp the useful regeneration, and in forcing early height growth without excessive low branch development. In all three types of shelterwood system unwanted trees in the shelterwood should ultimately be removed, though this is not necessarily always done (e.g. T.S.S. in Ghana). The immediate exposure systems are by far the simplest, but rely on an adequate initial stocking of regeneration which is capable of making a rapid growth response when released: such regeneration is in fact probably more widespread in the world's rainforest than is yet realized. In all systems subsequent follow-up liberation treatments, to keep the most desirable regeneration actively growing and free from impedence, appear most desirable, if not essential.

Uneven-aged Systems

The second major group of rainforest treatments which aim at producing regeneration are those where the object is not to form an essentially even-aged crop over extensive areas, but to maintain an uneven-aged stand by means of periodic partial harvesting. At first sight this appears an ideal method of treating rainforest since the natural stands are typically uneven-sized and presumably uneven-aged, though as was shown in Chapter 6 size classes and age classes bear only a very remote relationship to each other in virgin rainforest: indeed in Ghana the range of size classes present, in definitely even-aged stands, has been found to be so great that there has been a swing back towards the management of rainforest in an uneven-aged condition, from an earlier emphasis on even-aged regeneration (Foggie, 1960). Even within recent years there have been authoritative statements to the effect that a selection system is the ideal system of management in tropical rainforest on ecological grounds e.g. at the F.A.O. Asia-Pacific Forestry Commission meeting in 1952 (F.A.O., 1952; de Rosayro, 1957). However the argument that, because the natural rainforest appears all-aged, then the retention of an uneven-aged stand under management is automatically the best type of management, is of very dubious validity, as has been emphasized by Peace (1961).

There are of course other reasons why the management of an uneven-aged stand may be preferred. These include:

1. Only the mature and overmature trees need be removed at logging, leaving the smaller sized stems and any healthy, larger stems of currently useless but potentially merchantable, species to remain and grow till a later felling cycle.

2. The desirability of retaining as far as possible any existing sequence of size/age classes, however imperfect, present in virgin forest.

3. The continued protection of the soil against erosion, which may follow excessive opening.

4. The risk of devastation by cyclones to even-aged stands.

5. Better protection against other climatic hazards.

6. Aesthetic reasons, which may be of some importance adjacent to recreation areas.

All of these may, under certain circumstances, be perfectly valid reasons for maintaining an uneven-aged stand, though they must be weighed against the main objections, which include:

1. Most of the more desirable rainforest species tend to be light-demanding.

2. There are obvious economic advantages in having few, but heavy and concentrated, logging operations rather than frequent, light loggings.

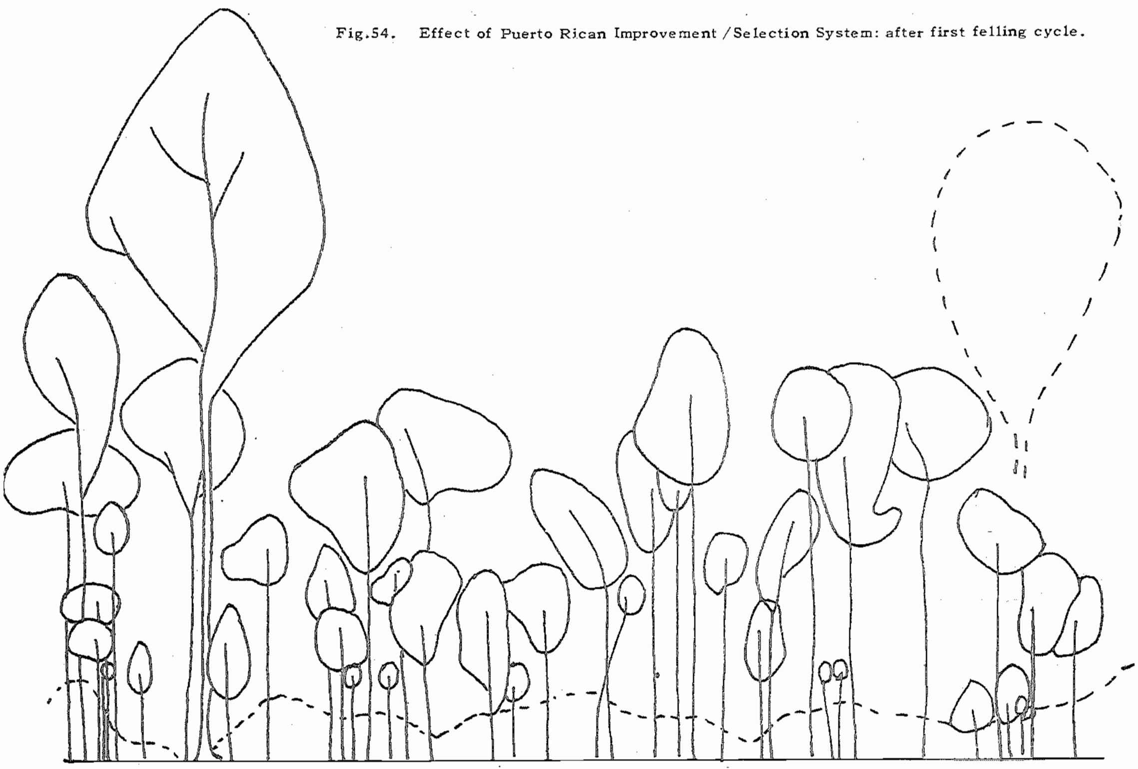
3. Many species, particularly in tropical rainforest, produce excessively large crowns which may damage in falling many of the trees which it is wished to retain.

In virtually all areas with rainforest, the first commercial logging operations have been of a selective nature, with the timberman only taking trees of prime species and good form.

Such "creaming" of the forest should not however be regarded as management, and certainly not as anything that vaguely resembles a true selection system. Earliest approaches to management have usually been along the lines of what Gordon (1957) has termed the "Tropical Selection System", in which a girth limit is specified, trees larger than this limit being removed on a fairly long felling cycle: Dawkins (1958) has termed this the "Stratified Uniform System", as the aim is to maintain several successive waves of even-aged regeneration (each corresponding to a felling cycle) in the one stand. As Gordon states, such a system might succeed if the main desirable species are shade tolerant and moderately gregarious, and if the fellings can be carried out conscientiously to avoid damage. All too frequently however this technique has resulted in the depletion of the more desirable species and their replacement by relatively worthless trees.

Despite these difficulties, systems which resemble the European selection or group selection systems are being applied with apparent success in a number of areas, and these deserve some further examination.

Fig.54. Effect of Puerto Rican Improvement /Selection System: after first felling cycle.



1. Puerto Rico (Fig. 54):

A combination of several factors have suggested the use of a selection system in the Luquillo Mountains. These are the importance of soil protection in one of the island's most important catchment areas, the prevalence of cyclones which are particularly damaging to even-aged stands, and the scenic value of the area. In addition, the main species appear able to maintain their numbers under such a type of management, many being able to grow slowly under partial shade whilst the more light-demanding develop in the larger logging gaps. The system is intended to function on a short (5 or 10 year) felling cycle, the initial cycle being concerned more with improvement than with yield of timber or inducement of regeneration. The ultimate composition of the ideal stand is indicated in Table 42 with the B. A. kept at about 80 square ft. per acre. To work towards this stand, logging and improvement (by poisoning other unwanted stems) are carried out together at each felling cycle, removing trees where the crowns are in contact, avoiding the creation of gaps in excess of 25 ft. across, and trying to give the remaining trees about 6 ft. of crown freedom. To achieve this, removal is concentrated upon the poorer species and the larger sizes. Fig. 54 indicates the appearance of the hypothetical stand after such treatment.

2. North Queensland (Fig. 55):

In the North Queensland rainforests the virgin rainforests tend to carry a moderately high stocking of small stems of the more desirable species, and the log price structure (Table 44) makes these of high potential, but low current, value. These two factors act strongly in favour of retaining all useful stems below the economic size, and thus in favour of maintaining a relatively uneven-aged forest structure. The treatment details are rather complex (appendix 3), but involve the following steps:

a. Climber cutting and the cutting of all useless undergrowth.

b. Eradication of any existing Laportea moroides

c. Tree marking to specified girth limits, but retaining any primary species for seed where the stocking of these is low, removing any unhealthy stems, and thinning any dense patches.

d. Exploitation of the marked stems (Fig. 55a) and further treatment of Laportea regeneration.

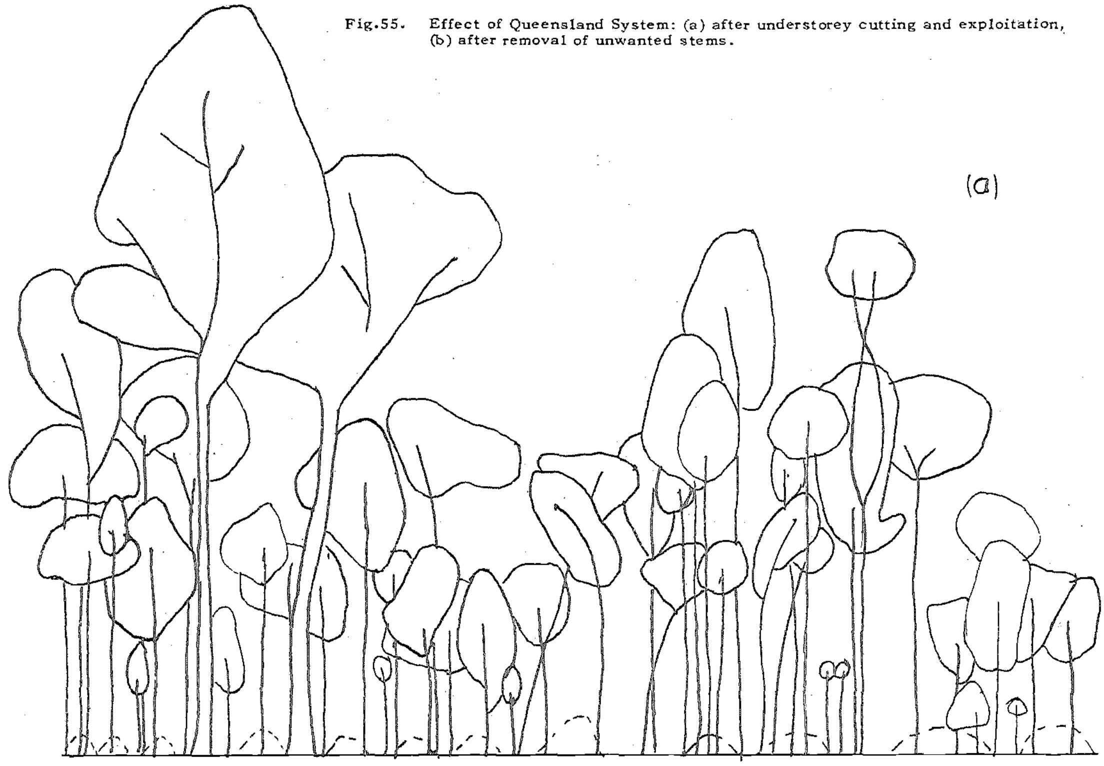
e. Removal of all useless stems and of some stems of the less desirable economic species to give a regular spacing and to favour all primary species (Fig. 55b).

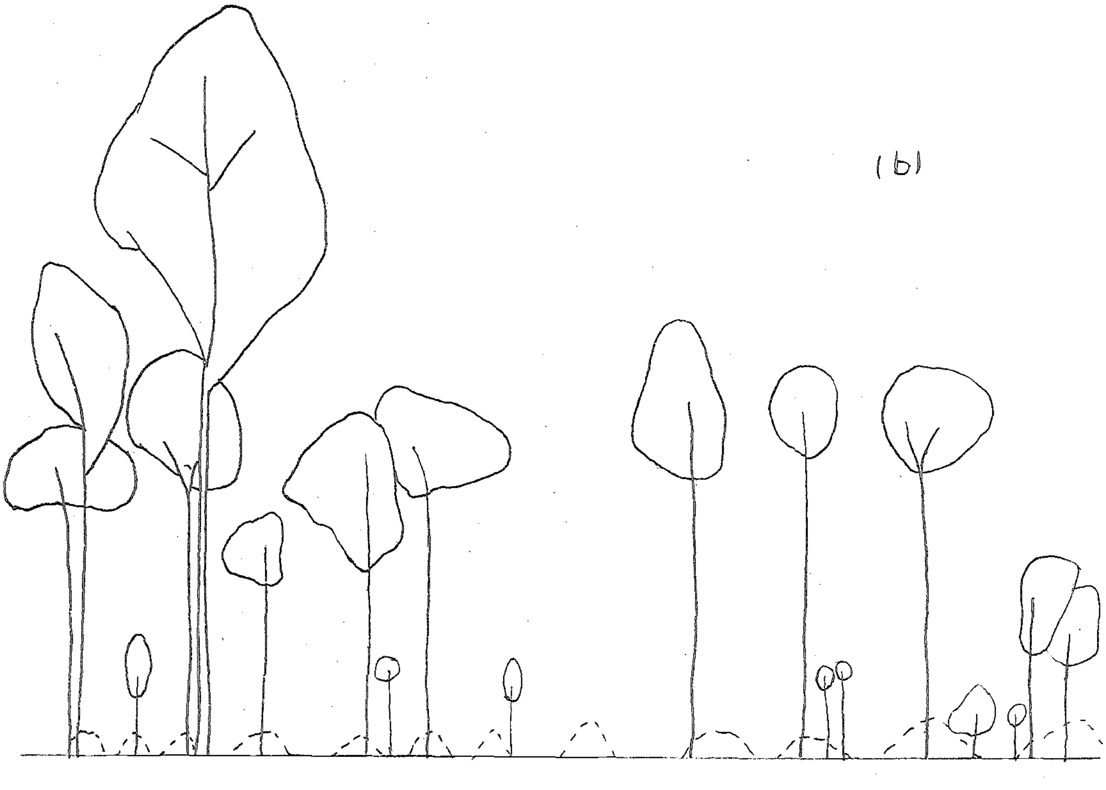
f. Soil treatment to induce seedlings where regeneration is scarce, and enrichment planting where seed trees are also absent.

g. Liberation treatment after about 3-4 years.

The treated stand has initially an almost park-like appearance, with the B. A. reduced to about 55 square ft. per acre from virgin forest values of up to 350 square ft. per acre: conditions are thus favourable over large areas for the development of even the most light-demanding species. The felling cycle is expected to be in the order of 15-20 years, and after this initial treatment, which is strongly of an improvement nature, the stand is subsequently expected to be managed by something akin to a group selection system.

Fig.55. Effect of Queensland System: (a) after understorey cutting and exploitation, (b) after removal of unwanted stems.





3. Assam (Fig. 56):

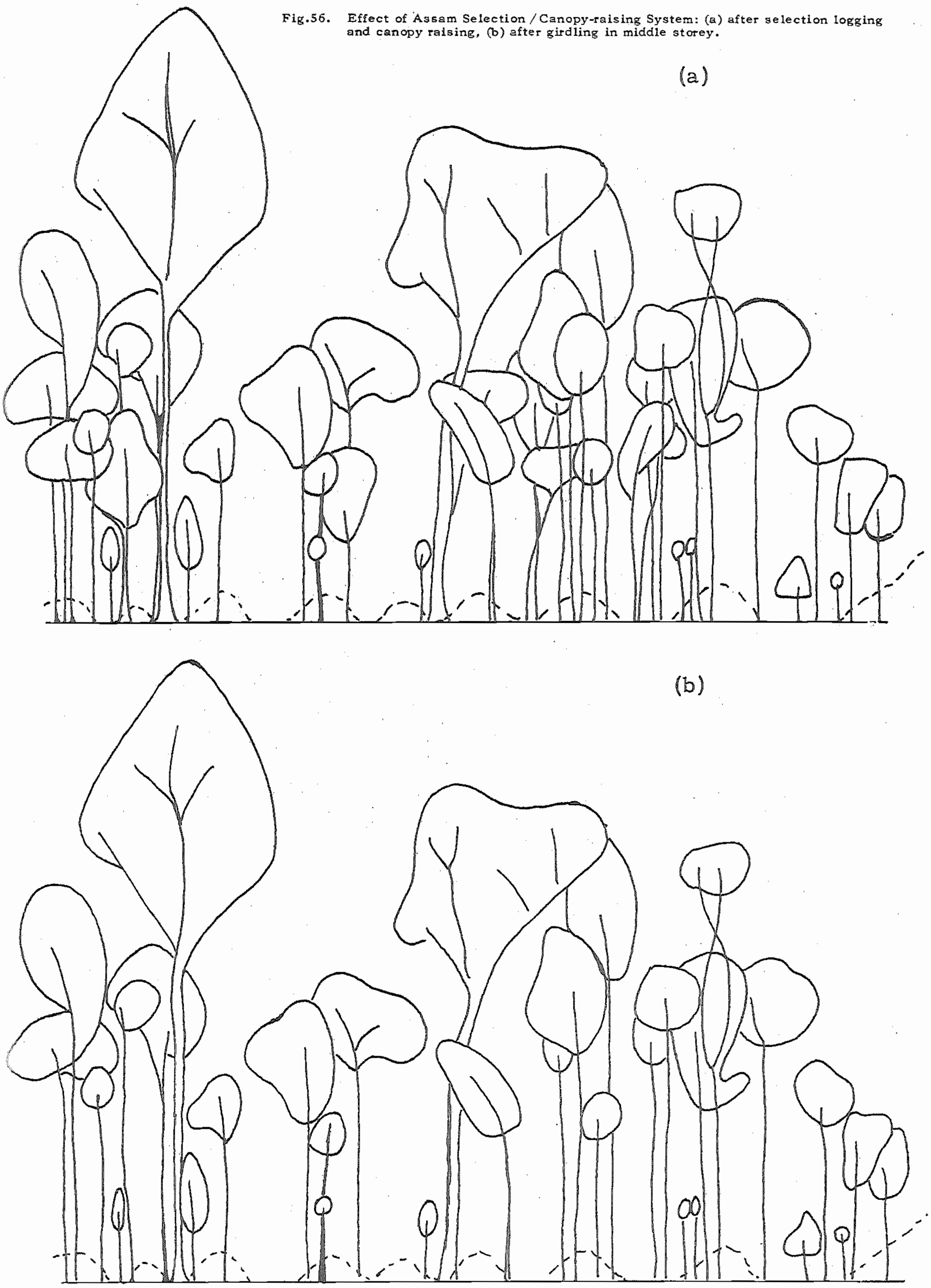
Various systems are used in different parts of India to treat natural rainforest and, in stands which are difficult to regenerate naturally, enrichment planting is commonly used. Some stands however regenerate moderately well, and these tend to be managed by a long felling cycle (25 to 45 years) selection system, in which the logging of selected mature stems (Fig. 56a) is followed by 3 years of fairly intensive tending during which climbers are cut, the regeneration is freed and weeded, and the useless understorey is destroyed by felling or girdling to raise the level of the lower canopy to a height of about 30 ft. (Fig. 56b).

4. New South Wales:

In the warm temperate rainforests of New South Wales a selection system has been favoured for several reasons. The log price structure, as in Queensland, places a premium on the larger stems, and thus deters the cutting of undersized stems which are usually plentiful, but which can, if necessary, be sold; the relatively small crowns of mature trees (Fig. 23) enables these stems to be felled without causing undue damage to the remaining stand; a severe opening of the canopy leads to crown die-back, and frequently ultimate death, in the smaller trees which are retained; whilst the rotation needed to raise an even-aged stand is too long to be considered in a country used to growing such species as Pinus radiata and Eucalyptus grandis. To avoid die-back the stand B.A. should not be reduced by more than about 40% of that in the virgin stand; this involves retaining a B.A. of about 130 square ft. per acre after logging, the reduction occurring partly through merchantable logging and partly through destroying any large useless stems which are present. A felling cycle of about 25 years is expected in these stands.

Selection systems are also being applied or have been suggested for other areas, such as the tropical rainforest of Ceylon and the nontane rainforest of the Venezeulan Andes. To be effective a selection system requires very careful control to ensure that only trees which have attained maturity or which, on silvicultural grounds, are no longer wanted in the stand are removed, and to ensure also that the remaining stems are healthy and undamaged and that adequate regeneration of desirable species is being obtained. These conditions appear to be met in the four examples outlined above. In these examples two rather different approaches can be recognized. In one, typified by Puerto Rico, New South Wales, and Assam, a deliberate effort is made to retain a fairly continuous canopy: these systems are similar to the European single-tree selection system. In the other, as illustrated in Queensland, the retention of canopy is unimportant compared with the desirability of retaining an even stocking of immature stems: as a result quite large openings may occur in parts of the stand, and the ultimate effect is towards a group selection system. In both types of system as applied to previously unmanaged rainforest, operations aimed at improving the stand (by removing useless stems, vines and so on) receive much attention.

Fig.56. Effect of Assam Selection / Canopy-raising System: (a) after selection logging and canopy raising, (b) after girdling in middle storey.



Improvement Treatments

Although improvement treatments are an important part of both the above types of silvicultural systems in the effort to convert unmanaged to managed rainforest, in a number of areas operations are carried out which are purely improvement treatments. In these cases there is no attempt to obtain an immediate commercial yield, and often none to obtain regeneration: the aim is to release the potentially useful growing stock already present in the stand, enabling it to put on valuable increment pending such time as exploitation can be carried out. This type of treatment is desirable in currently unexploitable stands which contain a fair quantity of useful trees suppressed or being competed with by large useless stems, climbers, etc: in other words, in most virgin rainforests which are unlikely to be exploited for 20 or more years due to inaccessibility, poor economic position, or the order of working laid down in the management plan. Thus treatment of this type has been recommended for parts of Malaya (Barnard, 1954; Wyatt-Smith, 1962), and has been put into operation in certain other areas. Allied to this are the suggestions (e.g. Keay, 1961) for a light selective logging of stands where prescribed exploitation is not due for many years, where the prescribed exploitation is part of an even-aged regeneration system (e.g. T.S.S. in Nigeria), and where the stands contain mature trees which will deteriorate by the time of prescribed exploitation: unfortunately logging of this type is nowadays rarely economically feasible (see also Brasnett, 1952).

Two examples of more or less routine improvement treatments will illustrate what such treatments may involve.

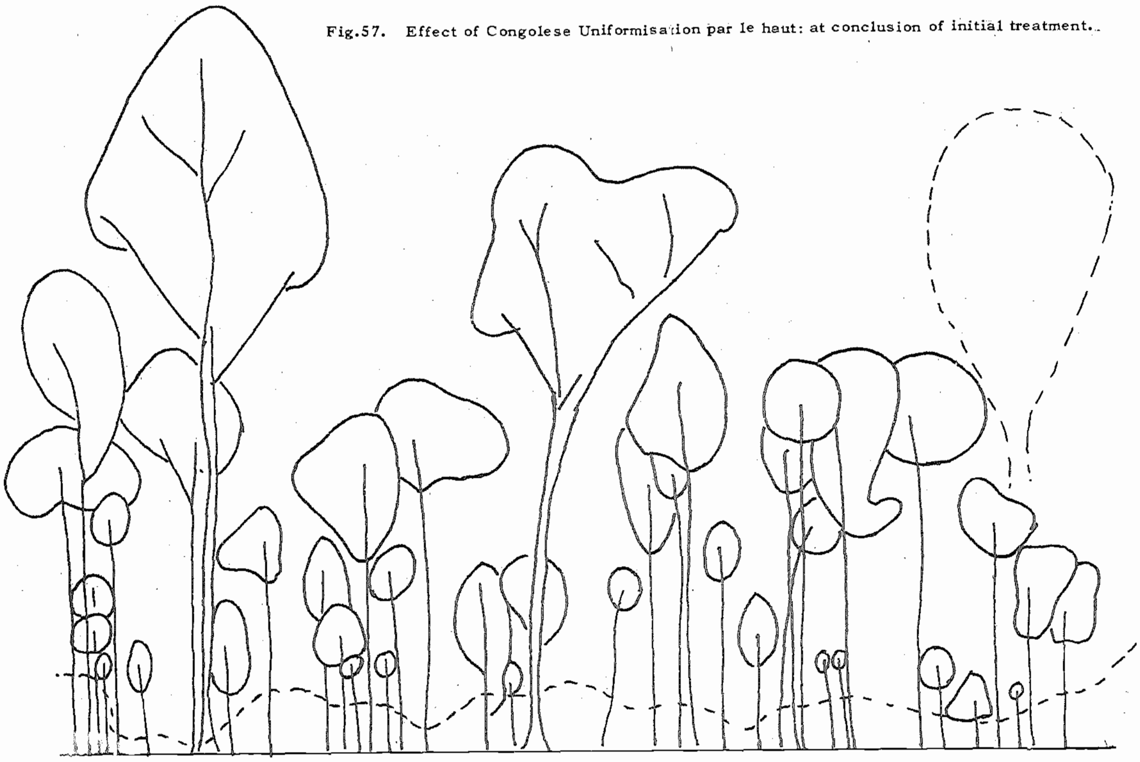


Fig.57. Effect of Congolese Uniformisation par le haut: at conclusion of initial treatment.

1. Belgian Congo (Uniformisation par le haut) (Fig. 57):

This treatment was only applied on a semi-routine scale, but it has influenced silvicultural thinking in several areas. Ahead of treatment an intensive enumeration of the existing stand is carried out, the results being used to indicate the precise form of subsequent treatment. The aim is to reduce the age (i. e. size) differences in the natural forest, and to remove the useless stems, leaving a relatively well spaced stand with an absence of large stems (excepting those of highly desirable species), and with conditions that favour the establishment and growth of regeneration. This is achieved by cutting all climbers, poisoning all unwanted stems larger than 20 inches D. B. H. and in addition poisoning selected smaller stems (particularly those which are characteristically useless) to an extent determined by the initial enumeration. The appearance of the hypothetical stand after such treatment is indicated in Fig. 57. Further openings should be carried out later if possible, and the stand should then be in a condition suitable for the operation of a selection system of silviculture in 10 to 20 years hence.

2. Ivory Coast:

A treatment similar to uniformisation par le haut has also been used in the Ivory Coast, but with greater attention paid to ensuring that regeneration is established. In this treatment, climber cutting is followed in turn by the removal of useless overstorey trees, thinnings in middle tree storeys, and careful openings in the understorey. Where less than 40 saplings or poles per acre are present enrichment planting is carried out, and the regeneration is subsequently cleaned at 3 yearly intervals for 10 years.

Treatments such as these do not constitute silvicultural systems which are defined (Empire Forestry Association, 1953) as "a method of silvicultural procedure worked out in accordance with accepted sets of silvicultural principles, by which crops constituting forests are tended, harvested and replaced by new crops of distinctive forms". They are in effect only a tending treatment applied in advance of the introduction of a true silvicultural system, and as such they correspond closely to the timber stand improvement (T. S. I.) operations which have been applied to extensive areas of previously unmanaged forest in North America and Australia. Such treatments are usually essential at some stage of bringing virgin forest under management* and, whilst there are obvious advantages to combining the improvement operations with commercial exploitation and regeneration treatments, there are, as already shown, many areas where this is not immediately possible and where a pure improvement treatment is well warranted.

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* An exception may be some of the North American conifer forests, where useless stems apparently constitute an insignificant proportion of the virgin stand.

Treatment Operations

The various types of treatments described above are made up of a number of separate operations, each of which has a definite contribution to make towards the ultimate aim of the treatment schedule. Although differing somewhat in the way they are applied, the operations are found to be repeated, in different order, around the world, and they can be regarded as the basic units of any silvicultural treatment in natural rainforest. For this reason the individual operations deserve some examination, even though some have already been discussed in relation to stands raised from artificial regeneration (Chapter 9) and in the more detailed discussions on silvicultural treatments in various rainforest countries (Chapter 10).

The operations fall into a number of classes, some of which contain several only distantly related operations which have, however, a similar broad aim. These are discussed below:

1. Soil Treatments:

Deliberate operations to alter in some way the nature of the natural soil are not commonly applied in the treatment of rainforest, but there are several examples where such operations are indeed carried out. These are of two types, burning and soil disturbance.

a. Burning: Unlike many forest communities where burning is a regular silvicultural operation, rainforest is typically very difficult to burn and, because of the fire-sensitivity of most rainforest plants, the results when it does burn are usually catastrophic, and tend to convert rainforest to savanna or some other different plant community (Chapters 2 and 5). The slash left after other operations (undergrowth cleaning, exploitation etc.) can however often be burnt, and this has been employed on an experimental scale in several areas. It had a one time vogue in India (Dawkins, 1958, p. 81) and was tried in Nigeria about 1927 as "Walsh's System", Lancaster (1961a) noting that it "was really a complete failure". In North Queensland burning discrete heaps of slash has been tried, the burnt areas being subsequently used for enrichment planting: the results were unsuccessful because the burnt sites attracted wallabies and other game which destroyed the seedlings (E. Volck, pers. comm.). Pitt (1961) used fire in Amazonia and found that severely burnt patches remained bare of both desirable seedlings and weeds for up to 3 years, but were capable of sustaining excellent growth when seedlings were planted: the results were sufficiently promising for Pitt to suggest burning as a possible routine silvicultural operation. Burning is of course a routine operation in most open plantation schemes (Chapter 9).

b. Soil Disturbance of varying intensities has been used as a means of inducing regeneration in a number of areas. The cheapest form of such disturbance is that which normally accompanies exploitation as tractors move over the soil, and Kirkland (1961) in New Zealand has taken this a stage further by suggesting that small bulldozers should be deliberately used in the cool temperate rainforests ahead of exploitation to remove the surface litter (which tends to accumulate in this cool climate) over about half the surface area. Manual soil disturbance tends to be very costly and consequently should only be employed in selected sites where regeneration is likely to be difficult to obtain otherwise: thus Nair (1952) recommends raking the soil ahead of seed fall around trees of Dysoxylum malabaricum in India, Pitt (1961) suggests similar treatment around selected seed trees in Amazonia, while in North Queensland areas inadequately stocked with regeneration, but carrying seed trees of certain prime species, have the undergrowth brushed down for a radius of up to 100 ft. and then the debris raked into heaps to leave the surface soil exposed and receptive to seed (see appendix 3). In view of the findings of Schultz (1960, p. 226), such treatments may also aid the germination of some species by covering the seed with soil or litter.

2. Canopy Opening:

Operations aimed at opening the canopy are among the most widespread operations in rainforest treatment. As shown in Chapter 3 the rainforest canopy usually consists of an upper storey of large trees, some of which are merchantable and some of which are useless on account of form or species. Beneath this are one or more lower storeys of trees, with climbers laced through the stand and binding the crowns together. To open this canopy four operations can be recognized: those removing the climbers, those removing the merchantable trees (which may include some stems in the lower storeys), those removing the unwanted overstorey trees, and those removing the unwanted lower storey trees. In the course of silvicultural treatment all these operations must ultimately be carried out (though climber cutting is often unnecessary in temperate rainforest since large vines are seldom common here). The sequence in which these operations is performed differs considerably in different areas, some favouring an opening from below (e.g. Andamans), some an opening from above (e.g. uniformisation par le haut), and others what is virtually a combined operation to remove all at once (e.g. Malaya, North Queensland).

a. Climber Cutting is necessary for four reasons: to improve access through the rainforest, to remove one of the worst groups of forest weeds, to effect an appreciable opening of the canopy, and to cut the Gordian knot which ties trees together and can cause excessive damage during logging. Where climbers are particularly common, as in West Africa, climber cutting is usually carried out as one of the first operations in silvicultural treatment. In Nigeria the operation was initially introduced to facilitate access (Lancaster, 1961a), but was soon shown to produce an appreciable opening of the canopy. In any area where climbers are common it appears necessary to cut these a year or more ahead of exploitation if the remaining stems are not to be unduly damaged during logging, and even in Malaya provision is now made for climber cutting several years before logging in sites where vines are plentiful. Cutting is usually by axe, machette, or similar implement, taking care to avoid bark damage where the climbers are resting against the stem of trees which are to be retained. Many species of climbers either root vigorously from the upper cut or shoot from below: in Nigeria a double cut, at ground level and at head height, partly overcomes this problem; elsewhere the appropriate end may be poisoned after cutting. Because climbers are extremely light-demanding, the cutting of dense tangles of vines may only promote further similar growth, and in Nigeria, where such tangles are very common, they are left uncut with a rim of trees around the tangle to shade it eventually out of existence. Climber cutting is also often required in young regrowth stands as one of the liberation treatments.

b. Exploitation, as well as providing the main yield of merchantable timber, can create considerable opening of the canopy, though the extent of this varies with the type of management being introduced (i. e. even-aged or uneven-aged stands being produced) and with the stocking of merchantable trees originally present. In some of the less advanced "tropical selection systems" exploitation is still the only canopy opening operation carried out, but this is seldom sufficient to produce an adequate response in either the inducement of regeneration of the increment of the remaining trees and saplings. Conversely in some of the purely liberation treatments (e. g. uniformisation par le haut) this operation is omitted, the merchantable stems being preserved to make further growth which is harvested at a later date. As shown by the studies of Nicholson (1958b) and Redhead (1960b), and as stressed by Dawkins (1958), exploitation can cause considerable damage to stems which it is desirable to retain. Previous climber cutting will reduce this damage appreciably and careful felling to avoid clumps of small stems, regeneration, etc. will also lessen the destruction, but with the very wide-crowned trees which are typical of many upper-storey rainforest species it is inevitable that much damage will result. This is usually compounded by damage caused when the logs are extracted from the forest, and together these sources of damage are potent reasons to favour the management of rainforest in even-aged stands, rather than in uneven-aged stands where exploitation is repeated at relatively frequent intervals.

c. Understorey Removal: In most regeneration treatments where the canopy is opened in a number of stages, the lower tree storeys are removed ahead of the unwanted trees in the upper storey. As shown in Chapters 2 and 3 trees of the lower storeys tend to be greater shade casters than the taller trees, with wider and denser crowns (see for example Fig. 4). The removal of these trees creates a very marked lightening of the canopy, thus favouring both the inducement of regeneration and, more importantly, the speeded growth of seedlings and saplings already present. For this reason this operation is a most important one in a number of regeneration treatments, including the systems used in Nigeria, the Andamans, New Zealand and Reunion; it is also recommended in Malaya in areas where regeneration is deficient. Removal is effected in a number of ways. Very small stems are commonly cut by axe or machette, but for larger stems, where felling becomes time consuming, girdling or, more commonly, poisoning is used.

Girdling (ringbarking) is still used in North Queensland*, but the tenacity of life of most rainforest species makes this rather unreliable unless it is very carefully and well performed. Poisoning is a more sure method, usually being applied either as solution to a frill girdle or as a spray direct on to the bark. The poisons generally used are sodium arsenite or one of the 2, 4D and 2, 4, 5T group of hormones. Dawkins (1957b, 1958) in Uganda has found the hormones highly effective, and recommends a 3% mixed ester solution in dieseline, applied as a bark spray. Other workers have not obtained such good results with this (e. g. Wyatt-Smith, 1960c), and in most areas the more lethal arsenic solution is used in frill girdles: in Malaya 2 lbs. of sodium arsenite are used in a gallon of water, while in Nigeria 1 lb. per gallon is used, with the more resistent species being girdled twice about 9 inches apart on the trunk. Care must be taken to girdle the stem completely, and in Malaya chisels are carried by the poisoning gang to ensure that crevasses in fluted or buttressed stems have the bark severed. Great care must obviously be taken in the handling of the poison, which is applied from closed, fine-spouted cans, is stained with a coloured dye, and is mixed and carried under rigorously controlled conditions: the safety record of the poisoning gangs in both Malaya and Nigeria bears witness to the efficacy of these measures. In Malaya hormones are used where the rainforest stand is in a town water catchment area, e. g. parts of G. Arong F. R., in the Mersing town supply catchment.

d. Overstorey Removal: Except in improvement treatments performed well in advance of logging, useless overstorey removal is usually carried out following logging. A major reason for this is the very real hazard formed by large, dead trees in a rainforest stand, a hazard which is increased when other large trees are being felled and mechanically extracted from the stand. In improvement treatments, such as uniformisation par le haut and the suggested treatment in Malaya, the overstorey trees are destroyed ahead of logging, but sufficient time is allowed for the dead trees to fall and start decaying naturally before exploitation is carried out. In the improvement treatments the aim of overstorey removal is to reduce stand B. A. to a more dynamic level, to give increased crown space to the remaining larger desirable stems, and to increase the light at lower levels for the benefit of the smaller desirable stems. In regeneration systems, where a shelterwood is deliberately formed from these larger stems, the aim of the shelterwood is to provide sufficient shade to protect those desirable saplings which are prone to scorching, insect attack, and so on in full light, and to deter the more rampant weed growth, while at the same time allowing sufficient light through for most of the regeneration to grow vigorously. When this regeneration is well established the overstorey is normally removed by poisoning: and indication of the response of the regeneration to this ultimate removal is given in Table 36 from Nigeria, and supplies support for the logical need for these trees to be destroyed as soon as they are no longer needed.

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* A rather paradoxical situation, as it was an article in the Queensland Agricultural Journal of 1917 that apparently first suggested the use of poison on a routine scale in rainforest silviculture (Dawkins, 1958).

The poisoned trees, once dead, tend to fall apart rather heavily, the larger limbs often damaging small trees below them and, in Nigeria, creating "craters" which act as focal points for the development of climbers, etc. Despite the damage which it causes, useless overstorey removal is an operation which must sooner or later be faced in all rainforest treatments during the first rotation: in subsequent rotations such trees should not be permitted to develop.

These canopy opening operations are among the most important performed in any silvicultural treatment of rainforest, since they provide the light and growing space needed by the regeneration and they remove the stems which are no longer needed in the stand. In some areas all four types of operation are performed at the one time or in close proximity (e.g. Malayan uniform system), though often the operations are spaced apart to give a regular sequence of gradual canopy opening (e.g. Nigerian T.S.S.); sometimes one of the operations may be given as two or more partial treatments (e.g. understorey removal in Ghanaian T.S.S., or exploitation in the various selection systems). However unless the rainforest stand diverges from the usual physiognomy of a multi-storied, viney community with useless trees of all sizes, all operations must be performed at some stage in the conversion of virgin, unmanaged rainforest to a managed forest producing a sustained yield of timber. Some indication of the amount of opening caused by the three tree-removal operations is given in Table 61, based on data presented in Chapter 10.

3. Artificial Regeneration:

The treatments being considered here are ones which by and large rely upon natural regeneration to produce the new crop. However, artificial regeneration is employed to some extent in a number of these treatments, usually to stock those areas which otherwise would tend to be deficient in regeneration. In this sense artificial regeneration provides a handy form of insurance to the silviculturist: though relying primarily upon natural regeneration, he has a tool at his disposal to use in particular sites where his efforts have failed to produce a satisfactory response in terms of seedling and sapling regrowth: Malaya, Queensland and the Ivory Coast provide examples of treatments where this insurance can be invoked whenever necessary by enrichment planting. In addition artificial regeneration may be used, as in Trinidad, less with the aim of producing a full stocking of trees in otherwise unproductive areas than to inoculate the treatment area generally with a scattering of trees of trees of non-endemic species which, on maturity will seed up the surrounding area and enrich subsequent rotations with new and valuable species. This practice of introducing new species may also be employed where artificial regeneration is only used in understocked sites, e.g. the use of Dryobalanops aromatica and Flindersia brayleyana in parts of Western Malaya. In a few cases artificial regeneration may be relied upon as the routine method of obtaining regeneration, though the obvious intention of the full sequence of silvicultural operations is to maintain a relatively mixed rainforest in which any natural regeneration is encouraged and retained: this is for example the case in Reunion and in the Phoebe - Amoora of Assam (Kadambi, 1957).

TABLE 61

Basal Area Reduction Produced by Canopy Opening Operations

Country:	Malaya	Nigeria	North Queensland
Locality:	Kluang F. R. (see Table 28)	Sapoba F. R. (see Table 33)	Average Values
Initial B. A.:	164 square ft. per acre	173 square ft. per acre	350 square ft. per acre
% B. A. removed in -			
(a) exploitation	19%	38%	37% (a + b)
(b) logging damage	13%	see note	
(c) understorey removal	33% (c + d)	16%	47% (c + d)
(d) overstorey removal		14%	
% B. A. retained -	35%	32%	16%

NOTE: Values for Sapoba are estimated from one plot and take no account of logging damage, which would reduce the percentage of B. A. retained in the final stand.

Despite the wide use of artificial regeneration in these, they still warrant consideration primarily as treatments of the natural rainforest. The Reunion technique is unusual in its reliance upon the sowing of seed rather than the planting of seedlings. Artificial regeneration techniques have been considered in some detail in Chapter 9, where it was stressed that the use of artificial regeneration to supplement natural regeneration, and its subsequent tending as natural regeneration, can prove a most valuable aid to the treatment of rainforest.

4. Undergrowth Cleaning:

Most natural rainforests stands possess a low, and frequently dense, shrub layer made up of true shrubs, small saplings and seedlings of larger trees, stemless and dwarf palms, bamboos, small vines, and other lifeforms (see Figs. 13 and 15). This understorey may appreciably reduce the light available at ground level, and its complete or partial removal is commonly a prescribed operation aimed either at inducing seedlings on the exposed soil or at releasing any dormant seedlings already present. Such operations, where the object is to establish regeneration, should be distinguished from the sometimes rather similar operations carried out subsequently to release and keep vigorously growing regeneration that is already well established. Cleaning operations feature in many treatment schedules: they were an important part of the early Malayan R.I.F. system and of the first version of T.S.S. in Nigeria, they are still carried out in Nigerian forests where the natural regeneration is deficient at the start of treatment, and they occur at an early stage in such varied treatments as those of Queensland, Reunion, New Guinea and the Andamans. The operation is essentially a manual one carried out by machette, brush-hook, bush knife or other similar implement, cutting the undergrowth usually at as low a height as possible and retaining any useful saplings which occur within the undergrowth. At the same time any malformed or damaged saplings of desirable species may be coppiced. Selective cleanings, aimed at the removal of a specific type of weed, may be given in some areas: Pitt (1960) experimentally tried the removal of "those undesirable species with opposite leaves" (i.e. mostly Melastomaceae) in Brazil to effect a partial undergrowth cleaning; in Malaya areas heavily infested with the stemless palm Eugeissona triste or with bamboos are treated ahead of logging, the palms being destroyed either by spraying a 2% solution of the butyl ester of 2, 4, 5T in dieseline on to uncut clumps or by cutting the fronds and pouring a 20% (2 lbs. per gallon) solution of sodium arsenite on to the smashed growing shoot, and the bamboos by spraying clumps with a 10% solution of T.C.A. (sodium trichloroacetate) in water (Wyatt-Smith, 1959c; Mohd. Alwy bin Haji Suleiman, 1961). Cleaning operations are costly and should only be applied if considered truly necessary. Even with skilled labour there is a risk of many useful saplings being accidentally cut down: Redhead (1960a) in Nigeria found that an average of 63 useful saplings per acre had been destroyed in cleaning one compartment - in an area where a stocking of 40 per acre was considered full stocking! In addition repeated cleanings, as in the early Malayan and Nigerian systems, have been found to promote the growth of the more aggressive secondary species including climbers: these, as was discovered in the untended Malayan forests during the Occupation, diminish when thicket conditions are established. For this reason it seems wise to use cleaning cautiously, and only where it is needed to establish regeneration, permitting thickets of useful regeneration and unwanted stems to become established as soon as possible.

5. Liberation;

Once the regeneration has become well established by the various operations outlined above it is desirable to ensure that the potentially useful stems are kept growing at a fast rate. The operations involved here appear to be of great importance if something approaching the maximum rate of increment is to be obtained on the desirable stems, and in view of the costs involved in establishing the regeneration, and of the effects of compound interest on these costs, this maximum increment rate is clearly an objective to seek. Two types of liberation operations can be distinguished, the first aiming to keep the desirable stems free from impedence by unwanted species, and the second seeking to encourage the potential final crop stems by periodic thinning.

a. Removal of Impeders: This operation can take various forms depending on local circumstances, but its prime aim is to ensure that the growth of desirable saplings is not hampered by competition from useless species such as weed trees and vines, while at the same time ensuring that stems of little value are retained where these are not competing with desirable stems. Such liberation operations thus tend to be highly selective compared with the cleaning operations described above. In Malaya the form of these operations is largely determined by previous diagnostic sampling ($\frac{1}{4}$ chain square plots at about age 5 years after exploitation, and $\frac{1}{2}$ chain square plots at about age 10 years). Based on the results of the sampling the type of operation which seems most necessary to the particular area is prescribed: this may include climber cutting, the destruction of certain palms, the removal of any useless stems surviving from the original crop (e. g. due to faulty poison-girdling or to deterioration of the exposed stem after stand opening), the poisoning of any listed weed-tree species (e. g. *Pasania* spp., *Ficus* spp.), the removal of unwanted species actively competing with a desirable stem, and possibly some selective thinning among the desirable stems. In Queensland liberation tending is carried out 3 or 4 years after the initial treatment with a limited brushing and climber cutting around each "key" tree, which is selected on the basis of species and spacing (see appendix 3). In addition in Queensland, areas liable to infestation by *Laportea moroides* are given special treatment to eradicate this weed which, if strongly established, can make entry into a regrowth stand impossible: spraying with a 1% solution of the sodium salt of 2, 4D has been found to give effective control of *Laportea* whilst causing little damage to the more valuable species. Similar operations are given in many other treatment sequences.

b. Thinning: If the removal of impeders is carried out properly in the early years after exploitation, the regrowth stand develops into one where the more desirable species dominate, though unwanted smaller stems may be plentiful beneath this upper storey (see for example Figs. 30, 32, and 33). Not all the useful stems which are initially present can be expected to form large final crop trees: this applies equally to stands which are in an even-aged or an uneven-aged condition. In even-aged crops, which are the more easily understood, the desirable stems sooner or later come into competition with each other with both their roots and crowns. The extent of the competition is a measure of the stocking of the stand, and stocking can probably be most readily portrayed as the standing basal area. In Fig. 58 the general and simplified relationship between standing B. A. and periodic B. A. increment is indicated.

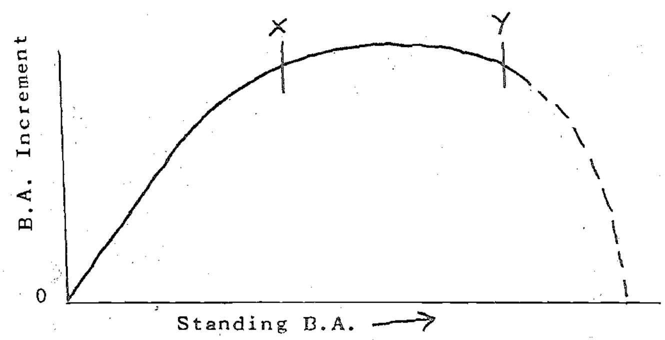

Fig. 58. Generalised Relationship between Standing Basal Area and Periodic Basal Area Increment.

(See text for details)

At low values of total B. A., the increment shows an almost linear relationship: over this range of values the trees are virtually free-growing. At very high values the increment falls away to nil, the condition prevailing in virgin stands where growth over a period is counterbalanced by mortality (see Chapter 6). Over some intermediate range of standing B. A. values, indicated by points X and Y in Fig. 58, the trees are in competition but the increment varies little within the range of B. A. stocking: a relatively low stocking (X) will produce about as much increment each year as a much higher stocking (Y) and, if the lower stocking represents fewer stems, these must, individually, be growing at a faster rate and will therefore attain their optimum merchantable size at an earlier date, with a consequent reduction of rotation and saving of compound interest charges. The value X apparently tends to increase somewhat with age in even-aged stands (see, e. g. Richards, 1955) but it is the level of B. A. stocking which the silviculturist should endeavour to maintain as a result of his thinning operations. In truly uneven-aged stands there will be a similar value (probably equivalent to the mean of the changing X value during the rotation of an even-aged crop) at which the maximum increment will be put on to the least number of stems, and again the silviculturist should try to maintain his stand at about this value. Dawkins (1958, pp. 90-92) believes this optimum B.A. value lies at about half to two thirds of the B.A. in virgin forest, with a value of about 100 square ft. per acre probably close to the desideratum under Central African conditions. In Brazil, Pitt (1961) suggests an optimum B.A. of between 65 square ft. and 80 square ft. per acre, in Puerto Rico the "ideal" B.A. is believed to be about 80 square ft. (Table 42), and in North Queensland the B.A. between felling cycles seems likely to fluctuate between 55 and 95 square ft per acre (Table 51). These values will doubtlessly be found to vary not only with site and age, but also with the species making up the stand. In this connection the apparent lack of competition between light-demanding species and shade tolerant species in the Trinidad thinning plots (see Table 39 and Fig. 45) is of outstanding interest, and detailed studies on the optimum stocking of rainforest stands under differing conditions represent a field of research most urgently needed by rainforest management With optimum values in the order of 80 square ft. to 100 square ft. per acre, it can be readily shown that a final crop stocking of between 15 and 30 stems per acre of merchantable size (24 inches to 30 inches D.B.H.) is all that can be hoped for (see Dawkins, 1958, Table 15). If there is little chance of being able to utilize smaller stems, then a well spaced stocking of this order is all that is needed from the time of regeneration, provided there is some surety that these will be of good form, and that treatment to concentrate growth upon these stems can be maintained through the rotation: this is the basis for the wide spacing adopted in many extensive enrichment planting schemes (see Chapter 9). In practice, of course, more stems are needed to ensure that some choice of final crop trees is possible. Thinning operations are already prescribed in a number of silvicultural treatments (e.g. Trinidad and the Andamans), and on the basis of the above arguments will undoubtedly prove necessary in all areas where a reasonable quantity of regeneration is established, if merchantable logs are to be produced in an economically feasible length of time. In uneven-aged stands (e.g. Queensland, Puerto Rico, New South Wales) thinning can occur each felling cycle, while in even-aged stands deliberate intermediate fellings are required. At the time of thinning the stems to retain are those of good form of desirable species, apparently vigorous, fairly evenly spaced, and with healthy, well developed crowns. Trees not measuring up to these standards should be progressively removed. Markets for the thinnings are frequently poor (see Chapter 7) but should be encouraged by the forest services, but even where no market exists the possibility of non-commercial thinning (e.g. by poisoning) deserves examination in view of the economic benefits which it brings by way of faster growth and shorter rotations. Intermediate fellings are often criticised on the grounds of the subsequent loggging damage, but as shown by Wyatt-Smith and Ja'afar bin Sudin (1961) this need not cause alarm if reliable contractors and adequate departmental control can be provided. In Trinidad, besides thinnings at earlier ages (8 and 15 years), intermediate fellings are expected at 25 years to remove the, by then, mature stems of Didymopanax, and at 30 years to remove the stems of the other faster-growing species, leaving the slow-growing species to form the final crop at 60 years. Keay (1961) has proposed a similar type of intermediate felling in Nigeria to remove the faster maturing stems of Triplochiton. Similar also are the salvage fellings carried out in various countries (e.g. in Malayan forests treated under R.I.F.) to remove useful trees, present in the shelterwood but unlikely to survive a full rotation: again logging damage is a deterrent to such fellings, but if at all possible the operation should be carried out.

6. Refining:

Dawkins (1955b) has introduced this concept into rainforest treatment, its aim being the complete elimination of useless species, such as climbers, weed trees and shrubs, from the managed rainforest. Some degree of refining is inherent in the canopy opening, cleaning and liberation operations, but Dawkins would take this further through a series of operations to remove ultimately from the stand all species not necessary for the healthy development of an economic crop. To some extent the operations of uniformisation par le haut and of the pre-logging treatment in Uganda are refining operations, but it must be expected that similar treatments will have to be repeated many times, either deliberately or in the course of other operations, before all unwanted species can be finally eradicated.

7. Sampling:

Sampling treatments are not truly silvicultural operations, but the development of diagnostic samping in Malaya and its subsequent spread to other areas have given it an important role in rainforest silviculture. Samplings of this type are carried out over a proportion of the stand, and the data recorded is used to determine the best type of treatment to give to the forest; Wyatt-Smith (1962) has described this as the "most important tool in the Malayan Uniform System", since it gives the system great flexibility, coupled with the assurance that the treatment likely to do the greatest amount of good for the crop will be prescribed. In the course of a normal Malayan uniform system treatment sequence, four samplings are carried out. The first two are carried out together ahead of exploitation. One of these is an enumeration of the exploitable trees present, and the other is an assessment of the regeneration under 5 ft. in height established in the area. The regeneration is assessed using a 2% sample with transects of milliacre plots, and in each milliacre plot the most desirable seedling or sapling present is recorded, an estimate of the frequency of stems of this species is made, and the presence of any palms and of more valuable, but less well developed, seedlings of other species is also recorded (Table 22). This information provides an indication as to whether the area is sufficiently well stocked for exploitation to proceed, or whether logging should be delayed and possibly some pre-logging inducement treatment given; it also indicates the composition of the regeneration, and this in turn determines the amount of canopy opening to be given after exploitation and the need for any special early liberation operations, such as are required where heavy hardwood species are common. The two subsequent samplings are given at roughly 5 and 10 years after exploitation. The first is a 5% intensity sample of $\frac{1}{4}$ chain square plots and is concerned with stems between 5 ft high and 4 inches D.B.H., and the second is a 10% sample of $\frac{1}{2}$ chain square plots concerned with stems larger than 2 inches D.B.H. In both cases the desirable stem most likely to succeed is recorded by size and species, along with a more valuable, but less well established, species if present. The dominance class (extent of crown freedom or suppression) of each selected stem is also recorded (Table 22).

This information is then used to determine what types of liberation operations are required to maintain these selected stems in vigorous growth (see Barnard, 1950b; Wyatt-Smith 1960b and 1962). Similar types of diagnostic sampling are used in other treatments. In the Belgian Congo a 10 % intensity of sampling was used to record all stems larger than 2½ inches D. B. H. as a basis for prescribing treatment in uniformisation par le haut (Donis and Maudoux, 1951). Dawkins (1958) describes in detail the sampling technique used in Uganda, while Cooper (1961b) has drawn up detailed prescriptions for use in Nigeria. Queensland experience shows that diagnostic sampling is not essential for the success of rainforest treatment, but there can be little doubt that, under normal conditions of relatively unskilled labour, diagnostic sampling pinpoints the types of operations most needed by the crop, and enables the minimum necessary treatment to be given while other costly, but unnecessary, operations can be avoided: as shown by R. I. F. and the early versions of Nigerian T. S. S., without diagnostic sampling much needless expense on treatment has been incurred by adopting a detailed but inflexible schedule of operations.

Basis of Silvicultural Treatment

The treatment of natural rainforest is not necessarily the most desirable approach to silviculture in all areas. Planting in some form or other must be considered for the following types of area:

1. Where there is strong pressure on the land for other purposes (usually agriculture), and more intensive management must be carried out with more efficient species on the smaller areas which will form the ultimate forest estate.

2. Where the high capital cost of plantation establishment can be readily met, even in the absence of land hunger, leading to the creation of compensatory plantations which can meet the region's future timber requirement.

3. Where there is a demand for a certain type of forest product which cannot be readily provided from natural rainforests (e. g. long fibred P. caribaea pulp in Surinam; high quality Araucaria ply logs in southern Queensland and New Guinea).

4. Where there are extensive areas of totally or relatively unproductive forest land located in a good economic position (e. g. the areas of inherently poor Kempas-Kedongdong rainforest close to Kuala Lumpur, and also the areas of grassland and worthless secondary vegetation resulting from wartime devastation in various parts of Malaya).

In many other areas the current lack of markets for much of the standing volume in the rainforest precludes treatment, and should also preclude exploitation, until a greater proportion of the crop becomes merchantable (Gordon, 1957). As shown in Chapter 8, lack of markets usually results from poor accessibility and unknown timber qualities, both factors which can be expected to alter for the better in time.

These exceptions still leave very large areas of rainforest where more extensive management of the natural forest is practicable. These stands differ in such important respects as imminence of exploitation, stem size class distribution, the necessity of maintaining indirect forest benefits, the occurrence of regeneration in the virgin forest, the response of regeneration to canopy removal, and the prevalence of aggressive weed species. These similar considerations foredoom the possibility of any single type of treatment being suitable for regenerating and managing all types of rainforest. Much as one may envy and admire Malaya for its very simple clear-cutting system, for example, systems of this type can be only applied with success where a certain set of fortunate conditions prevail. Indeed Malayan silviculturists are the first to stress that this system is only applicable to certain types of rainforest in the Federation, and it is quite unsuitable for other rainforest stands in the same country.

The treatment sequences described earlier in this chapter appear to be very varied,but there is in fact a definite pattern to them dependent upon certain local factors. Thus, for areas of rainforest where one of the objects of management is timber production, the following situations may be encountered, and the following types of silvicultural treatment be necessary:

	Situation	Action
1.	Timber not currently accessible	(2)
1X.	Timber accessible now or in near future	(3)
2.	Finance available for treatment	Improvement Treatment (e.g. uniformisation par le haut).
2X.	No finance available for treatment	Reserve and protect
3.	Management for indirect benefits (e.g. watershed protection, recreation) paramount.	Selection System (e.g. Puerto Rico)
3X.	Management for timber production paramount.	(4)
4.	Intermediate sizes plentiful: royalty rates make retention of these desirable	(5)
4X.	Intermediate sizes relatively scarce.	(6)
5.	Severe opening of stand deleterious.	Selection System. (e.g. New South Wales)
5X.	Severe opening not deleterious.	Group Selection. (e.g. North Queensland)

Situation	Action
6. Regeneration adequate in virgin forest, or occurs naturally with exploitation.	(7)
6X. Regeneration not naturally adequate.	(8)
7. Regeneration capable of responding to suddent and complete increase in light and exposure.	Clear-cutting. (e.g. Malaya, North Borneo).
7X. Regeneration needing partial shelter for some years.	Post-exploitation Shelterwood (e.g. Trinidad, British Guiana).
8. Regeneration induced by canopy opening and cleaning.	(9)
8X. Regeneration not readily induced naturally.	Artificial regeneration, combined with some other type of treatment (e.g. Reunion, North Queensland in part).
9. Regeneration, when established, responding to complete light and exposure.	Pre-exploitation Shelterwood: (e.g. Nigeria, New Zealand).
9X. Regeneration, when established, still requiring shelter for some years.	Extended Shelterwood: (e.g. Andamans).

This is not an exhaustive list of situations which may occur, but it does cover most of those which are normally encountered. Except for the improvement treatments, which make no pretence at being a system for regenerating forest, and for the artificial regeneration treatments which should be included in some broader treatment schedule where they are required (e.g. see Foury, 1956), the actions suggested to cope with each situation all clearly fall into the concept of a silvicultural system, and as such they provide the basis for introducing true sustained yield management to previously unmanaged rainforest.

Neglecting the highly theoretical and probably irrelevant argument about treatment needing to maintain the natural forest structure, present day extraction methods strongly point to the need for removing the original crop in a single, concentrated operation (Wyatt-Smith, 1959b). This leads to the introduction of a system relying on essentially even-aged regeneration, which is also favoured by the greater ease of management in such crops. The form of the system producing even-aged regeneration depends on the behaviour of both the desirable regeneration and the weed species, as shown above for the various shelterwood and clear-cutting systems.

Only where there are strong reasons for retaining a considerable proportion of the original canopy does an uneven-aged system seem warranted: as shown above this may occur when it is essential to retain the protective and aesthetic value of the stand (Puerto Rico) or when, on economic grounds, it is wiser to retain a fairly high stocking of small stems when their financial increment is at its peak, rather than to sacrifice these stems for an immediate, but low, cash return (eastern Australia). Economics, no less than ecology, determine silvicultural policy!

Reverting to the "natural forest structure", the evidence suggests that a group selection system most closely approaches the conditions under which most rainforest plants regenerate in virgin forest (Chapter 6), and group selection is virtually equivalent to clear-cutting on somewhat limited and scattered areas. Indeed where the rainforest is subject to occasional severe cyclones, a system equivalent almost exactly to clear-cutting may be responsible for regenerating the rainforest, as shown by Browne (1949) in the Kelantan "storm forest" of Malaya. Clear-cutting systems, in other words, are in fact a "natural" method of regenerating rainforest. Where the species are such that a shelterwood is temporarily necessary to control the species composition in the regeneration, this again is merely adapting natural phenomena to the silviculturist's needs. Subsequent treatment, once the desirable regeneration is established, should ensure that a well distributed stocking of good stems is kept free from unnecessary competition so that the stems can approach the maximum rate of growth of which they are capable, and gradually eradicating those species which contribute nothing to the growth of the desirable stems. Under such treatment rainforest can be managed to provide its highest possible sustained yield of timber.

Anticipated Results from Treatment

Silvicultural treatments such as are discussed above have been introduced on varying scales in many of the world's rainforests, and in most cases the results are regarded locally as satisfactory: that is, an adequate quantity of desirable regeneration is being established and is growing at what seems a reasonable rate, with increment being more or less concentrated upon the better stems in the stand. The actual level of an "adequate quantity of regeneration" varies widely between areas, but as was shown earlier, in most stands of tropical rainforest as few as 30 stems per acre are sufficient to produce a fully stocked final crop, provided that these all develop into vigorous trees of good form, and are more or less evenly spaced. To comply with this proviso some greater stocking is normally necessary initially to allow for mortality and suppression, and to give the silviculturist room to select and subsequently to favour the better stems, but the greater stocking need not be excessive: under rainforest conditions the shrubs and small trees which respond, along with the desirable regeneration, to canopy opening form a matrix in which the really useful stems are forced to grow upwards and to shed their lower branches. The main need, once regeneration is established, is to ensure that the selected stems are kept free from overhead or excessive lateral competition and are not suppressed by vines, fast growing weed trees, and similar impeders.

Under these conditions what rates of growth can be expected from treated stands? Unfortunately data on this subject is extremely sketchy, but in Table 62 some figures from areas under treatment are shown.

The most reliable estimate of increment in Table 62 is the lowest value, the 32 cubic ft. per acre per annum obtained by Cousens in Malaya. This does certainly not represent the full production capacity of these forests, as is well appreciated by Cousens, but it probably does indicate the order of increment loss in routine treatment areas compared with selected plots which, no matter how good the intentions, tend to be either located in above average sites or else treated more carefully and intensively than adjacent areas. It is quite possibly no exaggeration to suggest that all other increment and final yield figures in Table 62 should be halved for routine conditions, Queensland and New Zealand being possible exceptions.

The Nigerian, and to a large extent New Zealand, figures are outright estimates, and should be treated with reserve. It is however interesting to observe that their M. A. I. 's fall within the range of the other countries where the increments are based on plot data. These latter values range from 40 cubic ft. in Queensland, in plots where the B. A. is probably below the optimum production level, up to 90 cubic ft. in Trinidad, with increments between 60 cubic ft. and 80 cubic ft. being most common. Increments of this order will provide yields which are considerably higher than those being currently obtained from unmanaged forest. Even if the increments are halved, the ultimate yields of the new crops will be well in excess of present outturns from exploitation. Thus treatments, which can be completely, or almost entirely, financed from the revenue received from current exploitation, seem likely to produce a much higher yield at the end of the rotation or felling cycle. This is an important consideration in favour of the treatment of natural rainforest, since the high capital investment needed for most plantation schemes is avoided.

On the other hand the increments obtained by these treatments of natural rainforest are very much lower than those which can be expected in plantations. In North Queensland, where treated rainforest shows a P. A. I. of about 40 cubic ft. per acre, Haley (1957) records 20 years old plantations of Araucaria cunninghamii as having an M. A. I. of 280 cubic ft. per acre (C. A. I. 420 ft. per acre), and Flindersia brayleyana (which figures prominently in the natural forests) an M. A. I. of 160 cubic ft. per acre, though the form of the plantation Flindersia is much inferior to that of the naturally regenerated stems. In New Guinea, plantation Araucaria shows an M. A. I. at 9 years of 230 cubic ft. per acre (Anon., 1960); in New South Wales the same species gives M. A. I. 's up to 200 cubic ft. per acre at 19 years and certain Pinus spp. up to nearly 300 cubic ft. per acre at 9 years on rainforest sites (Baur, 1962b); plantation Tectona in Trinidad at 30 years gives an M. A. I. up to 150 cubic ft. per acre (Lamb, 1957); and Eucalyptus globulus in southern India has produced up to 550 cubic ft. per acre per annum over short (10 years) rotations (figures quoted by Champion and Brasnett, 1958). Plantations of many species on rainforest sites

TABLE 62

Expected Growth in Areas of Treated Rainforest

Country	Treatment	Rotation / Felling Cycle (Years)		Yield from Initial Exploitation (cubic ft. per acre)		New Crop P(M)A.I. (cubic ft. per acre)		New Crop Yield (cubic ft. per acre)	
Malaya	R.I.F. and clear-cutting	70	-	860	(1)	(32	(2)	2200	
						(60	(3)	4200	
Nigeria	T.S.S.	100	-	400	(4)	60	(4)	6000	(5)
New Zealand	Uniform System	120	-	3000	(6)	80	(6)	10000	(5)
Trinidad	T.S.S.	60	-	1300	(7)	89	(8)	5000	
Puerto Rico	Selection	-	5-10	?		60	(9)	3-600	
N.S.W.	Selection	-	25	c.300	(12)	75	(10)	1800	
Queensland	Group Selection	-	15-20	c. 400	(12)	40	(11)	6-800	

NOTES: Yield from the new crop is calculated in most cases by multiplying the P.A.I. by the rotation or felling cycle; for Nigeria and New Zealand the estimated yield has been provided and the P.A.I. has been calculated by division.

SOURCES OF DATA:
1. Vincent, 1960a
2. Cousens, 1957, from comprehensive sampling of pre-war regenerated forest in Perak; the M.A.I. is the average at age 40 years
3. Plots in good stands of old (33-50 years) regenerated forest, see tables 16 and 20
4. Rosevear, 1952
5. Final yield in both Nigeria and New Zealand includes an estimated 2000 c. ft. per acre obtained from intermediate thinnings.
6. Conway, 1952
7. Based on figures supplied by Mr. D. Moore (pers. comm.); sawlog yield of 125 c. ft. per acre and 15 cords (say 1200 c. ft.) per acre of fuelwood.
8. Plot mentioned by Moore, 1957
9. Sawlog increment only; Wadsworth, 1957
10. Plot described by Baur, 1959
11. Plots mentioned by Volck, 1960
12. Partial exploitation only.

thus appear to be able to produce merchantable timber at from two to ten times the rate that intensively managed natural rainforest is capable of maintaining. If the capital is available, plantations producing such high yields over relatively short rotations may well prove a far more profitable financial investment than treated rainforests with their low capital cost but longer rotations and lower yields.

The reasons for these different rates of increments between natural rainforest and plantation are varied. Part of the difference is artificial: management of natural rainforest normally aims at the production of large sawlogs, and the limit of merchantability is therefore considerably higher than in plantations where there is frequently a market for small sized stems. Thus adjacent areas of plantation and treated rainforest tend to be measured on different bases; if the same basis was used, treated rainforest would show anything up to twice the standing volume present, or conversely a plantation might show less than a third the volume that it is currently assessed as carrying. The relatively high increment shown by the treated plot in Trinidad is probably in part a reflection of this, since the island has good markets for small produce and even natural rainforest is assessed at a smaller limit of merchantability than say rainforest in Malaya. If stems down to 4 inches D. B. H., instead of 10 inches, had been considered in calculating the standing volume on the old treated plot at Pasoh F. R., Malaya (Table 20), the M. A. I. of this plot would have been raised from 60 cubic ft. per acre per annum to nearly 90 cubic ft.

The remaining difference in increment rates is more real. Partly it reflects the intensity of treatment. Plantations of the type considered here are usually established in the open from the start, and weed growth is ruthlessly and constantly removed (one result of which is the poor form of species such as Flindersia brayleyana in open plantations); all growth is concentrated in the planted stems, and when these are thinned the volume of thinnings removed is credited against the total volume production of the stand. By contrast, even in clear-cutting systems such as those used in Malaya, a considerable amount of overhead shade is retained in immature stems and in unwanted stems; these must reduce the growth rate of the regeneration. In addition the regeneration grows amid a mass of shrubs, vines and weed trees, all of which are producing cellulose. These compete with the desirable stems, and although liberation treatments are given periodically the growth of the desirable stems is reduced by this competition between treatments. Shrubs and smaller plants are usually retained and, whilst these do not compete for light with the useful stems, they do tax the water and nutrient supply capacity of the soil, again doubtlessly reducing the growth rate of the desirable stems. Again, although much growth is removed in liberation operations and in early unmerchantable thinnings, this is not credited to the volume production of the stand. Furthermore, the desirable stems which become established and grow to merchantable size are rarely evenly spaced: understocked patches abound in natural rainforest, lowering the production capacity of the stand. These reasons - suppressed early growth, undergrowth competition, high cellulose increments on useless stems, and irregular spacing - all depress merchantable increment compared with that in plantation and explain the difference between say the 60 cubic ft. per acre per annum recorded in the Malayan plots (Tables 16 and 20) and the 150-160 cubic ft. recorded in plantations of Flindersia and Tectona. The very much higher increments recorded by certain conifers and eucalypts are a different matter: these are apparently two groups of trees with inherent ability to utilize the site more efficiently (in terms of cellulose production) than most other trees. The silvicultural and ecological similarity between eucalypts and pines was mentioned earlier (Chapter 5) and it is interesting to note this different sphere of similarity in behaviour. Further than this, eucalypts and pines under plantation conditions are usually grown as exotics, and thus are removed from many of the insect and other pests which depress their natural growth rates: faster growth can thus be expected.

It therefore seems that whilst many broadleaved rainforest trees are capable of producing up to 150 cubic ft. per acre per annum under plantation conditions, and possibly even higher, different concepts of merchantability and almost constant competition with unwanted plants reduces the potential increment to about 100 cubic ft. at the maximum in the most intensively treated rainforest, and even this is unlikely to be attained on any but the most restricted areas. On a routine scale the rainforest silviculturist who can obtain 50 cubic ft. per acre per annum from his new crops is doing an excellent job: improvement on this figure will depend largely on being able to develop markets for small sized stems, particularly from currently unwanted species. To obtain the greatest return from the existing 50 cubic ft. being produced, frequent liberation operations to concentrate as much of the stand's increment as possible on well spaced, desirable stems are necessary, thus growing trees to larger size in less time: as Dawkins (1959) states, a study of the effects of compound interest "illustrates clearly the advantage of rapidity over mere productivity".

Review of Treatment Methods

This chapter has ranged over various aspects of treating natural rainforest, and the main conclusions to be drawn appear to be as follows:

1. The treatments applied, made up of a number of different types of operations, aim either at improving the composition of the stand well in advance of logging or at regenerating the more desirable species after, or at the time of, logging. The regeneration treatments, which in previously unmanaged rainforest inevitably must combine some improvement operations, are an approach towards the introduction of true silvicultural systems to rainforest.

2. These silvicultural systems are of two types, those attempting to maintain an uneven-aged forest structure and those aiming at establishing an essentially even-aged stand. Both types have their direct counterparts in virgin rainforest, and neither should be considered more "unnatural" than the other.

3. Uneven-aged systems require a high standard of management and run the risk of having many retained stems damaged at each of the periodic fellings. For this reason these systems, based fairly directly on the classical selection or group selection systems, should only be used where particular local conditions prohibit the use of more drastic systems that remove the old crop in a single operation or in several operations spaced over a relatively short period.

4. Even-aged systems are generally to be preferred for their greater ease of management and because they yield a greater volume of timber in a single operation, as is required by present day logging methods. These systems differ in technique, the differences being caused by the behaviour and site requirements of the regeneration being established.

5. The simplest system is where the merchantable stems and the useless canopy are removed virtually at the one time, to release regeneration which is already established and which can respond vigorously to almost complete exposure. This is akin to the European clear-cutting system, but differs in the regeneration being present ahead of any treatment, and in the retention of many smaller stems (e.g. the present Malayan system).

6. Other systems aiming to establish even-aged stands require the retention of a shelterwood for some years, the aim of this being:

   a. To induce natural regeneration ahead of exploitation (e.g. Nigeria).

   b. To foster the development of regeneration, which cannot tolerate immediate full exposure, for some years after exploitation (e.g. Trinidad).

   c. Both to induce regeneration and to protect it for some years after exploitation (e.g. the Andamans).

   These systems show a relationship to the European uniform system, but differ in that usually only one of the canopy opening operations yields merchantable timber, and in that, instead of having a series of partial openings in the single overstorey, opening is effected by removing different storeys of lifeforms (e.g. climbers, middle storeys, useless large trees), frequently by poisoning.

7. Where regeneration is difficult to establish naturally, very successful establishment can be effected by supplementing the natural seedlings with artificial regeneration.

8. To ensure that the regeneration, once established, is maintained in a vigorous condition with most of the growth of the stand being concentrated upon desirable stems, periodic liberation operations are essential.

9. To indicate the type of liberation operation which will produce greatest benefit at the least expense, as well as to indicate whether regeneration is already present before treatment starts, whether artificial regeneration is needed in any areas, and so on, diagnostic sampling has been found to be a most valuable tool for the silviculturist to use.

10. To produce the maximum increment on the least number of trees the stand basal area should be kept within a relatively limited range. For most areas of tropical rainforest this range appears to lie between 80 and 100 square ft. per acre, and in even-aged stands this B. A. means that only 30 stems per acre can be brought to maturity. In order to avoid unnecessary compound interest charges these potential final crop stems should be maintained at their maximum rate of individual tree growth by periodic liberation; the result of this will be to reduce the rotation length.

11. Even with the most intensive treatment it seems that natural rainforest cannot be expected to show an increment rate greater than 100 cubic ft. per acre per annum, and on a routine scale 50 cubic ft. can be regarded as very good. The main hope in being able to increase this value appears to lie in developing markets for small stems which can be extracted as thinnings.

12. The species which are raised in the new crops should obviously be ones for which there are established markets. They should also be ones which show a high rate of individual growth so that the rotation is not excessive, and in even-aged crops they should be ones which are established readily and in quantity, and which show vigorous early growth to enable them to compete successfully, and with a minimum of attention, with the usually prolific and fast-growing weed species. Such species, even if providing only a relatively low priced end product, are likely to prove far more profitable than slower-growing and less easily established species of greater intrinsic value. This is especially so if the species can be produced in quantity: markets can usually be developed for a species which is regularly available in large quantities. For areas managed by a selection (but not group selection) system, it is probably more important to ensure that the desirable species in the regeneration are those which can tolerate some overhead shade during their younger stages.

Rainforest, both tropical and temperate, can be managed successfully by a variety of methods. The initial requirement is to be able to market most, if not all, of the existing stems which are of large size and lacking any obvious defects. The treatment of such stands can normally be financed almost entirely from the returns from the sale of the old crop, thus obviating the need to raise investment capital from outside sources. The system of management should be kept flexibile and should be backed by constant research, permitting treatment to be fitted to the stand's requirement, not the reverse. Under these conditions future crops should yield appreciably more merchantable timber than their virgin or unmanaged predecessors. Until such time as land shortage or increased timber demand force the change to far more intensive methods of timber production, the forester who can achieve this limited result is indeed earning his keep.

CHAPTER 12

OTHER ASPECTS OF MANAGEMENT

> "One of the prime lessons which the forester learns in the tropics and which he has quite failed to grasp as a student is that it is to all intents and purposes impossible to practice silviculture and management in the absence of a fairly intensive and constant sale of the produce of the forest."
>
> Rosevear andLancaster (1952)

> "......progress in sound management of natural tropical high forest is chiefly dependent on the development of sampling techniques."
>
> Dawkins (1958, p.2.)

Scope of Management

Brasnett (1953) describes forest management as consisting essentially "in assessing the potentialities of a given area, in deciding what within these potentialities is desired from it, in organizing the area to achieve this object to the maximum extent consistent with the well being of the soil, in planning the operations necessary to this end, and in carrying them out from day to day. The primary object of good management is provision of the maximum benefit to the greatest number of people for all time". Clearly silvicultural treatment constitutes only one part of the management of any forest area, albeit a most important part and the part with which this report is chiefly concerned. Other aspects of management are, however, of no less significance and must be briefly considered.

These other aspects cover a host of topics. Indeed, together they cover virtually the whole range of professional forestry training, including such fields as forest policy, forest law, surveying, mensuration, valuation, silviculture, engineering, utilization, protection, business administration and labour relations. For the interrelationship of these topics into the subject of forest management, tests such as that of Brasnett should be consulted, but there are several of these topics which warrant slightly more examination as they affect rainforest management.

Permanent Forest Estate

Like any activity which relies upon the use of land, forest management is impracticable unless the managing authority has some title to the land. Furthermore, since forestry is a very long term undertaking, the title should be of a fairly permanent nature; very large sums of money can be wasted if capital is invested in improvement and treatment works on a forest, only to have the land wrested away for some other purpose. Thus before any management can be commenced, forest reservation must be carried out to establish a basic forest estate, the extent of which will depend upon its ability to provide for the present and future needs of the country or region. Some of the difficulties encountered in forest reservation have already been mentioned (Chapter 8), but these must be overcome before forest management in any area can be considered.

The degree of permanence of the forest reserves will vary in different countries. In some cases, as with State Forests in Queensland and National Forests in New South Wales, the reserves can only be revoked by passage of a special Act of Parliament: greater security of tenure is probably impossible for government-owned land in a democracy. Other titles are less permanent, but are still sufficient for management to be introduced. Where it is likely that some reserves will ultimately be required for other purposes, it seems desirable to reach some agreement about future revocation with the alternative land managers before introducing management. Thus in Malaya, where it is inevitable that some existing forest reserves will in time be needed for agriculture or mining, it appears generally agreed that no consideration will be given to revoking land already under silvicultural treatment until the end of the rotation.

In establishing reserves, the maintenance of local rights should as far as possible be avoided, particularly where these are likely to conflict in any way with the objects of management. At the same time the retention of some local rights, such as those of access and hunting, may be desirable in the interests of having friendly and co-operative neighbours. The reserve boundaries should be well marked in the field, especially where the forest adjoins land under different ownership and management. Where possible it is desirable for the boundary to follow natural features, such as ridges and watercourses, rather than artificial compass bearings or temporary tracks, although permanent structures such as main roads or railways frequently make satisfactory boundaries.

Before management is possible the forest must be surveyed and mapped. Forests, particularly in rainforest areas, are frequently extensive, and wide visibility over the estate is rarely practicable. Maps therefore provide the only usual means of obtaining an overall view of the area to be managed and of controlling the working of the forest in an orderly fashion. Management without reliable maps is virtually impossible. In the absence of reliable maps based on ground survey, aerial photo mosaics can provide a useful substitute, while even where good maps exist aerial photographs providing stereoscopic coverage of the forest are most useful supplements, and can of course be used to a large extent in preparing the final forest map.

The territorial unit of forest management is the compartment, and again before sound management can be introduced, the forest must be divided into compartments. As these will be the permanent basis for working the forest and recording the operations, much care is needed in making the subdivision into compartments. The size will vary with the intensity of management proposed, but as Brasnett (p.35) states "it should not be too large to be covered by treatment in one operation". Where plantations are being formed, the compartment is often between 20 and 50 acres in area, whilst in areas being managed as natural rainforest it is usually much larger; in Nigeria the compartments for T.S.S. are normally 1 sq mile (640 acres) and in Malaya they average about half this size. Where the old style tropical selection system is still employed, they may be very much larger. Attention must be paid to ensure that access will ultimately be possible to each compartment, and the boundaries should be such that they can be clearly and permanently defined: where the topography is hilly, natural features such as ridges and streams make desirable boundaries, as in the case of Malaya; conversely, on the flat and featureless Benin sands of Nigeria an artificial grid layout of compartments has been adopted, each compartment measuring 1 mile square and being bounded by a permanent track. A similar layout to this, using 1 sq kilometer compartments, has been adopted by F.A.O. in the Amazonian demonstration forest at Curua on the equally featureless "planalto".

Object of Management

Another prerequisite to the introduction of management is the determination of the objects of management. The choice here is in no small measure a matter of policy, as will be discussed in the next chapter, but many of the decisions must be made on the basis of local information. Areas where the object will be to manage for the indirect benefits (see Chapter 7) must be designated. Over some of these areas timber production will also be practised, but with restraints on the degree of logging and stand disturbance, and again the areas concerned must be known. Elsewhere less restrictive management for timber production can be countenanced and the choice must be made on such questions as to whether the aim will be gradually to convert to plantations, or to manage the natural forest, or to do both in differnt parts of the forest; where natural stands are to be managed, should the choice in silviculture favour conversion to more or less even-aged stands or a selection system where an uneven-aged forest is maintained on a relatively short felling cycle; where even-aged stands are desired, should a form of salvage cutting be carried out to remove mature stems from those areas which would not be otherwise be logged till the latter half of the first rotation, and so on. These points are considered in an interesting paper by Brasnett (1952, reprinted as an appendix to his 1953 book). In this, Brasnett stresses that the choice must be determined by the local conditions, particularly those dependent on the nature of the forest itself and its location, but that normally in tropical rainforest an even-aged system will be selected for the reasons already discussed. Where the size class distribution is suitable and the volume is sufficiently high in relation to logging costs, he suggests that the forest should be cut over twice in the first rotation, during the conversion of the all-aged forest to one with a regular series of even-aged coupes.

So far as possible the production forest should be managed from the first on the basis of providing a sustained yield of timber which will be at least maintained, and probably considerably increased, as the forest comes under organized management. Where conversion to evenaged stands is practised, an initial estimate of the allowable yield can be obtained from assessing the volume of merchantable timber standing in the forest and dividing this by the number of years in the anticipated first rotation to provide a conservative annual yield*. The desirability of maintaining a sustained yield is obvious, as it enables the managing authority to guarantee regular supplies of timber as the basis for establishing permanent and efficient utilization plants in the area. The advantages of such plants (sawmills, plymills, etc.) are stressed by both Brasnett (1952) and Gordon (1957), the latter urging the granting of long term security to the plants despite the monopolistic overtones which long term contracts carry. The drawbacks of long term contracts are warranted in the interest of

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developing previously unmanaged forest, and in any case, according to Gordon, they are larely overcome by the provision of three important terms to the contract:

1. Broad control of operations by the forest service, particularly in the allocation of logging coupes.

2. Sliding or revisable scale of royalty on timber extracted.

3. Insistence on construction of a suitable manufacturing plant, which may not be sold separately from the lease.

As Gordon points out, such leases act also in favour of the forest service as a protection against ill-conceived efforts to reduce the forest area.

Such schemes are by no means universally applicable, but they are nonetheless widely used in rainforest areas at the present time. Some form of security to the timber man appears a necessity wherever the forest service is aiming as sustained yield management.

Assessment and Yield

The concept of sustained yield requires both a knowledge of standing volume of timber in the forest and some indication of its rate of growth. As previously stated (Chapter 6), in virgin forst the nett rate of growth is nil and consequently, in the initial stages of managing virgin forest, growth can be disregarded and the yield based on the period during which the current standing volume is to be removed.

This volume can be assessed in various ways. For extensive areas of rainforest in the early stages of management, aerial photographs, supported by periodic ground checks to relate types distinguished on the photos to stocking and volume conditions in the forest itself, can be used to provide tolerable estimates of standing volume (Heinsdijk, 1960; Swellengrebel, 1959; de Rosayro, 1959). In the past, and to a very large extent still, assessment has been carried out by strip surveys, recording either stems of merchantable species and sizes only, or all stems down to a given size, within a given distance of a survey line. Such assessments can provide considerable data on stand composition, the occurrence of forest types and so on, and if suitably designed can give statistically reliable estimates of volume, as discussed by Dawkins (1958, Chapter 3). Elsewhere, assessment is carried out by means of randomly located plots, stratified by forest types and replicated to provide an acceptable measure of the standard error for the volume available on each forest type or group of related types.

The actual volume of individual trees located in the strips or plots can be assessed in various ways. Early assessments in many countries have often attempted to estimate centre girth and log length and to apply the standard local method of calculating log volume to each tree. More accurate results can be obtained by constructing local volume tables, based on accurate measurements, for the main species or groups of species present. Actual D.B.H. or diameter above buttress can then be measured and recorded, the log length estimated with occasional checks on the estimates, and the volume then calculated from the volume table. Where the volume table can be expressed as a mathematical formula, it is possible to "feed" the formula into automatic computers which can subsequently calculate the volume for each tree when the topography is hilly, natural features such as ridges and streams make desirable boundaries, as in the case of Malaya; conversely, on the flat and featureless Benin sands of Nigeria an artificial grid layout of compartments has been adopted, each compartment measuring 1 mile square and being bounded by a permanent track. A similar layout to this, using 1 sq kilometer compartments, has been adopted by F.A.O. in the Amazonian demonstration forest at Curua on the equally featureless "planalto".

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This volume can be assessed in various ways. For extensive areas of rainforest in the early stages of management, aerial photographs, supported by periodic ground checks to relate types distinguished on the photos to stocking and volume conditions in the forest itself, can be used to provide tolerable estimates of standing volume (Heinsdijk, 1960; Swellengrebel, 1959; de Rosayro, 1959). In the past, and to a very large extent still, assessment has been carried out by strip surveys, recording either stems of merchantable species and sizes only, or all stems down to a given size, within a given distance of a survey line. Such assessments can provide considerable data on stand composition, the occurrence of forest types and so on, and if suitably designed can give statistically reliable estimates of volume, as discussed by Dawkins (1958, Chapter 3). Elsewhere, assessment is carried out by means of randomly located plots, stratified by forest types and replicated to provide an acceptable measure of the standard error for the volume available on each forest type or group of related types.

The actual volume of individual trees located in the strips or plots can be assessed in various ways. Early assessments in many countries have often attempted to estimate centre girth and log length and to apply the standard local method of calculating log volume to each tree. More accurate results can be obtained by constructing local volume tables, based on accurate measurements, for the main species or groups of species present. Actual D.B.H. or diameter above buttress can then be measured and recorded, the log length estimated with occasional checks on the estimates, and the volume then calculated from the volume table. Where the volume table can be expressed as a mathematical formula, it is possible to "feed" the formula into automatic computers which can subsequently calculate the volume for each tree when the diameter and height are provided. Major difficulties in volume estimation occur with buttressed trees, which are awkward to measure (see Vincent 1960b), and with allowing for internal defect in individual trees. For the latter there still seems no method more reliable than the employment of experienced estimators who know the external signs of defect and the way different species normally react: defect is the major cause of error in estimating the volume of virgin stands. With time, as compartments are exploited and the volumes actually obtained can be compared with those estimated, factors can be calculated to allow for the errors due to defect, and more reliable estimates of standing volume can be made. Clearly where the aim is sustained yield, conservative estimates of volume are initially desirable and ample allowance for defect should be made.

Some knowledge of growth rate becomes of increasing importance as the new, regenerated crops develop in even-aged stands or as the second felling cycle approaches in unevenaged stands. From the growth rate the increment of the forest after treatment can be determined, and so gradually the yield from the forest can be related to the increment, at which stage true sustained yield management is in sight. Growth rate can be determined either from periodic measurements of individual trees, selected to cover a range of species and size classes, or from permanent yield plots. Individual tree plots have been widely used in the past in treatment systems similar to the tropical selection system, but their general utility is much less than that of yield plots which, in any case, are the only reliable approach to determining increment in even-aged regenerated stands. Nonetheless individual trees can be very useful in providing a fairly rapid means of determining average rates of growth for trees of the main species through a range of size classes. Yield plots, on the other hand, provide both information on the growth rate of individual stems and also a measure of the increment being produced by the entire stand: consequently, when provided in sufficient quantity either on a grid pattern or as randomly located plots, they can be used to determine not only growth rate but also an estimate of the total standing volume at any time. This is the basis of the continuous (or periodic) inventory method of assessing volume, as is used in the rainforests of north Queensland (Dawkins, 1961) and is being introduced into the older regenerated forests of Malaya (Cousens, 1957 and 1958b).

Whether plots or individual trees are used, they should be located in forest which has received treatment. Plots in virgin forest are of considerable ecological interest (e.g. Keay, 1961) but as pointed out in Chapter 6, the results obtained may bear little relationship to the growth in treated forest. The trees should be clearly marked so that each stem can be found on future occasions and measured for D.B.H. at the same point as previously. Diameter should be measured as accurately as possible, and other features of the tree may also be recorded, e.g. log length, crown conditions, merchantability, etc. (See Dawkins, 1958, Chapter 4). In yield plots, all stems over a given size (commonly 4 inches D.B.H. or 1 ft G.B.H.) are normally measured and recorded. Where facilities are available the results from continous inventory yield plots can be processed by computer to provide the necessary data on growing stock and increment rate, enabling the allowable yield to be calculated with increasing precision by one of the standard methods (see e.g. Brasnett, 1953). Where growth data from individual measured trees or from a few yield plots have to be used, more office calculations are usually necessary to relate the growth trends to assessment results and the yield so calculated is likely to be less accurate though still providing a tolerable estimate of productivity.

Logging and Extraction

Exploitation is a most important consideration in the management of production forests, and the economics of exploitation (particularly extraction) play a vital role in determining both whether an individual forest can be brought under management (see Chapter 8) and what type of silvicultural treatment should be employed (Chapter 11). The whole trend of exploitation at present is towards mechanized operations, and whilst techniques will doubtlessly alter and improve with time the current "ultimate" in logging technique appears to be felling with chain saw, tractor snigging of the log from stump to dump, winch or crane loading at dump, and truck haulage from dump to mill. Except for the use of chain saws, which to date have made little impression in most tropical countries (though widely used in the Australian rainforests), these techniques can be seen operating in most rainforest areas under management. Axe and saw are still the usual means of felling in the tropics

Mechanized exploitation of this type has two major requirements. Firstly, good access must be provided to each compartment by way of roads, and as previously stated this road network must be considered when planning compartment subdivision. The roading is commonly constructed by the timberman, though as management proceeds and access is required for protection and treatment it is usual for the forest service to take over first the maintenance of existing roads and then the construction of new roads which are paid for by higher royalties. Secondly, the high cost of roading and of obtaining mechanical equipment makes it essential for the timberman to get as high a yield per acre as possible in exploitation. This has two consequences; firstly the less valuable species are taken from the forest, leading to a higher standard of utilization (Gordon, 1957), and secondly, logging is concentrated and thus points to the need for some even-aged system of management which permits the entire crop to be removed in one operation. Thus direct results of mechanized logging have been to produce better utilization of the forest, and to force on forestry authorities the usually ecologically desirable even-aged system of management.

Other extraction methods are however still used in many rainforest countries. A survey by a sub-committee of the F.A.O. Asia-Pacific Forestry Commission (F.A.O. 1960b), carried out in rainforest countries of the Commission region, revealed that elephants were used in India, Ceylon, and Burma, bullocks in Fiji, buffaloes in Indonesia and occasionally in Malaya, high-lead systems in the Philippines and North Borneo (see Walton 1954), and winch lorries (for snigging) in Malaya. River transport was widely used in the region wherever conditions were suitable. Although mechanized extraction methods were developing rapidly the sub-committee noted that tractors were not permitted in the rainforests of Ceylon. Small railways are also used in some areas: in the Malayan swampy rainforests on deep peat, light railways, which in places virtually float on the peat, are constructed from adjacent dry land into the swamp. Logs are hauled from the stump to railside dumps in wooden cradles which are pulled by manpower along runways made of poles. Water transport is probably the cheapest method of extraction and is often used in conjunction with other methods.

Thus, in the Nigerian rainforests of the Benin Division, logs are snigged from the stump by tractor, bark is removed at the dump, and the logs are then loaded by winch on to large trucks which transport the logs to a riverside dump where the "floaters" are made into rafts, and the "sinkers" loaded either on to the rafts or on to lighters for the remainder of their journey to the timber mill and export port at Sapele. At the riverside dump also the logs are classed into sawlogs or plylogs, and are sprayed with Gammexane to protect them from insect attack. However except in certain seasonal swampy rainforests (e.g. some of the Amazonian "varzea"), water is unsatisfactory to the forester as the sole means of extraction: working is confined to the immediate river edge, and except for a few highly valuable species there is a strong tendency to utilize only known floaters. Such working, which is still common in parts of the Amazon region, is clearly unsuitable for forest management.

Exploitation methods have an obvious significance to forest mangement, since in no small degree they will determine the order of working (taking usually the more accessible compartments first and then gradually moving, by new road construction, into the less accessible area), the broad type of silviculture to be used (mechanization strongly suggesting some even-aged systems), and the intensity of silvicultural treatment, which is normally related to the revenue received from exploitation.

Other Points

As mentioned, forest management is the meeting ground for all the varied branches of forestry, and the relationship of such branches as silviculture, surveying, mensuration, policy, and logging to management have already been mentioned. Other branches may be of no less importance in rainforest areas.

Protection is a vital aspect of management in any forest. Unless the forest can be adequately protected against the various agencies causing damage, expense on silviculture is wasted and management ultimately comes to naught. In some cases the damage agency is of a type that makes complete protection impossible, and instead management must be directed in such a way that the forest can tolerate, rather than be decimated by, the agency: periodic cyclones of great destructive force are of this type, and suggest the need for uneven-aged management rather than the establishment of natural or artificial evenaged stands. Similarly, severe risk of insect or animal attack may force changes in management technique, though research into systematic insecticides and animal repellents may yet make protection possible in many of these cases. Fire, fortunately, is rarely a great threat to the humid rainforests, but in some of the drier sub-formations (e.g. semi-evergreen rainforest) it may be sufficient danger to warrant special protective measures. However probably the greatest danger to managed rainforest comes from the activities of man: through illegal and uncontrolled logging, through the activities of farmers using shifting cultivation, through careless felling and snigging. Management must thus provide staff to police the forests against these dangers, and must have the legal backing to make such actions prohibitive.

Marketing of the forest produce is another aspect which the rainforest manager must consider. Processing plants which can use a wide variety of species and sizes should be favoured over those which are more selective when long term contracts for exploitation are prepared (see Gordon, 1957). Royalty rates should bear some logical relationship to the value of the end-product, and a system such as that used in Queensland (see Table 44), where the royalty varies with species, log size and distance from the main market or milling centre, is suggested as worthy of consideration in areas where sales are made on a stumpage basis. Provision should be made for such rates to be varied periodically as marketing conditions change. Attention must also be paid to some suitable, and preferably inexpensive, method of recording logs felled and removed. This is often done at the log dump, though where extraction is by road or rail it may be more satisfactory to establish a checking station along the access route to measure the logs on truck. Periodic check measurements should be made by a different operator elsewhere to ensure that human frailties are not leading to malpractices. Where, as is usually the case, felling is done by the staff of the timberman, close watch should be kept on the forest as it is exploited to make sure that no logs are left felled, (but unextracted and unpaid for) in the forest. Records of the logs extracted are needed both for the issuing of royalty accounts and for the maintenance of records of yield as an aid to subsequent management.

Management requires manpower to police the forest, carry out silvicultural treatment, control exploitation, build and maintain roads, and so on. Management without a labour force is impossible, and consideration must be paid to sources of supply of labour, and where local sources are inadequate, to building suitable camps or forest villages to house the labour force.

Working Plans

A working plan has been defined as a written scheme of management aiming at continuity of policy and action, and controlling the treatment of a forest (Empire Forestry Association, 1953). It is the means by which all the factors involved in managing a forest area can be brought together, indicating what is known about the area, why it is to be managed, and how the management is to be carried out. Working plans, or some suitable substitute, are an essential part of forest management. They are usually prepared in some standard form, and the form drawn up by the late Mr R. Bourne (see Brasnett, 1953, Chapter 4), with a logical format and scope for all information of importance to be included, has been widely and successfully used in many British countries.

Working plan preparation and control is beyond the scope of this report, but because of the plan's pivotal position in relation to forest management several points should be stressed:

1. A plan can cover any area, large or small. Where different parts of the area are to be managed for different purposes (e.g. timber production, recreation, preservation of vegetation), or in different ways (e.g. as plantation, even-aged natural stands, uneven-aged stands, these can be split out into separate working circles. It is however most desirable that each timber production working circle should be capable of forming ultimately a unit which can produce a regular and sustained yield of timber in perpetuity.

2. The plan, once approved by the forest owner, should have some legal standing to ensure that the work laid down is indeed carried out as and when specified. Deviations from an approved working plan should not be undertaken lightly, and only with approval from some high authority (e.g. head of the forest service).

3. At the same time, many operations which are likely to be varied with changes in local conditions (e.g. silvicultural treatments), should be made flexible in the plan to permit the local manager to apply his on-the-spot knowledge of what, within the broad provisions of the plan, is most suited to the circumstances.

4. Two of the main provisions of any working plan are:

   (a) the order in which compartments in each working circle should be logged and treated;
   (b) the yield of timber to be produced annually from each working circle.

   In the early stages of management by an even-aged system, an area to be treated annually is often substituted for a yield: the assumption is made that all areas are equiproductive. As management proceeds it is however desirable to aim at a control of operations by yield rather than area, thus laying a firm foundation for sustained yield management.

5. The plan should operate for a given period only (frequently 10 years), after which it should be completely reviewed. This enables changing market conditions to be taken into account, silvicultural techniques to be amended in the light of past experience, allowable yields to be recalculated, the objects of management to be changed in emphasis if necessary, and so on. Forest policy in any area is constantly changing and regular reviews of working plans enable these changes to be implemented whilst maintaining a general continuity of management direction.

As stated earlier, it is desirable for the annual yield to be conservative in the early stages of management. It can then be gradually increased at subsequent reviews of the working plan in the light of experience and of actual growth being obtained (determined by periodic assessments). Occasionally this is not possible, and an example can be quoted from an area of cool temperate rainforest in northern New South Wales. Here the virgin stands are overstocked to the point of stagnation, but compared with most rainforest stands the proportion of useless stems is low. The forest is being managed by a selection system on a 30 years felling cycle *, and in the first cycle it is necessary to reduce the B.A. to a level suitable for optimum growth. Since the stand is in effect overcapitalized, yields during the first falling cycle will be higher than the forest can support subsequently, when yield will be related to increment.

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* Felling cycles of this length are often considered incompatible with true selection management, but this in reality depends upon the rate of growth. A 5 years cycle may be too long in a forest producing an increment of 15 square ft B.A. per acre per annum, whereas 30 years is not excessive where the increment is only 2 square ft B.A. per acre per annum.

To conclude, the working plan for the forests under concession to African Timber and Plywood Limited in the Benin Division of Nigeria can be taken to illustrate some of the features discussed above. These forests cover an area of 1084 square miles, consisting of 10 separate forest reserves or parts of reserves which are amalgamated into a single working plan area. This area has two working circles, a taungya W.C. of 85 square miles divided into 21 series, each based on a single village (see Chapter 9), and a T.S.S. working circle of 999 square miles. The A. T. & P. licence is effective for 25 years, and the T.S.S. circle is divided into 4 periodic blocks, only one of which may be worked during the first 25 years. Control is by area, and theoretically the periodic block should be of 250 square miles, but in fact the Company's licence permits the working of 202 square miles during the period to obtain their allocation of sawlogs, plus an additional area up to a maximum of 180 square miles over 25 years for the supply of plylogs. In the words of the working plan, this additional plywood allocation was "sanctioned at a higher level than the Forestry Department as an insurance against failure of the Plywood Mill from lack of supplies, the tenure being of very great importance to Nigeria and to Forestry". It was expected that any initial overcutting as a result of this arrangement would be balanced by the end of the rotation, without loss of revenue, by increasingly effective utilization from the rainforest. Commencing 5 years ahead of exploitation the compartments start to receive the treatment prescribed under the tropical shelterwood system (Chapter 10). Compartments exploited under this system show the dangers inherent in relying upon control solely by area: yields have ranged from 61 cubic ft per acre on one compartment up to 722 cubic ft per acre on another.

CHAPTER 13

DEVELOPMENT OF FOREST POLICY IN RAINFOREST AREAS

"Forest Policy must rest upon broad studies of the ecology of the human species itself."

Beard (1947).

Importance of Policy

A forest policy is the statement of precepts underlying any authority whose purpose it is to own and manage an extensive area of forest estate, and explaining why and to what ends the forest estate should be managed. Forest management, as indicated in previous chapters, is the means whereby this policy is put into effect. Attempting to manage forests in the absence of a forest policy is like attempting to drive a car without a steering wheel, and it can likewise only ultimately lead to a costly disaster.

No attempt will be made here to establish what the policy for any area should be, but some of the more important points to be considered in developing a forest policy for rainforest areas will be reiterated. In this connection it is pointed out that many forest services with rainforest under their control also have other types of vegetation to manage, e.g., eucalypt and Callitris forests in eastern Australia, mangrove in Malaya, savanna in much of West Africa, and pine stands in parts of Central America. The relative importance and value of these will have a considerable bearing on the country's forest policy as a whole, but these considerations will not be dealt with here.

Earlier chapters have shown what can be done with rainforests. Policy, as understood here, must determine what should be done in particular cases, and in what way. It must take account of the myriads of factors which influence good land usage, many of them quite unrelated to forestry as such. Since these factors are constantly changing it follows that forest policy must be dynamic, facing up to new and altered situations, changing its emphasis, and reflecting these changes in new approaches to forest management. Rarely can forest policy afford to remain static for any lengthy period, even though some particular aspects of the policy may be unchanging.

Aims of Forestry

In Chapter 7 the major uses of rainforest were discussed and it was concluded that in most cases the indirect benefits of rainforest, for the preservation of flora and fauna, for watershed protection and possibly for recreation, must take precedence over the management of areas purely for timber production. The policy should therefore give first consideration to reserving and managing adequate areas for these purposes, before considering those areas where the primary aim will be to supply forest products. At the same time it is often possible to use one area concurrently for two or more purposes (e.g. flora preservation, watershed protection and recreation in national parks; watershed protection and timber production by conservative logging methods; etc.). Multiple use of forest land should nver be overlooked.

Of the various products obtained from rainforests, the minor products are usually capable of only very low yields per acre. Many of these products can be more efficiently produced by agricultural practices (e.g. rubber, vegetable oils, fruits), whilst others can be supplied in conjunction with forest management for major products. Management of rainforests soley to produce minor products can seldom, if ever, be justified on a continuing basis.

Timber, the major product of forests, is a different matter and the great preponderance of rainforest areas under management are intended to produce this commodity in its various forms. Therefore an important aim of any forest policy should be to maintain the highest possible yield of timber, satisfying first the local demand and then if a surplus is available, export markets. Among the timber products, fuel still accounts for a large proportion of the total local consumption of timber in most rainforest countries. The worldwide trend, as evidenced in the Caribbean region and to a lesser extent in southeast Asia, is for wood fuel to be replaced by oils or electricity, though it is worth recording that, as living standards rise, wood fuel ultimately makes a minor comeback via the summer barbecue and the winter log fire. It seems desirable to maintain forests to supply fuel in the vicinity of most centres of population, though where forests are managed for other types of production the fuel requirements can frequently be met in excess from thinnings. Where such forests are not available plantations of fast growing species seem best suited to supply fuel needs. The same conditions apply to the supply of poles and other small timber: these can usually be more than adequately provided from thinnings, and indeed in most areas the demand is quite insufficient to absorb the supply available from rainforest under treatment.

Wood pulp, which on a worldwide scale has accounted for much of the increased demand for timber in recent years, has to date offered little hope for using the undoubtedly large reserves of cellulose available from rainforest. Fibreboards can probably be produced relatively easily from many rainforest species, but the demand for such products is limited in rainforest contries and the needs appear to be satisfactorily met from the use of agricultural waste (e.g. sugar cane bagasse). Paper which, in its various forms, is the major end product from wood pulp, apparently nowhere is produced from mixed rainforest stands. The Ivory Coast experience suggests that technologically many rainforest species can be used to produce acceptable grades of paper, but the problems to be faced are firstly that such paper is more expensive to manufacture than, and probably of inferior quality to, that from certain conifers, and secondly that individual rainforest countries with few exceptions do not have the local demand for paper to support the very large scale plants which are necessary to manufacture the various grades of paper at an economic cost. In other words, the production from plants capable of operating reasonably economically would be vastly in excess of the needs of most countries wishing to establish a local, tariff-protected industry, whilst the cost of the product and its quality, when produced from mixed rainforest species, would place it in an uncompetitive position on world markets. This is not to say that rainforest countries cannot hope to be self-sufficient in paper, or even exporters of it, but it does suggest that this is unlikely to occur through the use of mixed rainforests: if paper is to be produced at a reasonable cost in these countries, it seems that attention must be focused on the growing of a few fast developing and amenable species, probably in concentrated plantations. Thus it appears that much of

Malaya's requirements at present could be met from the utilization of the plantation-grown Para rubber trees at the end of their rubber-producing rotation, while in Surinam and probably in Trinidad, thought is being directed at the use of Pinus caribaea (possibly supplemented with certain rainforest species) to produce paper, in the case of Surinam with export markets definitely in mind. These factors must have a very strong influence on the development of forest policy in rainforest areas.

Sawlogs and plylogs thus remain the main outlet for rainforest production at a profitable price. What is the future of these? Locally, the per capita consumption of sawn timber is extremely low in most tropical rainforest countries compared with the more industrialized, temperate countries, as shown in Chapter 1. Rising living standards and the rapid increases in population in these countries must inevitably cause increased home consumption in timber. For example, if the per capita consumption in Nigeria (population about 50 million) were to rise to the world average of about 5c ft per annum, the local demand would be in order of ten times the Federation's current production, most of which is exported! Periodic studies on world trends in timber consumption, such as those published by F.A.O., coupled with local knowledge on the economic growth of the country, can provide useful pointers as to how a country's local demand for timber will shape, and thus can permit the forest authorities to make tolerably reliable estimates of future demand. It is largely on these estimates that planning for the future by the forest service must be based: forestry, probably more than any other profession, must look to the future.

Most countries with relatively extensive areas of rainforest still extant are exporters of timber, and timber is frequently one of their major earners of foreign currency. In the past exports from rainforest have largely concentrated upon a few speciality lines, typified by mahongany-type timbers. More recently these timbers have declined in relative importance by the increased demand for lower value utility timbers, such as the Malayan Shorea spp. and the West African Triplochiton, which are regularly available in large quantity. This indicates an important phenomenon which will apply to local markets no less than export markets: demand in sawlogs is primarily for light, easily worked and easily preservatized timbers which can be supplied in quantity. Such species are usually also the more rapid growing and the ones which regenerate most freely under the more drastic silvicultural systems aimed at producing even-aged stands; as shown in Chapter 11, they are the type of species which on economic grounds it is most profitable to grow.

Despite the value of exports, the forest policy should normally aim to satisfy all present and future local demands for timber before supplying overseas markets. Export markets are highly selective, and forests worked for export timber alone are usually only creamed over, leaving a large residue of unmerchantable trees in the forest: silviculturally this is most objectionable. Further, many importing countries, to protect their own milling interests, place high tariffs on the import of processed timber. This, of course, acts to the detriment of developing local processing plants in the producing countries, though the encouragement of such industry is normally a desirable feature of any forest policy. Exports fill important roles in the management of rainforests in many countires, but probably the most important at present is not to provide foreign currency, but to enable the utilization (albeit imperfect) of existing stands, and so to permit silvicultural treatment of some type or another to produce more highly productive forests for the country's own future needs. Timber exporting countries often have reserved greater areas of forest than are necessary, under reasonably intensive management, to provide for forseeable local needs. The future of such excess areas must be viewed carefully, particularly from the viewpoint of economics, when pressure is brought to revoke some of the forest: provided adequate reserves are maintained for the future, it may be difficult to justify managing forest for an export trade when the same land, under more intensive agricultural practices, could earn greater export earnings from the production of cacao, rubber or similar items.

From the foregoing, it can be seen that important aims in any forest policy must be:

1. Ensure adequate forest areas to maintain the indirect forest benefits for the present and anticipated population.

2. To supply present and future local requirements of timber, paying special consideration to:

   (a) adequate supplies of fuel wood in all areas of population density, recalling that this is likely, however, to be a diminishing demand;

   (b) providing supplies of sawlogs (and plylogs) to satisfy the local needs, bearing in mind that both population and per capita consumption can reasonably be expected to increase and that demand will be greatest for the light utility woods;

   (c) the desirability, remembering the economic factors involved, of providing part or all of the local requirements of paper and other wood pulp products.

3. To provide an export production of timber, preferably in processed form, provided that this does not involve mismanaging the required permanent forest estate, jeopardizing future local requirements, nor wastefully tying up land which could more profitably be employed under some other more intensive type of land management.

Areas of Forestry.

Policy aims such as those above are worthless unless there is also provision for establishing an adequate forest estate from which these aims can be realized. Often several of the aims can be satisfied, at least in part by multiple use management of forest. However, some uses are more restrictive than others, and as indicated in Chapter 7 there is usually a definite order of priority as to which uses of rainforest are of the greatest long term importantce.

Reserves protecting viable samples of the natural rainforest vegetation are of immeasurable long term value. Such reserves between them should cover all the major types of forest present in the country and they should be sufficiently large to include an overwhelming proportion of the species present in the native flora. So far as possible these flora reserves should be kept free from human interference and should be available only for bona fide scientific study. They can occur conjointly with forest estate intended to preserve wildlife, to protect watersheds or, provided they are in relatively remote and inaccessible areas, to serve for recreation purposes.

Rainforest appears to be a particularly favourable cover for watersheds, maintaining even stream flow, avoiding all but geological erosion and the subsequent risk of excessive siltation, and possibly even tending to attract increased rainfall. Forest reserves with this primary aim are thus highly desirable in all major catchment areas. These reserves can also be used for the other indirect benefits, and in the less critical areas they can also provide regular timber yields provided logging methods are careful and conservative.

The extent to which undisturbed forest should be reserved for recreation purposes is a highly controversial subject, but it seems inescapable that reasonable provision should be made for natural recreation reserves or national parks, even though this may involve some reduction in the production forest area. Further than this, the need for such reserves increases as the management of production forests becomes more intensive and as consequently the production forests become increasingly unlike natural forest. Often recreation reserves can be combined with catchment reserves: these usages are compatible, and in addition are located in the upland areas where scenic attractions are usually greatest. There is, however, a real need for similar reserves, probably of smaller area, located fairly close to the large population centres whence they are readily accessible to the nature-loving elements of the urban population. The popularity of areas such as Templer Park near Kuala Lumpur or Bukit Timah Nature Reserve near Singapore illustrates the need for these smaller reserves, whilst the preservation of larger but less accessible national parks should in time serve much the same purpose for a much wider range of population.

The protection of natural wildlife can be carried out in conjunction with all the above uses of forest land, while in addition most animal species will probably adapt themselves to conditions inside natural rainforest under even the most extreme systems of silvicultural treatment. Some of the wider-ranging creatures may indeed find reserves for other indirect forest benefits insufficient for their needs, and thus to survive will have to have access to adjacent production forests also. The danger here lies in some of these species having undesirable habits so far as forest management is concerned; for example, large herbivores damaging regeration, and large carnivores damaging (or at least scaring) the forest labourers. Because of those habits there is often a tendency to exterminate these from managed production forest as pests. The forest policy may therefore have to allow that, where certain species have to enter production forests to survive, the management of these forests should tolerate these species even at the cost of obtaining reduced timber yields from the forest as a consequence.

Once the land requirements for these indirect benefits have been satisfied, there remains the reservation of land for production foresty. The minimum area, where the aim of the forest policy is to make the country self-sufficient in timber, is that which will provide all anticipated needs under the most intensive type of management, i.e. by the establishment of well-tended plantation s of suitable high yielding species such as pines or eucalypts. This in time is likely to be the type of management applied to most of the world's more highly productive forest areas, whether rainforest or not. At present, however, most rainforest areas are not yet at the stage where the initial choice is inevitably for this reservation of a minimum productive forest estate, though the time is fast approaching in many of the West Indian islands and it can even be foreseen for areas such as Malaya in the not too distant future. It has virtually arrived in a few very densely populated islands such as Mauritius, and in areas where fire and other factors have destroyed most of the suitable natural production forest areas, as in parts of East and South Africa. The maximum area to be set aside for production forestry can be defined as the largest possible area of highly productive forest land (even if not entirely covered at present by highly productive forest) not required for other purposes in the near future. In this case the forest service must be prepared to face the revocation of a large proportion of its estate in due course, but in the meantime reservation as forest reserve offers the best possible protection of the land against uncontrolled abuse until it is required for these other purposes, while over the more extensive areas (which are likely ultimately to be lost to forestry) rudimentary management can be applied, for example by the generally unsatisfactory, girth-controlled, tropical selection system. This system, despite its obvious drawbacks, at least avoids the extreme misuse of the land; it usually leaves the forest silviculturally no better, but probably also little worse, than in its virgin state; it provides the forest service with some revenue which can be used to finance more intensive management in what can be expected to become the permanent forest estate; and it can also provide the country as a whole with foreign earnings by the development of an export market to dispose of the excess supplies of timber.

In most rainforest areas where active forest services have been established, the area reserved for production forestry has lain somewhere between these two extremes with a tendency towards the maximum rather than the minimum level. The question is complicated by matters of land ownership, as discussed in Chapter 8, but usually it has been possible to reserve appreciably more than the bare minimum area needed to supply future requirements and this is reflected in the history of forest management in such areas, as discussed in Chapter 10. However, as population rises there will be pressure to reduce these areas, and for production forests this pressure will be difficult to resist on the grounds of sound land management. At the same time rising living standards are likely to demand an increasing availability of timber, and this will necessitate making more intensive use of the reduced forest estate remaining.

Management of Productive Forest Estate

Rainforest reserved primarily for its indirect benefits leaves little room for decision as to the broad form which the management should take, though at the local managerial level there are innumerable details which must be attended to. This is not the case with areas intended for timber production, whether for producing timber alone or in conjunction with some of the indirect benefits. Before management can be introduced into production forests, high level policy decisions must be reached as to the form that the management of the areas should take. These decisions must be reached by carefully considering and weighing various factors which have already been mentioned. Among the questions which must be considered:

1. Are there any silvicultural factors which necessitate particular consideration? As shown, the faster-growing species which in most cases it will be desirable to grow, usually prefer drastic canopy opening, as in even-aged systems or a fairly heavy group selection system. However, other overriding factors may be present to indicate some different approach. Thus the need to avoid heavy logging or extreme canopy opening in important catchment areas, the need to preserve an all-aged forest structure to guard against cyclone damage, the need in some temperate rain-forests to avoid crown deterioration after exploitation by preserving adequate canopy, these are all features which may make management by a selection system essential in certain areas (e.g. Puerto Rico and New South Wales).

2. Are there any management factors which necessitate particular consideration? Mechanical logging, with its high volume per acre yield requirements, and the severe damage which may result from logging operations both point to the need for complete, concentrated exploitation and an even-aged system of management. On the other hand a regular series of size classes of the more desirable species in the virgin forest and a royalty structure which makes immature stems uneconomic to remove both suggest the desirability of maintaining an uneven-aged stand by a selection or group system (e.g. North Queensland, Ghana).

3. Is it necessary to maintain supplies of a particular type of product? In most cases the major demand is for general utility timbers supplemented by a sweetening of more valuable cabinet timbers, and these can usually be produced by a variety of silvicultural approaches. If, however, it is desired to supply a paper-pulp mill the general run of rainforest species cannot yet be regarded as supplying a truly satisfactory source of raw material, and it appears wise to concentrate upon growing a small number of fast-growing species with good pulping qualities, probably in plantations (e.g. Surinam). By the same token in both southern Queensland and eastern New Guinea, Araucaria spp. form the basis for highly important plywood production industries: these species are extremely difficult to regenerate naturally, and emphasis is upon establishing plantations of these species.

4. How adequate is the forest estate to supply anticipated needs? If the forest estate is large compared with the local population and its needs, a relatively extensive system of management, relying primarily upon natural regeneration (though supplemented if need be in places by artificial regeneration), should be adequate to maintain necessary timber supplies for the foreseeable future. Provided the temptation to exploit remote stands before they become economically accessible is avoided, the revenue from logging will normally be sufficient to pay for silvicultural operations in these extensive treatments without needing to invest new capital. On the other hand, if the forest estate (or that part of it which the forest service can expect to be able to retain in perpetuity) is small in comparison with timber needs,

intensive management producing high yields per acre is called for, and the establishment of plantations of highly productive species will be needed: as shown in Chapter 11, even well-tended extensive systems can probably not be expected to yield more than about 50 c. ft per acre per annum over any large area, whereas plantations of the more efficient species will provide at least 4 times this yield and often very much more.

5. Do particular areas require special attention? Even where the reserved forest estate appears adequate to supply the anticipated needs by extensive management, there may be large areas of the forest estate located in particularly favourable economic positions, yet for a variety of reasons quite unproductive (e.g. areas of Imperata grassland and useless secondary forest resulting from wartime devastation close to Kuala Lumpur in Malaya; stands of the low value Kempas-Kedongdong rainforest type in the same area). Intensive treatment to bring such areas back into production may be well justified in these cases.

6. Can capital for investment in rainforest treatment be readily obtained? If there is little chance of raising money for forest expenditure from outside sources, the forest service has no option but to finance its forest operations from its own revenue. This means that areas logged must be treated by some extensive system, or else that treatment bears no relation to the area of natural forest logged, the revenue being used to carry out intensive treatment (usually by establishing compensatory plantations) in a few concentrated and highly economic locations. Conversely if outside finance is readily available, the natural rainforest can be treated extensively whilst the investment capital is used to finance plantations on a large scale with the aim not only of supplying local needs but of establishing a permanent and important export industry: the very favourable growing conditions of the rainforest environment make these sites particularly suited to high volume cellulose production (far more so that in most of the world's present day major timber exporting countries), and where land is not in short supply there is much in favour of utilizing rainforest sites as intensively managed timber production areas. This in effect is the basis behind forestry development in New Zealand, with its large plantations of Pinus and Pseudotsuga; the P. caribaea plantations being established in Surinam; and the Araucaria plantations of New Guinea.

7. Where extensive systems are indicated, what form should the system take? This has been discussed in some detail in Chapter 11. Whilst certain circumstances necessitate the maintenance of uneven-aged stands, in most cases an even-aged system will prove most desirable. The exact form of this system will depend very largely on the ecological characteristics of both the stand as a whole and the more desirable individual species, and the forest service should, so far as possible, take a flexible viewpoint on this matter and allow the details to be determined locally by its trained and competent forest officers. In determining the system, the value of enrichment planting should never be overlooked but at the same time, if the stand proves refractory to

regenerate with desirable species, then serious consideration must be given to using an itensive system of management with routine planting: this appears to be the case with the Malayan Kempas-Kedongdong rainforests, and quite possibly also with the Tarrietia-dominated subtropical rainforests of New South Wales.

8. If planting is to be used, what species should be selected? How should they be planted? These questions have been considered in Chapter 9. In some cases the species are selected by the particular end-product to be produced (e.g. Araucaria for high quality ply-timber), but in most cases there is considerable room for choice within a large range of species. If the aim is to produce general utility timber, then it seems wise to consider firstly the more efficient, high volume-producing species such as Pinus or Eucalyptus before going to endemic rainforest species. If cabinet timbers are tobe produced, the world's rainforests provide a greater selection of species than any other type of vegetation, but many of these are difficult or unsatisfactory in open plantations (e.g. Hysiphlya damage to many Meliaceae; poor form in Flindersia brayleyana). These species seem much better suited to natural forest conditions than to planations, and they can if necessary be introduced into the natural rainforest during silvicultural treatment by enrichment planting. Countries which are so reduced in forest estate that they cannot afford to have some forests managed by extensive "natural" systems must face the fact that they cannot, in any case, afford the luxury of growing most cabinet timbers on any wide scale. With these limitations, the species to be raised artificially are those ecologically suited to the site and capable of producing the most profitable returns. The returns are, of course, compounded from the value of the produce, its rate of growth, its rotation length, and its cost of production (planting costs, tending costs, etc.). The method of planting will vary also. Scattered enrichment planting to regenerate isolated understocked areas in natural rainforest is here considered as part and parcel of extensive treatment, whilst the writer is very dubious of the economic worth of extensive enrichment planting (see Chapter 9). Intensive enrichment, taungya, and open plantations established by paid labour all aim at establishing fully stocked and intensively tended, artificial stands. Where it can be employed, taungya is undoubtedly the most profitable, though socially it is possibly undesirable since it perpetuates a generally subsistence level of agriculture. Taungya in any cases can only be employed under certain economic conditions. The other two approaches also have various limitations. Strong light demanders require open plantations, whereas species needing shade in their younger stages (e.g. Dryobalanops, probably Flindersia) prefer intensive enrichment, where clearing the planting site in effect follows, rather than precedes, planting. Intensive enrichment of course can only be employed where a forest stand of some type already exists.

As can be seen there are various ways of managing rainforest for the production of timber, and the questions which must be answered before deciding which type of treatment should be introduced in specific areas involve complex and important considerations of ecology, economics and general government policy. Often, indeed usually, reliable answers to these questions are not immediately available, but only become known with the effluxion of time and as a result of consistent and well directed research. This is one major reason why forest policy must always be dynamic. The question of using intensive or extensive management techniques can be a particularly difficult one to answer and, without entirely agreeing, the conclusion reached by Eggeling (1952) can be quoted as food for thought: "Work must whenever possible be concentrated and except where natural regeneration can be obtained easily, the emphasis in replacementoperations should be on a compensatory planting".

Research and Training

With the complexities associated with rainforest and its management it is essential that active research should constantly be carried out by competent staff to solve the hosts of problems which are continually cropping up. It is on the basis of the recommendations of the research staff that many of the policy decisions of the forst service must be made, and it cannot be stressed too much that one of the unchanging tenets of any forest policy in a rainforest environment should be to establish and adequately support a vigorous research unit. An interesting account of the development of such research units in small rainforest countries is given by Setten (1961).

Research problems fall into a number of categories, but a major division can be recognized between research into forest products and their utilization on the one hand, and research into various aspects of forest management (silviculture, protection, mensuration, etc.) on the other. At the same time it is most desirable that these two branches should be carried out by the one organization and united at least in the higher echelons of the research unit. Progress in either branch has definite repercussions in the other, and it is highly desirable that there should be close liaison between the two and at least some degree of co-ordination in their programmes. The type of organization best suited to carry out research will vary in different countries, though usually and probably preferably it will function as part of an established forest service. It is however important that its research staff should be technically competent with a flair for research, and that the research officers should be freed from most routine administrative duties, allowed considerable latitude in their approach to research problems, provided with adequate facilities to carry out their studies, and allowed plenty of contract with their fellow workers both within the service and elsewhere. Whilst some research units are habitually staffed by officers with previous administrative experience in the area, there is much in favour of recruiting also younger research workers who lack field experience but who can approach problems with minds untrammelled by the restraints of preconception and past departmental policy. The major lines of research to follow or problems to solve should seldom be left to a single senior officer to determine, but neither should the individual research officers be given complete freedom to draw up their own research programmes at will. A suitable compromise appears to lie in having a departmental research committee, containing both administrative and research officers and possibly also some outside representation, to review regularly the research programme as a whole, indicate where new research is needed, and determine the priority to be accorded each research project, whilst at the same time permitting individual research officers some freedom to follow their own particular interests even where these are not at the time considered by the committee to have high priority. The research officers should meet regularly to discuss each other's projects (this is particulary important where the officers are geographically scattered) and any results should be made readily available to all who are likely to be interested.

The emphasis of the research programme in any area will of course be constantly changing. In the early stages much of the research will tend to be empirical,. but as experience is gained it becomes increasingly important for the programme to take on a more fundamental aspect; to discover the "hows" and "whys", not merely the "whats". This inevitably requires greater specialization by research officers and poses difficulties for smaller forest services; at this stage co-ordinated programmes between countries, e.g. under the auspices of such organizations as F.A.O. or I.U.F.R.O., seem to have much merit.

The problems to be answered by research differ in different areas, but there are a number of very widespread rainforest problems which have been mentioned elsewhere in this report and which appear worth repeating. In the field of utilization and products research, it is obviously desirable to know the properties (and the way in which these vary) of all timber species, and not just of those currently merchantable. This information lays the foundation for subsequent work in determining the most desirable uses for these species, in improving certain properties of the timber, in protecting them from decay and insect attack, in developing new uses for them, and in improving the techniques for processing and subsequently using them. This work both leads to improved utilization of the forest and indicates to the silviculturist which species, from their utilization value, are the most desirable.

Management research, in its broadest sense, falls into a number of categories. An important branch in most rainforest countries (particularly in tropical areas) is that of botanical research; identifying the local rainforest species in all their stages of growth, and particularly as seedlings; preparing field keys for these species (e.g. along the lines of Symington (1943) for the Malayan dipterocarps); distinguishing local rainforest types in the area; carrying out ecological research into various phases of the growth and development of both virgin and treated rainforest as discussed by Wyatt-Smith (1959c); and, in the borderland between products research, seeing that phytochemical surveys of the local flora are carried out. Silvicultural research is particularly varied, with much needed studies to be carried out in the germination processes of individual species; in developing storage techniques for seed of low viablity; in the light requirements for germination and early growth of the more important species, both desirable and undesirable; in determining the optimum stocking level for maximum growth of various species at different stages of growth and in undertaking the factors which influence maximum production (including fundamental studies of soil and tree physiology); in establishing arboreta and growth plots to determine which species are likely to be of greatest value in planting programmes, including comparative provenance trails of the more wide-ranging species of potential value for planting; in developing satisfactory methods for establishing plantations of the various more desirable species; and of linking all these studies together into well based recommendations as to the best type of treatment to apply to any particular area.

Methods of protecting the growing trees from various damage agencies should not be overlooked, with close study of certain recently developed systemic poisons to protect against insect attack and to repel larger animals appearing of considerable value for species such as many Meliaceae or Chlorophora. Mensurational study is required to develop improved methods of assessing the forest stands, to produce reliable volume tables, to discover the growth rate of rainforest trees in treated stands, and to indicate which types of treatment in a given area produce the best results. This is related to economic research which attempts to balance the cost of various types of treatment against the resultant growth, and thus to indicate which types of treatments under given conditions are the most profitable: the results of such studies should have a profound bearing on the development of local forest policy. This is a very incomplete list of research which should be undertaken in rainforest areas, but it does indicate the vast scope and the necessity for maintaining a vigorous and relatively large research team.

Staff training is to some extent related to research, since for a number of reasons it is common for subprofessional and even professional training schemes to be associated with the local research organization and to call upon research staff for much of the instruction given. Professional forestry staff form the backbone fo any forest service aiming at a high standard of achievement. They should receive their training at recognized and financially well-supported schools of university standard where they receive instruction in all the basic elements of forestry and are taught to think logically and independently. Practical experience of local conditions appears to be of much less importance in professional training than does imparting the ability to see problems as a whole and to understand the basic principles involved in overcoming these. Local experience can be gained by the young trained officers when they join their forest service. In this connection the Malayan system of requiring new appointees to pass examinations in dendrology, timber identification, departmental administration and other subjects has much to recommend it.

By contrast, subprofessional staff who are required to put into effect the management of forests need a more practical type of training. Many rainforest countries now run departmental-controlled subprofessional forestry schools where students are instructed in the general principles of forestry and its various branches, with emphasis on the practical aspects which they are likely to encounter when they complete the course. With this background, appointees to the forest service can be given responsibility for carrying out various provisions of the working plan, under the general supervision of professional officers, and the excellence and extent of managed rainforest in many parts of the tropics bears witness to the effectiveness of this type of arrangement. Providing for the constant recruitment of adequately trained staff of both professional and subprofessional status must be another feature of forest policy.

Application of Policy

Reduced to its essentials, any forest policy should aim at managing the forest estate to provide "the maximum benefit to the greatest number of people for all time", and a statement of policy should indicate what, under the local conditions, is required to achieve this aim and how, in broad outline, it should be achieved. Thus it should state what purposes the forests are expected to serve, what areas are required to serve these purposes and what action is needed to translate the policy into effect by providing competent staff, solving the many problems that will evitably be encountered, and managing the forests in the most efficient manner practicable.

Policy must be determined in terms of estimated requirements and of economic profitability, limited by the ecological facts of the forests themselves. These factors will be continually altering, and so the policy itself must be regularly reviewed, with changes made in its emphasis to keep the essential aims of the forest service firmly in view and capable of increasingly efficient achievement with the resources available. With rainforest, where changes in technology and increased silvicultural knowledge can so greatly affect the possibility of management, such regular review of the policy is doubly necessary.

CHAPTER 14

THE FUTURE OF RAINFOREST

> ".... thé whole of the Tropical Rain forest may disappear within the lifetime of those now living, except for a few inaccessible areas and small 'forest reserves' artificially maintained mainly as sources of timber."
> Richards, p. 405

The Long Term View

Rainforest is the most complex type of vegetation existing on the earth. Despite very great destruction it still covers, in its various forms, nearly one tenth of the world's land surface, mostly in three separate tropical regions. Its floristic richness is probably unequalled in any other type of vegetation, to the extent that from an anthropocentric viewpoint the value of many of its species is completely unknown, and indeed in many areas even the identify of a large proportion of the species is obscure. Because of the variety in the flora, rainforest poses the synecologist with the greatest test of his skill.

Besides the indirect benefits which rainforest can provide, the products of rainforest are of value not only to those who live in its immediate environs, but also to the world at large. However, it must be stated that these direct benefits of rainforest are such that the world could exist without them. As example the most important single product from rainforest plant is probably rubber, yet this can be produced more efficiently in artificial plantations or synthetically than it can from the natural rainforest. Similarly specialty cabinet timbers such as the Mahoganies may, in cold economic analysis, prove to be unprofitable to produce when land is urgently needed for agriculture: the world would be the poorer for their passing, but it could survive, while the greater demand for general utility timbers can undoubtedly be supplied more efficiently by concentrating upon intensively managed plantations of a few highly productive species. It seems likely that with careful selection of species and subsequent tree improvement programmes rainforest sites can, by virtue of their climate, produce cellulose more effectively than any other type of forest site, and this point should never be lost sight of by those whose responsibility is to decide the ultimate, and presumably optimum, utilization of rainforest areas. At the same time such a policy casts a heavy responsibility on soil scientists to ensure that the highly leached soils are maintained in a condition where these high yields can be kept up in perpetuity: the long-recognized dangers of soil deterioration under arboreal monoculture are likely to be greater in rainforest areas than in less humid regions, though the danger is probably less with forest crops than with most agricultural food plants which are likely to provide the main alternative use for rainforest sites. The important lesson is that rainforest areas, both tropical and temperate, can probably produce cellulose more efficiently than any other sites, and when land use planning rises above national boundaries the significance of this will be realised.

Rainforests can be managed naturally to produce timber at a profit, though the production is relatively inefficient and could not be tolerated in the face of a rising damand for agricultural land.

Such managed rainforests will be impoverished shadows of the virgin primeval stands, as Richards infers in the chapter quotation. For the reasons discussed earlier in this report (Chapters 7 and 13) it therefore becomes imperative that adequate areas of virgin rainforest in all parts of the world should be reserved to provide the most important indirect benefits of preserving the type and its constituent flora and fauna and of providing recreation areas for increasingly urbanized populations. In addition, fairly extensive areas must be reserved for the primary purpose of protecting catchment area. This then is what appears to be the long term view of the rainforest future: heavy alienation for agriculture; adequate reservation for flora and fauna protection, for recreation, and for watershed protection; and the major timber production, probably still maintaining the five-centuries old pattern of production largely for export, coming from intensively managed plantations of species which, by and large, show little relation to the original rainforest.

The Ecological Basis of Rainforest Management

In most parts of the world, though not in all, this ultimate development still lies well in the future. In areas such as Amazonia it is hard to believe that such a time will ever come, although it has virtually arrived in a few areas such as Trinidad, Jamaica and Mauritius. In the majority of rainforest areas however the present problem is to manage the existing natural rainforest with the facilities available, and it is this problem with which this report is chiefly concerned. It is therefore perhaps opportune to conclude with the main theses which have been developed in earlier chapters.

1. Rainforest can be defined as a closed community of essentially, but not exclusively, broadleaved, evergreen, hygrophilous trees, usually with two or more layers of trees and shrubs, and with dependent synusiae of other life-forms, such as climbers and epiphytes (Chapter 1).

2. Two rainforest formations can be recognized, tropical and temperate, distinguished both by their structural characteristics and their floristic origins (Chapters 1, 3 and 4).

3. Each formation contains a number of distinct subformations which differ in relatively minor structural characteristics (Chapters 1 and 3).

4. The formations and subformations are distributed on the basis of environmental factors (Chapter 2).

5. These environmental factors are numerous and interact in a complex fashion to produce the ultimate climax vegetation. It is not believed that the recognition of different types of climaxes as the result of a single environmental factor (e.g. climatic climax, edaphic climax) is either realistic or desirable (Chapter 2).

6. The environment factors affecting rainforest development fall into five main groups, each made up of a number of individual factors. These main factors are climate (including rainfall, other atmospheric moisture, temperature, light, wind), soil (including nutrient availability, moisture supply and physical conditions), topography (as it affects both climate and soil), biotic factors (including regional flora, fauna, micro-organisms, man and fire), and past history (Chapter 2).

7. The microclimate of rainforest is of considerable importance, with very marked gradients in the various microclimatic components existing between the forest top and ground level. Alterations to the rainforest structure greatly affect these gradients (Chapter 2)

8. The rainforest is remarkable for the variety of life forms present, but to the forester the most important structural characteristics are the dominance of trees, usually occurring in a number of more or less distinct layers, and the frequent prevalence of vines (Chapter 3).

9. The trees of the lower storeys tend to have more shadecasting crowns than the individually larger crowned trees of the uppermost storeys (Chapter 3).

10. The "saturation basal area" of virgin rainforest ranges from under 100 square ft per acre to over 400 square ft per acre in different subformations (Chapter 3).

11. The most valuable species in the rainforest are usually those trees which form all or part of the uppermost storeys (Chapters 3, 6 and 11).

12. In most rainforest communities, and particularly in tropical rainforests, tree species are very numerous over small areas. Stands with more than 100 species of trees larger than 4 inches D.B.H. on a single acre occur in various parts of the world (Chapter 4).

13. The species/area relationships vary with both local floristic richness and with the favourability of the site. Stands in areas with a particularly rich flora, and on the most favourable sites, tend to have the most species on a given area (Chapter 4).

14. In tropical rainforest a tendency for a single species to dominate a stand is relatively rare, though it does occur, particularly where certain environmental conditions are suboptimal for rainforest development or in the late stages of some primary and secondary successions. Single species dominance is more common in temperate rainforest. Dominance by single genus or family is rather more widespread (Chapter 4).

15. Any rainforest community can be regarded as a continuum made up of a mixture of species which alter with area as the environmental factors become less favourable to some species and more favourable to others. Attempts to recognize

ecologically distinct forest types from these heterogeneous mixtures are therefore artificial, and such attempts usually rely upon the presence or absence of a few key tree species to distinguish the forest types. These types, despite their somewhat artificial nature, can prove extremely valuable in such matters as forest assessment and silvicultural treatment (Chapter 4).

16. Rainforest in all areas ultimately adjoins some other type of vegetation which does not fit the description of rainforest. Frequently those other communities are present through the influence of climatic or edaphic conditions which are unfavourable to rainforest development, but much of the rainforest margin adjoins communities, often of considerable economic value, which have been derived from rainforest under the influence of fire and other biotic factors (Chapter 5).

17. Rainforest, and more particularly tropical rainforest, is characteristically marked by frequent gaps. These gaps result from the falling of large, overmature trees which bring down with them adjoining smaller trees. Such gaps vary in extent but often are of appreciable size and are ecologically equivalent to the clear-felling of rainforest over limited area (Chapter 6).

18. Most of the silviculturally desirable upper storey species, along with most climbers, are light-demanding species which can only make satisfactory growth in fairly open conditions. For this reason such species typically develop only in the gaps (Chapter 6).

19. Rainforest species differ widely in their seeding and initial regeneration processes. Most upper storey species are highly irregular, or at best seasonal, in their seed production, though some typical species in secondary succession may bear seed almost continually. In many cases however the seeds will germinate in the shade and a reservoir of virtually dormant seedlings of desirable species will normally persist in the undergrowth between successive seedfalls. Such dormant seedlings are capable of responding immediately to improved growing conditions. In other species the seed may be dormant, apparently germinating under the influence of increased light. A few irregular seeders lack either of these facilities (Chapter 6).

20. A majority of upper storey species have seed which is disseminated either by wind or animals (Chapter 6).

21. Areas which have in the past been subject to considerable disturbance (e.g. by farming or cyclone damage) often tend to be richer in the light demanding desirable species than areas which have to rely on these species becoming established in isolated gaps. Against this, past disturbance (and especially frequent disturbance) may also result in a dominance of climbers and other undesirable light-demanding species (Chapter 6).

22. Species occurring in gaps usually show very rapid early growth, with severe competition between species. Included in the gaps are many typical species of secondary successions: these normally have short life spans. More shade tolerant species, usually of the lower tree storeys, come in beneath these rapidly developing thickets (Chapter 6).

23. Competition in the thickets of regeneration developing in gaps is extremely severe and natural mortality is high. In what may be quite impenetrable regrowth stand shortly after the gap is formed, this mortality and the growth of the survivors produce in a few years young stands which can be entered without difficulty. At this stage tending, to liberate the more desirable saplings, is practicable (Chapters 6, 11).

24. However excessive opening of the regrowth stands, either by over-tending or by frequent disturbance by large animals, usually prolongs the stage where unwanted scrubby vegetation and vines are dominant (Chapter 6).

25. Many of the most important rainforest timber trees regenerate naturally in these gap conditions, their growth usually being somewhat slower than the fastest growing, short lived, light-demanders under which they persist, to take over dominance of the thicket when the extreme light-demanders reach the end of their short life. Some of the most desirable species are indeed unable to tolerate full exposure to light in these early stages of growth (Chapter 6).

26. In virgin rainforest the nett growth of a stand over a period of years is nil, the increment being balanced by mortality (Chapter 6).

27. Growth rates of the living trees in rainforest show very great individual variations both between and within species. These variations are due, at least in part, to stem size, crown condition, crown position, crown impedence and forest stocking (Chapter 6).

28. As a result of these differences in growth rate, trees of the same age may be very different in size: in rainforest an even-aged stand may still be an uneven-sized stand. For the same reason the average growth of probably most rainforest species in virgin forest tends to be slow (Chapter 6).

29. Different rates of growth during different stages of development in an individual stem explain in part the common deficiency of stems of upper storey species in the middle range of size classes in rainforest (Chapter 6).

30. Rainforest is of value to man through both its direct and indirect benefits. Although most attention has been paid to the direct benefit of the production of timber, in the long range view the indirect benefits are probably likely to be of greater significance (Chapters 7, 13, 14).

31. Early interest in rainforests has in most cases been centred on the production of cabinet timbers and, more recently, of utility timbers. The use of mixed rainforest species on any scale to satisfy the increasing demand for paper pulp appears remote (Chapters 7, 8, 13).

32. The production of minor products from rainforest species can in most cases be more profitably met from artificial plantations (Chapter 7).

33. For the production of timber from managed rainforest the greatest problem to be overcome by the silviculturist is frequently the disposal of currently unmerchantable species. This is partly an artificial economic problem which will solve itself as the demand for forest products increased. Usually the species most readily sold are those with specialty properties or those which are available in large quantities (Chapter 8).

34. Most rainforest areas can expect to pass through two distinct phases of using artificial regeneration in the management of forests. The first occurs at an early stage when the problems of managing the mixed stands seem insurmountable; the second occurs much later when the demand for agricultural lands forces a swing to more intensive means of timber production (Chapters 9, 10, 13).

35. There are numerous difficulties in plantation establishment on rainforest sites, but worldwide experience has now provided answers to most of these (Chapter 9).

36. In addition to outright plantation schemes, planting has been widely used in rainforest areas to enrich the stands with desirable seedlings. Enrichment planting has occurred in various ways, of which the most important are the establishment of regeneration at wide spacing over extensive areas, the stocking of blank areas in stands where management relies mainly on natural regeneration, and the conversion of low quality stands to plantation by underplanting at close spacing beneath the existing vegetation. The value of the first of these three practices is regarded with some doubt (Chapter 9).

37. In treating natural stands of rainforest many different approaches have been used in different areas. However, basically these fall into two types, those aiming to improve the composition of the previously unmanaged forest, and those aiming to regenerate the desirable species (Chapters 10, 11).

38. Improvement treatments are ultimately required in all areas where virgin rainforest, with its many useless stems and species, is to be managed. Where exploitation of the merchantable stems is unlikely to occur for many years a pure improvement treatment (e.g. uniformization per le haut) can be carried out to eliminate much of the useless growth, and thus allow the remaining potentially useful stems to put on valuable increment prior to logging. Elsewhere improvement treatments are usually combined with the regeneration treatment (Chapter 11).

39. Regeneration treatments are of two types, those aiming at maintaining an uneven-aged stand, and those aiming at creating a primarily even-aged stand. Whilst both of these rely essentially on natural regeneration, the artificial enrichment of all or part of the stand is quite widely used and provides a form of insurance for sites where natural regeneration is difficult to obtain (Chapter 11).

40. Because of the need to obtain heavy, concentrated timber yields with modern logging methods, because of the risk during logging of damaging trees intended for retention, and because of the greater ease of management, even-aged systems are generally preferable to uneven-aged systems. However, in certain circumstances the choice of systems for regenerating and managing the stands will nonetheless lie with uneven-aged stands (Chapter 11).

41. The earliest, and probably still the most widely used management system, is the so-called tropical selection system which consists of highly selective exploitation governed by little more than a minimum felling girth limit. Because this system provides for no improvement treatment, it tends to leave the forest if anything poorer than before (Chapter 11).

42. Other uneven-aged systems, chosen for such purposes as the protection of soil or the retention of potentially valuable undersized stems, can be used with success to regenerate and improve the rainforest. These systems range from conservative true selection systems (e.g. Puerto Rico) to fairly drastic group selection systems (e.g. North Queensland) (Chapters 10, 11).

43. Even-aged systems, where all merchantable stems are removed in a single operation, fall into several well-defined classes dependent largely upon the ecological characteristics both of the stand as a whole and of the individual more desirable species (Chapter 11).

44. These systems are (a) those where there is adequate dormant regeneration ahead of logging, and where the regeneration will tolerate and respond to sudden exposure, allowing the stand to be completely opened in a single operation (e.g. Malaya); (b) those where regeneration is deficient initially, and must be induced to develop by gradually opening the stand under a shelterwood ahead of exploitation, the shelterwood being removed at or shortly after exploitation (e.g. Nigeria); (c) those requiring inducement of regeneration ahead of exploitation, with protection still required for some time after logging (e.g. Andamans); (d) those where regeneration is present ahead of exploitation or develops as a result of exploitation, but where it requires protection for some time after exploitation (e.g. Trinidad) (Chapters 10, 11).

45. Once regeneration is established it requires periodic tending to ensure that the desirable stems are able to grow at about their maximum rate free of competition and impedance. Diagnostic sampling has proved a valuable tool in indicating what type of liberation operations are required without wasting effort on unnecessary operations (Chapter 11).

46. Under the most favourable conditions it seems unlikely that treated natural rainforest can produce a merchantable yield greater than 100 cubic ft per acre per annum, and under routine conditions half this increment will probably be exceptional. By contrast certain highly efficient cellulose producers grown under planation conditions in rainforest sites can produce increments of 200-500 cubic ft per acre per annum and occasionally even higher (Chapter 11).

47. Other factors must also be considered when bringing rainforest under management. Further than this management is merely the means of implementing the forest policy in particular areas, and the policy will depend not only on ecological and silvicultural factors, but to a very large extent on economic, sociological and political considerations (Chapters 12 and 13).

These points lead to the rather gloomy, but not, it is felt, unrealistic prognostications made at the start of this chapter. Some areas, such as Amazonia, have barely yet felt the effects of rainforest exploitation and will certainly be producting timber from the natural rainforest for many decades yet, while many other areas will be managing and producing timber from natural stands for long periods, though probably on considerably reduced areas. It is on these areas that the matters discussed in this report will have particular application. The long range view however strongly indicates that in time all these rainforests areas will be tremendously reduced and depleted, with most of the timber requirements coming from intensively managed plantations. The time for this to occur will vary with the speed of population growth, tempered by the ability of agriculturists to produce food more efficiently from existing farmland, and thus reducing the pressure to release forest land for agriculture. However barring some human catastrophe or an unlikely voluntary control of population growth, the end pattern seems inevitable, and for this reason the early need to ensure that adequate areas of rainforest are reserved permanently for the indirect benefits is once again stressed.

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NIGERIAN TROPICAL SHELTERWOOD SYSTEM - 1944 INSTRUCTIONS

1. TROPICAL SHELTERWOOD SYSTEM:

1. This is founded upon the Malayan Regeneration Improvement Felling system and is applicable to high forest with a tolerably closed upper canopy and adequate seedbearers of the species it is desired to regenerate. It can only be carried out in forest in which there is some control of cutting and in which it is reasonably certain that exploitation will take place within a given number of years, usually from 6-15. It is the method that will normally be applied to extensive areas of good high forest to be exploited under a timber exploitation scheme. The operations are as follows:

(i) Climber-cutting

2. This operation is largely to allow freedom of movement within the forest; it is not in itself a regeneration operation in that it does not induce regeneration though it may to some extent aid that which is already on the ground. For this latter reason, it should include "Seedling Assistance" which may be defined as the cutting of any unrequired shade casters which can be felled with not more than 5 slashes of a machet. At the same time misshapen volunteers of valuable species up to 4 inches in diameter should be coppiced at not more than 1 foot from the ground. For this purpose the matchet must be sharp and arrangements should be made for files or stones to be available. The coppicing of these species is carried out in the hope that the stools will send forth straight shoots which, under the more favourable conditions about to be created, will stand a better chance of maturing into well-shaped trees. Climber-cutting is an operation that can be carried out at any season and is essentially one to keep labour employed when other work is slack but the considerations given in the next section should be kept in mind.

(ii) Removal of the middle-storey canopy

3. The operation consists of the removal of all or part of the middle-storey in order to admit sufficient light to the forest floor to encourage the growth of the desired species but not enough to enable weed growth to capture the area. The middle-storey comprises low, spreading trees of from 20 to 50 feet in height and the degree to which its canopy is opened should, in general, be determined by the adjacent seed-bearers, favour being given to the dominant valuable species of the locality. Patches where few or no seed-bearers occur should be lightly dealt with and left for further consideration and possible assistance during a later treatment. The essential problem being the admission of just sufficient light to encourage regeneration but insufficient to permit a lush tangle of weeds and ground-creepers to flourish, the canopy, at this stage, should be interfered with too little rather than too much as once a tangle is allowed to establish itself, regeneration operations become extremely difficult if not entirely impossible by reason of the cost. The edges of a compartment where light enters from rides should be dealt with very cautiously.

4. The operation should not be embarked upon sooner than one month after the initial climber-cutting in order to give the leaves of the lianes time to wither and drop off so that a clearer idea of the remaining canopy can be obtained. It can be delayed up to as much as a year or even two if necessary without losing the value of the first operation and, if the measure now about to be described cannot be conveniently carried out within a few weeks of the first, such a delay is probably advisable in order to allow the climbers to fall from the trees and disintegrate. The timing between the first and second operations is of no silvicultural importance and the only question involved is one of convenience of movement and of studying the canopy.

5. The method by which the middle-storey is removed will depend upon whether there is a ready local sale for poles and firewood or not. Where there is such a sale the trees can be removed by felling and the operation will probably more than pay for itself. The trees must be carefully marked by a responsible operator and it is essential that they, together with the log and top, should be removed immediately in order not to interfere with regeneration. This method is obviously of limited application and can only be employed in areas not far distant from urban centres.

6. Where the middle-storey cannot be removed in a profitable fashion, it is necessary to employ some method less expensive than felling. Ordinary girdling almost invariably fails in the rainforest and it must therefore be combined with poisoning. For this an ordinary open girdle cannot be used as the poison escapes too readily; "frill-girdling" must therefore be employed. In this method downward sloping cuts are made in a complete ring round the tree, penetrating the sapwood to a depth of about 1 inch. This must vary with the size of the tree and the incisions in moderate sized stems must not be so deep as to cause the tree to fall in a wind at an early age. The cuts must be continuous with one another and the bark must stand away from the hole to form a trough into which the poison can be poured. Sodium Arsenite is the poison used, the normal strength being 1 lb to the gallon though, if particularly quick action is required, solutions up to six times this strength can be used. The poison can be introduced by means of an ordinary engineer's oil-can but it is better to devise some container less likely to contaminate the hands of the operator. Sodium Arsenite is an extremely potent poison, as much as will stand on a sixpence being a fatal dose, and the utmost care must therefore be exercised. The poison can be absorbed through an open wound or ulcer and the officer-in-charge of the operations should acquaint himself fully with the symptoms and must have bottles of the antidote and a cup on the spot.

7. Death of the trees should take place in from 3 months to 2 years but it is desirable to effect it in not longer than 6 to 12 months. Some species, particularly Annonidium, are extremely resistant. The great advantage of poisoning over felling is that it results in a gradual opening of the canopy and thus permits seedlings to accomodate themselves to more intense light conditions. Moreover, there is no slash on the ground to interfere with young seedlings: the dead branches drop off gradually and the tree does not fall until the seedlings have achieved a certain amount of strength and elasticity.

8. The timing of this operation is of great importance whether the middle-storey canopy is opened by felling or by poisoning. It is absolutely essential that young seedlings should not be suddenly exposed to the full force of the dryseason sun and for this reason the removal of poles by felling must take place at the beginning of the rainy season. Frill-girdling in the rainy season, however, results in the loss of poison and in many of the trees dying early in the dry-season thus exposing the tender seedlings. It should therefore be carried out early in the dry-season, i. e. in November or December. Probably the earlier in the season the more active will be the sap and the poison may be expected to act correspondingly quicker.

(iii) <u>1st Regeneration Count</u>

9. About the middle of the following wet-season a second climber-cutting should be carried out to free any regeneration and, once again, to permit freedom of movement within the forest. With this operation, should be combined a Regeneration Count, distinguished from a seedling count in that small saplings are included and not every one is tallied, some account being taken of distribution. Three classes are used for this purpose:

Up to 3' in height.
From 3' - 10' in height.
From 10' in height to 1' in girth.

All measurements are estimated, the first being waist height, the second as high as two men and the third as wide as a closed fist. Only one plant of two or more standing within 6 feet of one another is reckoned. Not more than 12 species at the outside should be dealt with. The method employed is to cover the compartment in strips of 6 or 8 labourers 6 feet apart followed by a forest guard. Each labourer carries a bag slung round his waist and picks a leaf of each seedling which is not more than waist high and places it in the bag, being careful not to pick more than one leaf unless the second tree lies at more than two paces from one alredy counted. At the same time the forest guard books trees of the other two classes as they are called out by the labourers; at the end of each strip he should note whether the distribution has been fairly even or markedly sporadic. A minimum of 40 well grown seedlings per acre, fairly well distributed, is considered satisfactory.

(iv) <u>2nd opening of the canopy</u>

10. Based on the information gained in the 1st Regeneration Count and on observation, a second opening of the canopy should be carried out early in the second dry-season. If there is any danger of ruining young regeneration by the felling and extraction of poles, only poisoning should be employed. Removal of poles might be carried out where there is insufficient regeneration or none at all.

11. The 1st Count may indicate that in some areas no second poisoning is essential but nonetheless they should be gone through to see whether the admission of more light is desirable. This second poisoning may include small misshapen specimens of the valuable species and, if necessary, but with great caution, some of the uneconomic upper-storey canopy trees in order to encourage very strong, light-demanders. The utmost care must still be taken to avoid creating light conditions favourable to the growth of ground-tangle.

(v) Early cleanings

12. A light cleaning should be carried out twice a year for two years after the second poisoning. The two most appropriate months are June and September. During the first of these cleanings, surplus coppice shoots should be carefully removed from the stools of those trees coppiced in the first climber cutting, leaving one per stool.

(vi) 2nd Regeneration Count

13. This should be carried out together with the 4th cleaning in the same manner as the 1st Count. Satisfactory regeneration is considered to be a minimum of 40 well grown seedlings and saplings per acre. If the count shows less than this, further operations will be abandoned or the Assisted Tropical Shelterwood System be applied if funds are available and the expenditure considered justifiable.

(vii) Pre-exploitation cleanings

14. After the 4th cleaning and 2nd Regeneration Count the area should be left for a year till the next September before being cleaned again. Thereafter, cleaning should be carried out at four-yearly intervals until the forest is exploited.

(viii) Exploitation

15. It is undesirable that exploitation should take place until at least 6 years after the 1st opening of the canopy in order that the young trees should have attained a sufficient height, say 15 feet, to complete with any incoming weed growth consequent upon the opening of the canopy. It should be thorough without being too intense, that is to say that while a very great deal that can reasonably be used should be taken out, it is not considered that completely clear felling is desirable as some slight high shade should remain for a few years. The degree of exploitation permissible will depend to some extent upon the silvicultural requirements of the chief species regenerated, full light-demanders being capable of standing a more complete opening of the canopy than shade-loving species.

(ix) Post-exploitation Cleaning

16. A cleaning should be carried out in from 6 months to a year after exploitation has ceased in order to free any regeneration which has been trapped and to coppice any saplings which have been broken. A second cleaning should be undertaken after an interval of 2 years, and thereafter the area should be cleaned about 5-yearly until the young crop is 20 years of age from the time of the 1st opening of the canopy.

Timetable and approximate costs

17. The year, for the purposes of this timetable, will be taken as commencing with the dry-season even though this may imply differing from the calendar year by inclusion of the previous December. R. S. and D. S. are Rainy- or Dry-Season.

Year	Operation	Estimated cost/acre
0.	Demarcation	9d.
0.	Climber-cutting	1/-
1.D.S.	Removal of middle-storey	3/- (poisoning)
1.R.S.	1st Regeneration count & climber cutting	1/6d
2 D.S.	2nd opening of canopy	1/6d
2 R.S.	1st and 2nd cleaning	1/- each
3 R.S.	3rd cleaning	1/-
	4th cleaning and 2nd Regeneration Count	
4 R.S.	5th cleaning (or Exploitation)	1/-
8, 12, 16 etc, R.S.	Pre-exploitation cleanings	1/- each
n	Exploitation	
n + ½ to 1:RS	1st Post-exploitation cleaning	1/6d
n + 3	2nd Post-exploitation cleaning	1/-
n + 8	3rd Post-exploitation cleaning	1/-
n + 13	4th Post-exploitation cleaning	1/-

Note - It should be noted that no provision is made for a full stocktaking as this is not essential to the working of the system. Should one be considered necessary for silvicultural or administrative reasons, it should be paid for from other funds as it is not a fair charge to regeneration.

FORESTRY DIVISION WESTERN REGION INSTRUCTION NO. 1/1961

T.S.S. STANDARD INSTRUCTION WITH SUBSEQUENT AMENDMENTS

INTRODUCTION

1. For the past seven years silvicultural treatment in all T.S.S. Working Circles has been carried out as prescribed in the Revised Forest Department Western Region Instruction No. 1/1953. During the this period there has been a growing feeling among provincial and other forest officers that Operation II, which is a standard Operation in all T.S.S. Working Circles, was in need of modification. In the Benin forests particularly, experience has shown that the indiscriminate cutting back of unecomonic saplings tends to encourage the development of *Acacia* and *Calamus* tangles. Furthermore, where the advance growth of economic species is well represented, considerable numbers are carelessly cut back during this operation. It is now considered that where advance growth is present, the uneconomic saplings should be retained in order to form a close thicket within which undesirable climber tangles would be less likely to develop.

2. It has also become evident that Operation IV (Regeneration Count and Enumeration of Pole Crop), which has never been considered a very satisfactory operation, should be discontinued. The Federal Department of Forest Research have now adopted a modification of the Linear Regeneration Sampling Method developed in Malaya as standard practice. It is considered that this method would also suit our requirements.

3. The need for modifications to our silvicultural techniques was fully discussed at a meeting of Senior Forest Officers, including the Director of Forest Research, in February, 1961. It was agreed that an assessment of the economic advance growth prior to treatment was a first essential, subsequent treatment to depend on the stocking of advance growth present. Where advance growth was sufficient a general release in the form of a climber cutting and poisoning would be carried out in the first year. Where advance growth was deficient, operations to induce regeneration would be necessary. It was also agreed that Revised Instruction No. 1/1953 should be replaced by a new instruction which would incorporate all the points agreed upon at the Conference.

4. For convenience, the revised sequence of operations which may now be carried out under the Tropical Shelterwood System is represented diagramatically. Thereafter the various operations are described separately and a reference made to the year in which an operation should be carried out. In all cases year 1 is five years before the year in which exploitation is prescribed. Where standard practice is already well known, it is not proposed to give a full description of operations.

5. The Federal Department of Forest Research have prepared two instructions on sample surveys. The first is a "General Instruction for carrying out a sampling survey in forest areas" and has been issued as Technical Note No. 11. The second is a Field Instruction for Technical Staff for a sampling survey in forest areas.

Operation I <u>Dry Season before year 1</u> (a)
Milliacre Assessment

Operation IA <u>Year 1</u>
Demarcation

Where Stocking of Advance Growth is Sufficient

Operation III. Climber Cutting Only <u>Year 1.</u>

Operation V. Clearance Poisoning <u>Year 1.</u>

Where Stocking of Advance Growth is Deficient

Operation II. Climber cutting and cutting of uneconomic saplings. <u>Year 1</u>

Operation IV. Second Milliacre Assessment (b) <u>Year 2.</u>

Operation V. Clearance Poisoning <u>Year 2.</u>

Operation VI and VII	Pre-exploitation climber cutting	Year 4 or 5
Operation VIII	Exploitation and repair of exploitation damage	Year 6
Operation IX and X	Post-exploitation climber cutting	Year 8
Operation XI	Removal of the Overwood	Year 8
Operation XII and XIII	Sample Enumeration	Year 15

(a) If the stocking of advance growth is deficient and the results also show a paucity of seed-bearers, it may be decided not to proceed with T.S.S. operations.

(b) If the stocking of advance growth is still deficient full details and recommendations for future treatment should be referred to the Conservator of Forests.

6. This Instruction will apply to all T.S.S. Working Circles in Benin Division and Ondo Province as from the 1st April, 1961. Eventually as experience in the application of the new methods increases, this instruction will apply to all T.S.S. Working Circles in the Region.

7. (Note: The following terms are used in this instruction and are to be accepted for general use in all correspondence relating to T.S.S.).

Upper Storey (Emergents).
Middle Storey
Lower Storey
Shrub layer
Herb Layer

8. Operation I. <u>First Assessment of Advance Growth by Milliacre Quadrats</u>

To be carried out in the dry season preceding year 1 in all compartments scheduled for treatment. It will first be necessary to reopen compartment boundaries and cut quarter lines. These must be cut straight regardless of any obstruction such as <u>Acacia</u> and <u>Calamus</u> tangles which they must penetrate and not go round. Where compartments scheduled for treatment are contiguous, the compartments should be treated as a unit for purposes of assessment, even in cases where there are variations between the compartments.

9. The assessment of advance growth by milliacre quadrats will then proceed in accordance with the Instructions prepared by the Federal Department of Forest Research (see paragraph 5). It is sufficient to state here that in working circles where assessments of this kind have not previously been carried out, the initial intensity of sampling should be 1%. A normal square mile compartment will then be considered as forming 16 blocks each of 40 acres or 8 blocks of 80 acres. Each block having two .1 chain wide transects the position of which are fixed on a base line using tables of random numbers. The direction of the transects should be across any well defined contours or main drainage channels in order that the sample should be as representative as possible. Where any doubt arises concerning the layout of sampling schemes, the officer in charge should consult with the Conservator of Forests.

10. The species to be recorded in the assessments are divided into two classes on the basis of timber value, rate of growth and frequency. The following list will apply to all T.S.S. Working Circles in Benin Division and may be modified as required for Working Circles in other areas. All modifications to the list must be approved by the Chief Conservator of Forests.

CLASS I

Khaya ivorensis	K
K. anthotheca	Ka.
K. grandifoliola	Kg.
Entandrophragma cylindricum	Ec.
E. utile	Eu.
E. angolense	Ea.
Lovoa trichiliodes	L
Triplochiton scleroxylon	T
Gossweilerodendron balsamiferum	G
Chlorophora excelsa	C
Afrormosia elata	Ae.
Nauclea diderrichii	N
Mansonia altissima	Ma.
Terminalia ivorensis	Ti.
Nesogordonia papaverifera	Np.
Afzelia africana	Aa.
A. bipindensis	Ab.
A. pachyloba	Ap.
Mitragyna ciliata	Mc.

CLASS II

Guarea cedrata	Gc.
G. thompsonii	Gt.
Terminalia superba	Ts.
Mimusops heckelii	Mh.
Entandrophragma candollei	Ecan
Distemonathus benthamianus	Db.
Piptadeniastrum africanum	P.
Pycnanthus angolensis	Pa.
Pterygota macrocarpa	Pm.
Pterygota bequaertii	Pb.
Cordia millenii	Co.
Sterculia oblonga	So.
Sterculia rhinopetala	Sr.
Alstonia congensis	Ac.
Antiaris africana	Aa.
Brachystegia spp.	Brac.
Celtis spp.	Cel.
Daniellia ogea	Do.
Cylicodiscus gabunensis	Cg.
Scottellia coriacea	Sc.
Albizia spp.	Al.

11. Size classes will be recorded separately as follows:

Up to 1' high
1' high to 3' high
3' high to 10' high
10' high to 1' girth
1' girth to 3' girth in 1' girth classes
Over 3' girth in 1' girth classes

Note: The "up to 3' high" and the "3' girth and over" classes are not strictly required for the purpose of deciding if a compartment is adequately stocked with advance growth. This additional information, which should be recorded separately, provides a useful indication of the recruitment to be expected when opening up takes place and of mother trees present, i.e. potential seed-bearers.

12. The "Chosen Tree" or by definition - "the listed tree most likely to survive and form a useful constitutent of the new crop" - will be recorded for each quadrat.

13. The importance of accurate assessments cannot be over-stressed. To ensure a high standard of work, 10% of all quadrats will be checked by an officer not lower in rank than Forest Superintendent and the field sheets signed to this effect.

14. In Working Circles where Operation I is being carried out for the first time the probable sample error should be calculated in respect of each compartment. Adjustments to the intensity of the sample can then be made in order to achieve acceptable limits of accuracy with the minimum of expense and effort. For the present it is considered that the probably sample error should not exceed 20%.

15. It is important that all Officers of Assistant Conservator of Forests rank and above should be thoroughly acquainted with the method of calculating the probable sample error. The intensity of sampling can then be adjusted where necessary without undue delay. The necessary formulae and worked examples are set out in Technical Note No. 11 and Officers in charge should consult with the Conservator of Forests if difficulties arise.

16. A compartment will be considered to have a sufficient stocking of advance growth when the mean of the sample shows that there are:

Either Not less than 100 stocked milliacre quadrats per acre of which not less than 30 contain advance growth of Class I species between 3' high and 3' girth.

Or Not less than 60 stocked milliacre quadrats per acre containing advance growth of class I species between 3' high and 3' girth.

For the purposes of applying this criterion, advance growth is defined as all class I and class II trees between 1' high and 3' girth.

17. In compartments where the results of operation I show not only a deficiency in the stocking of advance growth but also in desirable seed bearers, then the advisability of carrying out T.S.S. operations arises. In these circumstances, the matter should be referred to the Conservator of Forests for a decision.

Operation IA. Demarcation Year 1. Cutting of grid lines $2\frac{1}{2}$ chains apart, or where additional control is required the interval may be reduced to $1\frac{1}{4}$ chains, e.g. Operation III. Peg at 1 chain intervals. As in the case of compartment boundaries and quarter lines these must be cut straight regardless of any obstruction such as *Acacia* or *Calamus* tangle which they must penetrate and not go round. Compartment number plates must be fixed at the four corners of the compartment and wherever a permanent road enters and leaves a compartment. Any durable locally available material may be used to carry the plates but normally these will be nailed to poles cut from durable uneconomic species available locally (e.g. Strombosia, Diospyros, Xylopia). Poles should be about 8 feet long and sunk at least 2 feet in the ground with number of plates fixed 6 feet from ground level.

18X. Operation II. Climber Cutting and cutting of small uneconomic saplings and control of shrub and herb layers. (Year 1)

To be carried out as soon as possible in year 1 where the stocking of advance growth is deficient. The object of this operation is to induce regeneration. It must therefore be done very thoroughly as experience shows that any areas not treated will be missed out in all subsequent operation.

The normal operation will be cut back all climbers and creepers (including figs and "ropes") at ankle height. Cut single stems of Calamus. Cut at knee height or below all stems of uneconomic (not listed) species up to 2 inches in diameter and uneconomic softwood species up to $2\frac{1}{2}$ inches diameter. Care must be taken not to cut back economic species. Cut climber and creeper growth right up to the edge of Acacia and Calamus tangle, but leave standing poles of all species to a depth of about 4 yards from the edge of these tangles. Where the tree canopy is very broken the number of uneconomic stems cut may be reduced. This reduction reaches its climax in open areas where heavy weed growth has invaded the forest. In such areas only climbers and creepers should be cut, leaving untouched all poles and all erect woodly growth of all species with the possible exception of Musanga. In forest with this very open canopy (e.g. certain compartments in the Okumu reserve), extensive areas of blanketing weed growth, about 6-12 feet in height and forming even higher "climber towers", are sometimes found. Acacia is usually present but Calamus is comparatively rare. These areas present a difficult problem but even without them a determined effort must be made to carry out cutting back of climbers and creepers while leaving the pole crop and other erect woodly growth untouched. Where the forest floor is reasonably clean (i.e. seed can reach the ground without undue obstruction) there should be no interference with the herb layer, but where monocots and other weeds have invaded the forest floor to an extent which will prevent seed reaching the ground; the herb layer must be cut back to ankle height. Double leaders of advance growth of economic species must be cut during this operation and malformed economic saplings and poles which can be dealt with by matchet must be coppiced at about 6 inches above ground level. Less valuable species must be cut back where they interfere with the growth of more valuable species; for order of preference see paragraph 10.

19. Operation III. Climber Cutting and selective cutting of unecomic saplings. Year 1.

To be carried out in year 1 where the stocking of advance growth is sufficient. The object of this operation is to effect a general freeing of the advance growth. The normal operation will be to cut back all climbers and creepers (including figs and ropes) at ankle height and climbers at a second point above head height. Cut single stems of Calamus. Erect stems of uneconomic species (except Musanga) will not be cut unless interfering

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X Re Operations II and III. In certain circumstances a less valuable tree should be preferred to a more valuable one. For example, a well shaped pole or sapling of Terminalia ivorensis or superba should be kept, if it interferes with an advance growth of Khaya ivorensis less than 3' high.

directly (i.e. overtopping) with the growth of an economic seedling or sapling.

Less valuable species must be cut back where they interfere with the growth of more valuable species; for order of preference see paragraph 10. Double leaders of advance growth of economic species must be cut during this operation and malformed economic spalings and poles which can be dealt with by matchet must be coppiced at about 6 inches above the ground level.

20.X Operation IV. Second Assessment of Advance Growth by Milliacre Quadrats. Year 2.

Where the original stocking of regeneration and advance growth was deficient, a second assessment by milliacre quadrats, following the general lines of Operation I, should be carried out in the dry season of year 2. The object of this assessment is to gauge the success of Operation II in inducing regeneration.

21. For the purposes of this second assessment, regeneration is defined as all Class I and Class II trees between 0' high and 3' girth and a compartment will be considered to be adequately stocked when the mean of the sample shows that there are:

Either Not less than 100 stocked milliacre quadrats per acre of which not less than 30 contain regeneration and advance growth of class I species between 0' high and 3' girth.

Or Not less than 60 stocked milliacre quadrats per acre containing regeneration and advance growth of class I species between 0' high and 3' girth.

22. If the second assessment shows that the stocking of regeneration and advance growth is still deficient, full details and recommendations for future treatment will be submitted to the Conservator of Forests.

23. Operation V. Clearance Poisoning of shade casting uneconomic trees of the middle and lower storeys. Year 1 or Year 2.

To be carried out in the dry season of year 1 following Operation III, or in the dry season of year 2 when the second assessment (Operation IV) shows an adequate stocking of advance growth. The object is to give additional light and crown space to the advance growth of all sizes. Normal treatment will be to poison all shade casting uneconomic trees (i.e. trees with wide spreading crowns like Myrianthus and Annonidium) of the middle and lower storeys. Where only a very selective cutting of uneconomic spalings has taken place, as prescribed inOperation III, poisoning should extend down to uneconomic stems of 2 inches diameter. Straight boled uneconomic trees with small crowns casting comparatively little shade may be left untouched and wherever possible a single ring of shade casting trees should be left round the edge of Acacia - Calamus tangles

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X A second assessment of advance growth should for the present be omitted. All compartments should be treated as if adequately stocked as a result of operation II in the first year.

24. An important exception to the normal treatment is the leaving of an occasional shade casting lower and middle storey tree where the canopy would otherwise be completely absent. This refinement is particularly important where much of the regeneration has been induced as a result of Operation II and a drastic opening of the canopy would tend to encourage the development of lower creeper tangles.

25.‡. Experience has shown that the regulation of light conditions by the poisoning of unwanted species is the most difficult and the most critical of all the silvicultural operations. The difficulties arise because of the scale of our operations and because our forests vary considerably in composition and structure. These variations occur not only between one reserve and another but also within any one reserve. It is considered impracticable therefore to describe in detail a clearance poisoning which would be of general application to all T.S.S. Working Circles. With increased knowledge and experience it should evenutally be possible to describe in detail the poisoning requirements of each reserve or group of reserves: for the present the general principles on the ground must rest with the local professional and technical staff who must take into account the silvicultural requirements of the forest in which they are working. It follows therefore that all professional and technical staff engaged on T.S.S. operations have a special responsibility to acquire, by keen and intelligent observation, a thorough knowledge of the forests under their control.

26. The use of unskilled labour adds to the difficulties when poisoning operations are carried out on a large scale. It has been found that one supervisor is required for a gang of about six men and wherever possible available labour should be organized on this basis. Every effort should also be made to build up and retain an experienced labour force in each working circle.

27. <u>Operation VI. Re-Demarcation. Year 4 or 5.</u>

Re-opening of compartment boundaries, quarter lines and grid lines prior to Operation VII.

28.X <u>Operation VII. Pre-exploitation climber cutting and selective cutting of uneconomic saplings. Year 4 or 5.</u>

It seems probable that an additional freeing operation just before exploitation would benefit the new crop by reducing felling damage. If this is confirmed by an investigation, Operation III should be repeated in year 4 or 5. This operation will only be prescribed after approval has been given by the Conservator of Forests.

29.* <u>Operation VIII. Exploitation and repair of exploitation damage. Year 6.</u>

Revised Instruction No. 1/1963 prescribed a freeing

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‡ The responsibility for interpreting the principles enunciated for clearance poisoning should rest with an officer not below the rank of Forest Superintendent.

X The usefulness of this operation is doubted in the majority of cases. The operation should be regarded as suspended.

* This operation (repair of exploitation damage) should be postponed till year 8, and carried out together with operation X.

or coppicing of economic stems obstructed or damaged as a result of exploitation. Unfortunately, the carrying out of this operation has not proved very practicable. The need, however, remains and officers in charge of T.S.S. Working Circles should make every endeavour to reduce the effects of exploitation damage by the most effective means possible.

30. Operation IX. Re-Demarcation.

Reopening of compartment boundaries, quarter lines and grid lines prior to Operation X or XI.

31. Operation X. Post-exploitation climber cutting and selective cutting of uneconomic saplings.

Repeat operation III in year 8 or in the second year following the cessation of major felling. This is an optional operation and should only be prescribed in consultation with the Conservator when the officer in charge has made a thorough inspection and satisfied himself that a general freeing will benefit the new crop or is necessary in order to make access possible for Operation XI. Access can usually be obtained more cheaply by gridding at one and a quarter chain intevals.

32. Operation XI. Removal of the Overwood.

Year 8 or in the second year following the cessation of major felling. The object is to remove by poisoning any trees which are interfering with the growth of the new crop. All trees poisoned during operation V but not yet dead should be repoisoned. All trees not included in the list at paragraph 10 which are overtopping the new crop, including any malformed listed trees, must be poisoned.

33. Operation XII. Re-damarcation. Year 15.

Reopening of compartment boundaries and quartter lines prior to Operation XIII.

34. Operation XIII. Sample Enumeration Year 15.

The object of the sample enumeration is to obtain details of the stocking of economics in all compartments where regeneration treatment has been completed. The initial intensity of a sample enumeration should be 10% on a two transects per block stratified random layout. Adjustments to the intensity of the sample to be made as the work proceeds in order to obtain a sample error of not more than 20%. The methods follows the general lines of the Milliacre Assessments (operation 1), with the exception that the sample units are $\frac{1}{2}$ chain square. For detailed instructions on the actual field work, Forestry Division Western Region Instruction No. 1/1959 should be referred to.

Modification of Working Plans

35. This instruction will require modification of existing working plans for working circles managed under T.S.S. and silvicultural prescriptions in future working plans based on this system willbe in accordance with this Instruction.

36. In working circles managed under T.S.S. as prescribed in Revised Instruction No. 1/1953, operations in coupes to be opened in 1961/62 will now be carried out as laid down in this Instruction. As regards coupes already open to treatment, prescriptions will be modified to conform as closely as possible to this Instruction.

37. Forest Officers in-charge Working Plans should now prepare an amended Schedule of Operations for all existing T.S.S. working plans and future prescriptions will be in accordance with this Instruction.

Note:- Paragraphs 35, 36 and 37 apply only to the Benin and Ondo Working Plans for the present.

RULES FOR TREE MARKING, FOR LOGGING AND FOR NATURAL REGENERATION TREATMENT - NORTH QUEENSLAND RAINFORESTS

(1954 Treatment Rules)

The principal object of tree marking in the North Queensland Rainforests is the full utilization of the merchantable timber in the forest consistent with the aim of maintaining:

(a) Growing stock of actively growing trees of the best species available at reasonably spacing.

(b) Where this growing stock is inadequate the retention of seed trees of the most desirable species available.

The full utilization of all utilizable species and the improvement in the constitution of the forest must be constantly in the tree marker's mind.

These rules have been laid down for complete application to the best of the ability of the marker, but it must not be assumed that they represent anything more than attempt to apply the limited knowledge available at the time of writing - and as such they should be subject to continuous and critical analysis. However, there is to be no departure from these rules in routine pracice unless approval is first obtained.

Order of Desirability of Stems

The utilizable species in North Queensland have been grouped into 4 groups; group A being of higher desirability than Group B, and so on. The constitution of the group has been determined after considering the wood value and silvicultural characteristics of the trees concerned. Only in Group A is the order of species in accordance with their individual desirability.

Stumpage Group		Standard Name	Botanical Name
Group A	I	Maple	Flindersia brayleyana
	I	Red Cedar	Toona australis
	I	Silkwood	Flindersia pimenteliana
	I	N.Q.Kauri Pine	Agathis palmerstoni Agathis. microstachya
	II	N'ern Silky Oak	Cardwellia sublimis
	II	Q. Silver Ash	Flindersia bourjotiana
	I	Q. Walnut	Endiandra palmerstoni
	III	Hickory Ash	Flindersia ifflaiana

Stumpage Group		Standard Name	Botanical Name
Group B	II	White Beech	Gmelina leichhardtii
	III	Scented Maple	Flindersia laevicarpa
	III	Briar Silky Oak	Musgravea stenostachya
	III	Satin Silky Oak	Embothrium wickhamii
	III	Black Pine	Podocarpus amarus
	IV	Northern Sassafras	Daphnandra aromatica Daphnandra dielsii
	IV	Grey Satinash	Eugenia gustaviodes
	IV	Red Silkwood	Palaquium galactoxylum
	II	Silver Silkwood	Flindersia acuminata
	IV	Red Siris	Albizia toona
Group C	IV	Blush Alder	Sloanea australis
	IV	Rose Alder	Ackama australiensis Ackama quadrivalvis
	IV	Stoney Backhousia	Backhousia highesii
	IV	Black Bean	Castanospermum australe
	IV	Salmon Bean	Archidendron vaillantii
	IV	Rose Butternut	Blepharocarya involucrigera
	IV	Grey C .rabeen	Sloanea macbrydei
	IV	White Carabeen	Sloanea langii
	IV	Damson	Terminalia seriococarpa
	IV	Johnstone R. Hardwood	Backhousia bancroftii
	IV	Magnolia	Galbulimima baccata
	IV	Miva Mahogany	Dysoxylum muelleri
	IV	Northern Brush Mararie	Geissois biagiana
	IV	Caledonian Oak	Carnarvonia araliaefolia
	IV	Red Tulip Oak (Tarrietia)	Tarrietia peralatum
	IV	Pepperwood, Camphorwood	Cinnamomum laubatii
	IV	Brown Quandong	Elaeocarpus coorangooloo
	III	Silver Quandong	Elaeocarpus grandis
	IV	Kuranda Satinash	Eugenia kuranda
	IV	Bolly Silkwood	Cryptocarya oblata
	IV	Satin Sycamore	Ceratopetalum succirubrum
	IV	Brown Penda	Xanthostemon chrysanthus
	IV	Scrub Turpentine	Canarium muelleri
	IV	Yellow Walnut	Beilschmiedia bancroftii
	IV	Rose Silky Oak	Darlingea ferruginea
	IV	Rose Silky Oak	Darlingea spectatissima
	IV	Rose Silky Oak	Opisthedepis heterophylla
	IV	Red Penda	Xanthostemon pubescens
Group D	IV	Scaly Ash	Ganophyllum falcatum
	IV	Hard Aspen	Acronychia laevis
	IV	Black Apple	Planchonella australis
	IV	Yellow Boxwood	Planchonella pohlmanianum
	IV	Hickory Boxwood	Planchonella euphlebium
	IV	Macintyre Boxwood	Xanthophyllum octandrum
	IV	Candlenut	Aleurites moluccana
	IV	Peach Cedar	Trema orientalis
	IV	Spur Mahogany	Dysoxylum pettigrewianum
	IV	Blush Silky Oak	Kermadesia bleasdalei

Stumpage Group	Standard Name	Botanical Name
Group D. contd		
IV	Lamingtons Silky Oak	Helica lamingtoniana
IV	Lomatia Silky Oak	Lomatia sp. nov.
IV	Whelans Silky Oak	Macadamia sp. aff. whelani
IV	N'ern Evodia	Stenocarpus sinuatus
IV	Yellow Penda	Tristania pachyspermus
IV	Blush Satinash	Eugenia hemilampra
IV	Brown Satinash	Eugenia grandis
IV	Cherry Satinash	Eugenia leuhmanni
IV	Coast Satinash	Eugenia smithii
IV	Creek Satinsash	Eugenia australis
IV	Brown Salwood	Acacia aulacocarpa
IV	Red Touriga	Calophyllum costatum
IV	Brown Walnut	Endiandra subtriplinervix
IV	Rose Walnut	Endiandra discolor
IV	Blush Walnut	Beilschmiedia obtusifolia
IV	Ivory Laurel	Cryptocarya angulata
IV	N'ern Laurel	Cryptocarya hypospodia
IV	Corduroy Laurel	Cryptocarya corrugata
IV	Hard Milkwood	Alstonia muelleriana
IV	Barringtonia	Barrintonia racemosa
IV	Nutmeg	Myristica muelleri

Note: Any utilizable species not listed are to be included in Group D.

Girth Limit

The following girth limits, above which trees are to be retained only when required as seed trees - and then only in accordance with the seed tree definition in these rules - are to be adopted:

Species	Normal GBH limits	GBH to which well formed very vigorous trees may be retained
Group A	GBH feet	GBH feet
Qld Walnut	10	10
Maple, Kauri, Silkwood) Cedar, N. Silky Oak, Silver Ash)	8	10
Group B. Species	7	9
Group C. Species	6	8
Group D. Species	6	6

Seed Trees

In areas that are inadequately stocked with stems of acceptable species, seed trees are to be left with the object of regenerating the area concerned. Where the combined representation of desirable species of Groups A and B would, in the opinion of the marker, be less than 30% of the required stocking of the area after treatment, seed trees of Groups A and B, if available, are to be left irrespective of whether the area is fully stocked with Groups C and D species or not.

The following are the requirements of seed trees:

Spacing which is to be aimed at between seed trees - 120' x 120'.
Minimum girth of acceptable seed tree - 6" g.b.h.
Maximum girth of acceptable seed tree - 120" g.b.h.

As far as possible, seed trees should be well formed, well crowned and vigorous trees. Diseased or dying trees should be avoided, but allowance should be made for the increased vigour that should result from silvicultural treatment, or from logging.

Seed trees should be of the most desirable species available, i.e. give preference to the species in Group A as listed - prefer Group A to Group B, Group B to Group C, and so on.

Where a choice exists, seed trees in the lower girth ranges (60" - 84") that are well formed and vigorous and of the most desirable species are to be given preference.

Trees of Qld walnut - Endiandra palmerstoni - are not to be retained as seed trees.

Merchantable Thinning below Normal G.B.H. Limit

Thinning on a merchantable basis shall be, unless otherwise indicated, carried out from the girth limits set for the particular species down to 48" g.b.h.

The spacings to be arrived at are:

72" + G.B.H. to girth limits set - 30' x 30' (48 per acre)

60/72" G.B.H. to girth limits set - 25' x 25' (70 per acre)

48/60" G.B.H. to girth limits set - 22' x 22' (90 per acre)

Where choice between species in different groups exists, the groups are to be unequivocally favoured in order of preference, i.e. providing the trees of the better species are well formed and healthy. No tree or Group D is to be favoured against a 48" + stem of Groups A, B and C. No tree of Group C is to be favoured against a 48" + stem of Group A and B, and no tree of Group B is to be favoured against a 48" + stem of Group A.

In addition, any satisfactory tree in Groups A or B that is 10' in height or higher is to be unequivocally favoured against any tree in Group D. Furthermore, should regeneration of Group A or Group B species 10' in height or higher occur under the crown of any merchantable stem of Group D species and be considered capable of stocking the area, such regeneration is to be favoured by the removal of the D group stem concerned.

Where none of the above conditions exist, the aim is to conduct a normal thinning according reasonable preference to the better species and aiming at a well distributed stand of vigorous trees of good form.

Salvage cutting

When marking for logging, any badly damaged tree containing merchantable timber and which, in the opinion of the marker, is likely to die within the next 15 years, should be marked for removal.

Miscellaneous

Marking for logging - A system should be iniated to ensure that all trees marked for removal and no more are logged.

On the completion of logging the Harvesting and Marketing Officer should furnish areport covering such points as marked trees not logged, damage to seed trees, damage to regeneration and any other points which may have a bearing on the treatment of the area.

In cases where marked trees in D Group are not logged, removal should be insisted upon and the purchaser informed of the Department's willingness to carry out studies on the species concerned.

Silvicultural Treatment

Whenever it is possible, silvicultural treatment should be combined with logging under tree marking.

When this is possible the area to be treated should be brushed leaving all stems of desirable species not more than 6 months before logging.

The area should then be treemarked in accordance with the tree marking rules and logged.

As soon as possible after the completion of logging, the area should be further treated with the object of removing useless trees and species and with the further object of according reasonable space to the most desirable stems to provide the stocking of the area.

In this statement, no useful trees in the respective groups above the girths shown below are to be removed:

Group A - 30" g.b.h.
Group B - 36' g.b.h.
Group C - 36" g.b.h.

In the case of Group D, trees less than 48" g.b.h, are to be retained only when there is no alternative stem of Groups A, B or C available.

The remaining stand is to be thinned aiming at the following spacings:

Stand Height

Below 10' - No thinning.
10' - 20' - No thinning but in cases where stems of Groups A and B are available, they are to be cleared around to a distance of 5'.

20' - 50' - 10' x 10'.
Over 50' - 16' x 16'.

In thinning, preference is to be accorded to the species in order of desirability.

Although the above spacings are necessarily average, no stem is to be left closer to another stem than half of the spacing quoted.

Where trees above and below 50' are involved, a spacing of 12' x 12' should be adopted.

Removal of Stinger (Laportea moroides)

In those areas being brushed prior to logging, action should be taken immediately after the completion of brushing to destroy all of the stinger on the area either by:

(a) falling (where the stinger is sufficiently large, and by swabbing the stemp with a selective weedicide; or

(b) by spraying small stinger with a selective weedicide.

On the completion of logging, germinating stinger is to be removed from snig tracks and from tree heads without waiting for the invasion of the area by stinger seedlings following treatment.

The treatment of stinger along the lines laid down should facilitate the control of stinger on the area during later treatment.

Tending

When the first germinated stinger on the treated area is one foot (1') high, or as soon as possible thereafter, the area shall be tended to remove stinger and tobacco, and any other weeds competing with required stems or seedlings.

Further tendings should be carried out as necessary and to check on this aspect, the area should be inspected at 6 monthly intervals. At these tendings, competing vegetation of useless species or of Group D should be removed to a radius of 5' from any required stem less than 10' in height. All regeneration of trees in Groups A, B and C is to be retained.

Regeneration

In treated areas that are inadequately stocked with regeneration and where seed bearing trees of seed tree size of Maple, Silkwood, Ash or N. Silky Oak are available, the treatment should be carried out around these trees starting not earlier than 6 months before seedfall and terminating at seedfall as follows:

(a) Brush if necessary to a radius of 100' around seed trees leaving all useful regeneration.

(b) Rake brush into heaps leaving the majority of the surface of the ground free of debris.

Areas so treated are to be kept under observation and if regeneration is secured, then tending on the lines previously laid down for areas subjected to general treatment is to be applied

Underplanting

Following treatment, interplanting of the better species may be carried out in blanks remote from seed trees (i.e. more than 60' from the nearest seed tree).

The spacing for interplanting shall be 12' x 8'.
Areas to be interplanted are not to be burned.

On areas within a compartment where only "C" and/or "D" class seed trees are available, the amount of interplanting may be increased, e.g. planting could be carried out to within 30' of such seed trees.

PRESCRIPTION FOR TENDING REGENERATION ON AREAS WHICH HAVE HAD SILVICULTURAL TREATMENT FOLLOWING TREE MARKING

In this prescription the term "Key" tree is used to signify the stem which is selected as the one best fitted by virtue of species and development to stock the section of the stand under consideration. In selecting the "Key" tree, satisfactory Group A stems are to be unequivocally favoured over Group B and Group B over Group C.

1. No tending of regeneration is to be done within 10' of a Group A or B Species 20' + in height to 60" g.b.h. that has been selected as a "Key" stem. Vine tending of the established species is to be done as necessary.

2. Regeneration under 10 feet

Liberate Group A, B and C by brushing to a radius of 5 feet. As necessary, Group A should be favoured by removal of B and C and Group B by removal of C species.

3. Regeneration 10-20 feet

Brush around the key stem to a radius of 5 feet.

4. Ringbarking

(a) Where Group A or B species occur under the crown of Group D species, the latter is to be ringbarked.

APPENDIX 4.

TENTATIVE LIST OF PREFERRED TIMBER SPECIES

AMAZONIA

		Botanical Name	Value Class (1960)
	1.	Bertholletia excelsa	
	2.	Voucapoua americana	
	3.	Ocotea sp.	
	4.	Tachigalia myrmecophyla	
	5.	Holopysidium jarana	B
	6.	Mezilaurus itauba	C
X	7.	Vochysia maxima	B
X	8.	Manilkara huberi	(A
	9.	" amazonica	(
	10.	Astronium sp.	(B
	11.	" lecontei	(
	12.	Goupia glabra	C
	13.	Virola surinamensis	
	14.	Caryocar villosum	A
X	15.	Carapa guianensis	B
	16.	Copaifera multijuga	
	17.	Lecythis paraensis	
	18.	Didymopanax morotontoni	
	19.	Jacaranda copaia	
X	20.	Cedrela odorata	A
	21.	Aspodospermum desmanthum	
	22.	Hymenolobium excelsum	B
	23.	Eschweilera sp.	
	24.	Couratari spp.	
	25.	Dinizia excelsa	B
	26.	Buchenavia grandis	(C
	27.	Terminalia amazonica	(
	28.	Hymenaea courbaril	
	29.	Symphonia globulifera	
	30.	Simaruba amara	B
	31.	Cedrelinga catanaeformis	
	32.	Clarisia racemosa	
	33.	Cordia goeldiana	A
	34.	Bagassa guianensis	

Botanical Name	Value Class (1960)
35. Dalbergia spruceana	
36. Mora paraensis	
37. Calophyllum brasiliense	
38. Tabebuia serratifolia	
39. Peltogyne paniculata	A
40. Hura crepitans	
41. Macoubea guianensis	
42. Sclerolobium (sp. nova undet.)	
43. Diplotropis martiusii	
44. Parahancornia amapa	
45. Roupala brasiliensis	
46. Vatairea sp.	
X 47. Bowdichia nitida	A
48. Apuleia molaris	
X 49. Platymiscium trinitatis	A
X 50. Euxylophora paraensis	A

Note 1. The felling of Bertholletia excelsa is at present forbidden by law: this is the species that provides the Brazil Nut of commerce.

2. The Value Classes are based on the prices quoted by Glerum and Smit (1960) for timber in Belem in 1960.

Classes are:

A - \$cr 1500 - 2000 per cubic meter
B - \$cr 1000 - " " " "
C - \$cr 500 - 750 " " "

At the time £1 (sterling) = \$cr 560.

1 cubic meter = 35.3 cubic ft.

3. Species marked X are listed by Aubreville (1961) as figuring in the export trade from Amazonia.

BRITISH - METRIC CONVERSIONS

Length

1 inch	= 2.54 cm	1 centimetre	= 0.394 in.
1 link	= 20.117 cm.	1 metre	= 39.37 in.
1 foot	= 30.48 cm.		= 3.281 ft
1 yard	= 0.9144 m.		= 1.094 yds.
1 chain	= 20.117 m	1 kilometre	= 1094 yds.
1 mile	= 1.609 km.		= 49.71 ch.
			= 0.621 miles

Area

1 sq inch +	= 6.451 cm^2	1 cm^2	= 0.155 sq in
1 sq ft	= 0.0929 m^2	1 m^2	= 10.764 sq ft
1 sq yd	= 0.836 m^2		= 1.196 sq yds
1 milliacre	= 4.05 m^2	1 hectare (ha)	= 10,000 m^2
1 sq chain	= 404.7 m^2		= 11958.6 sq yds
1 acre	= 0.4047 hectares		= 2.471 ac.
1 sq mile	= 259 ha.	1 sq km	= 100 ha
	= 2.59 sq km		= 247.1 ac
			= 0.386 sq miles

Volume

1 c inch	= 16.39 ccs	1 cubic sm	= 0.061 c inches
1 c ft	= 0.028 m^3	1 m^3	= 35.31 c ft
	= 28.31 litres		= 1.308 c yds
1 c yd	= 0.7646 m^3	1 litre	= 0.035 c ft

Capacity

1 pint	= 568 ccs	1 litre	= 1.760 pints
	= 0.568 litres		= 0.880 quarts
1 quart	= 1.136 litres		= 0.220 imp galls
1 imp gall	= 4.544 litres		

Weight

1 ounce	= 28.35 gm	1 gram	= 0.035 oz
1 pound	= 453.6 gm	1 kg	= 2.205 lb
1 cwt	= 50.81 kg		= 0.020 cwt
1 ton	= 1016 kg	1 tonne	= 1000 kg
			= 0.984 tons

Other Measures

1 sq ft/acre	= 0.230 m^2/ha	1m^2/ha	= 4.356 sq ft/ acre
1 c ft/acre	= 0.06997 m^3/ha		
1000 c ft/ac	= 69.97 m^3/ha	1 m^3/ha	= 14.30 c ft/ acre
1 lb/c ft	= 16.02 kg/m^3		
1 cord	= 3.625 m^3 or steres	1 kg/m^3	= 0.062 lb/ c ft
		1 stere (m^3)	= 0.267 cords

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