MANAGEMENT INVENTORY

OF

MIXED TROPICAL FORESTS OF BURMA

by

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ORIGINALITY OF THESIS

Except where otherwise acknowledged, the work described in this thesis is my own original work.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The mixed tropical forests of Burma, covering over one half of the land area, are vitally important to the national economy. These forests must be managed more intensively than ever before to meet the increasing demand for wood and wood-based products for both local consumption and export. Hence, there is an increasing demand by management for unbiased and precise inventory data.

The cost of inventorying the tropical forests of Burma is very high and, in this thesis, ways of improving the efficiency of the stratified two-stage sampling method currently applied in Burma are investigated. For both a teak-bearing and a deciduous Dipterocarp forest, the optimum number of sampling units yielding estimates within specified precision levels was determined for the most important subpopulation of a single species by conventional statistical methods. The optimum number of sampling units, in the case of subpopulations of a mixture of species, could not be determined by similar methods and Bard's (1967) nonlinear programming package was used. It is shown that the number of second-stage units can be reduced from 14 in the current inventory to 2-6 with little increase in the number of first-stage units while meeting requirements for an appropriate precision of the estimate. This amounts to a reduction of approximately 50% in the actual cost of inventory.

The main purpose of management inventory is to provide information from which the allowable cut can be determined. Ways of calculating the precision of the allowable cut of teak are examined, taking into account the sampling errors attached to the stand table and time of passage through various girth classes. Owing to the complicated relationship between allowable cut in different felling cycles and the number of trees in the stand table and time of passage in each girth class, a Monte Carlo approach was used to estimate this precision. The effects of sampling errors in the stand table on the sampling error (95% confidence level) of the estimates of the allowable cut for four 30-year felling cycles are indicated. In the first 30-year felling cycle, a standard error of 20% of time of passage in each girth class increases this sampling error in the estimate of the allowable cut by only 3.5%. Although sampling errors of the estimated allowable cut due to sampling errors in the stand table and in the time of passage decrease in later felling cycles, errors in survival per cent in the smaller size classes become much more important in their effects.

The author suggests that research on construction of volume tables, the collection of information on growth and mortality through repeated inventory (including the use of sampling with partial replacement), and the development of growth and yield models for the mixed tropical forests of Burma, is opportune.

INTRODUCTION

Terminology

For the purpose of this study it is necessary to classify various types of forest inventory. Although many types of inventory exist for different purposes, most can be classified into one of three categories (Johnston *et al.*, 1967):

(1) Forest resource inventory

(2) Forest management inventory

(3) Forest operational inventory

A forest resource inventory provides information on the overall potential of a large forested area of a country or part of a country (state) for formulating land-use and forest policy and for general development (Carron, 1968).

Forest management inventory usually supplies information necessary for planning long term management of a particular forest of fairly large area (5 000 to 50 000 ha or more) (Cunia, 1968; Avery, 1975). Ferguson (1963) defines management inventory as:

> "an inventory designed to furnish an overall picture of the extent, nature, condition and productive capacity of the forest without specific detailed location in place. It should be of sufficient intensity to furnish the basis for management planning for the coming period of control and would normally be duplicated at the beginning of each control period".

Forest operational inventory provides a basis for planning operations scheduled for the coming year on small areas of a forest, for example, a group of compartments.

Scope and aim of the study

This study has two major aims, the first being a critical examinati of the management inventory of the commercially important sectors of the mixed tropical forest of Burma.

The second aim is an investigation of ways of improving the efficiency of forest inventory in Burma.

Field inventory in tropical forests is very expensive due to problems of access both to and within the forest and to the great variety of species of varying commercial value. Sampling is usually carried out in stages to reduce the cost of travel. The size of sample and the allocation of sampling units at each stage of the sampling process largely determine the cost of the inventory. Optimum allocation at each stage is essential to reduce cost. However, optimum allocation differs for different species, size classes and precision requirements, and a compromise must be reached. In this study, optimum allocation of first and second stage units is considered for assessing both a single variable and multiple variables in both the teak-bearing and deciduous Dipterocarp forests of Burma.

Metrication

In Burma, imperial units are currently used in the forestry sector and the data available for this study were recorded in those units. Since most countries either have changed or, like Burma, are in the process of changing to metric units, metric conversion was undertaken for this study. However, since the conversion was merely direct e.g. the same girth class interval has been maintained, the results of the calculations are the same as would have been obtained had they been done in imperial units.

CHAPTER 1

THE FORESTS AND FORESTRY OF BURMA

1.1 Physical Features of Burma

Burma has an area of 676 580 sq km and is situated between latitude 10°N and 29°N and longitude 93°E and 103°E. It is bordered in the south by the Bay of Bengal and the Andaman Sea and has land borders with Bangladesh, India, China, Laos and Thailand. About two-thirds of the country is in the tropics.

The country is drained by three main river systems, the Irrawaddy, Sittang and Salween which flow into the Bay of Bengal. The Irrawaddy which is the most important river,has its source in the Himalayas and runs through the middle of the country to the sea in the south. It is navigable throughout the year and forms the most economic means of transport. This applies especially to timber and bamboo which are rafted south to market.

The greater portion of Burma is covered by ranges which divide the country into zones. The elevation of the ranges varies from place to place. The Pegu Yoma ranges which are the site of the best teak forests are situated between the Irrawaddy and Sittang rivers. These ranges have an average elevation of 400 m above m.s.l., but the elevation rises to about 2000-2500 m in the Chin Hills and further north. By comparison, the highest point in Burma, Mount Kakaporazi, is about 6000 m.

Over most parts of Burma, there are three well defined seasons, the rainy season, the cold season and the hot season. The rainy season starts about mid-May and ends in mid-October. The rainy season is followed by cold weather from November to January. The hot season is from February to mid-May with the hottest period occurring before the rains. The annual rainfall varies according to locality. The heaviest rainfalls occur in the coastal regions and range from 3000 mm to over 5000 mm a year. Rainfalls of up to about 3000 mm occur in the hill tracts. The rainfall gradually decreases down to about 760 mm a year in the middle of the country.

The average range of temperature in most parts of the country is from 21° to 32°C in the rainy season, 10° to 30°C in the cold season and 32° to 38°C in the hot season. In central Burma, the temperature can reach 43°C in the hottest months. In some places above 1000 m, frosts occur regularly.

1.2 The Forests and their Distribution

1.2.1 Classification, distribution and area of forests

The forests of Burma cover about 57 per cent of the total land area. All forests are State-owned. They are classified as reserved and unreserved forests. The location of the reserved forests is shown in Fig. 1.1.

The reserved forests are well defined, legally constituted forests under the complete control of the Forest Department. They generally consist of contiguous blocks of forest in the watersheds of rivers and streams away from villages. The reserved forests are usually divided into compartments of about 2-3 sq km in area by natural or artificial boundaries. The area of reserved forests in each forest division is shown in Appendix 1.

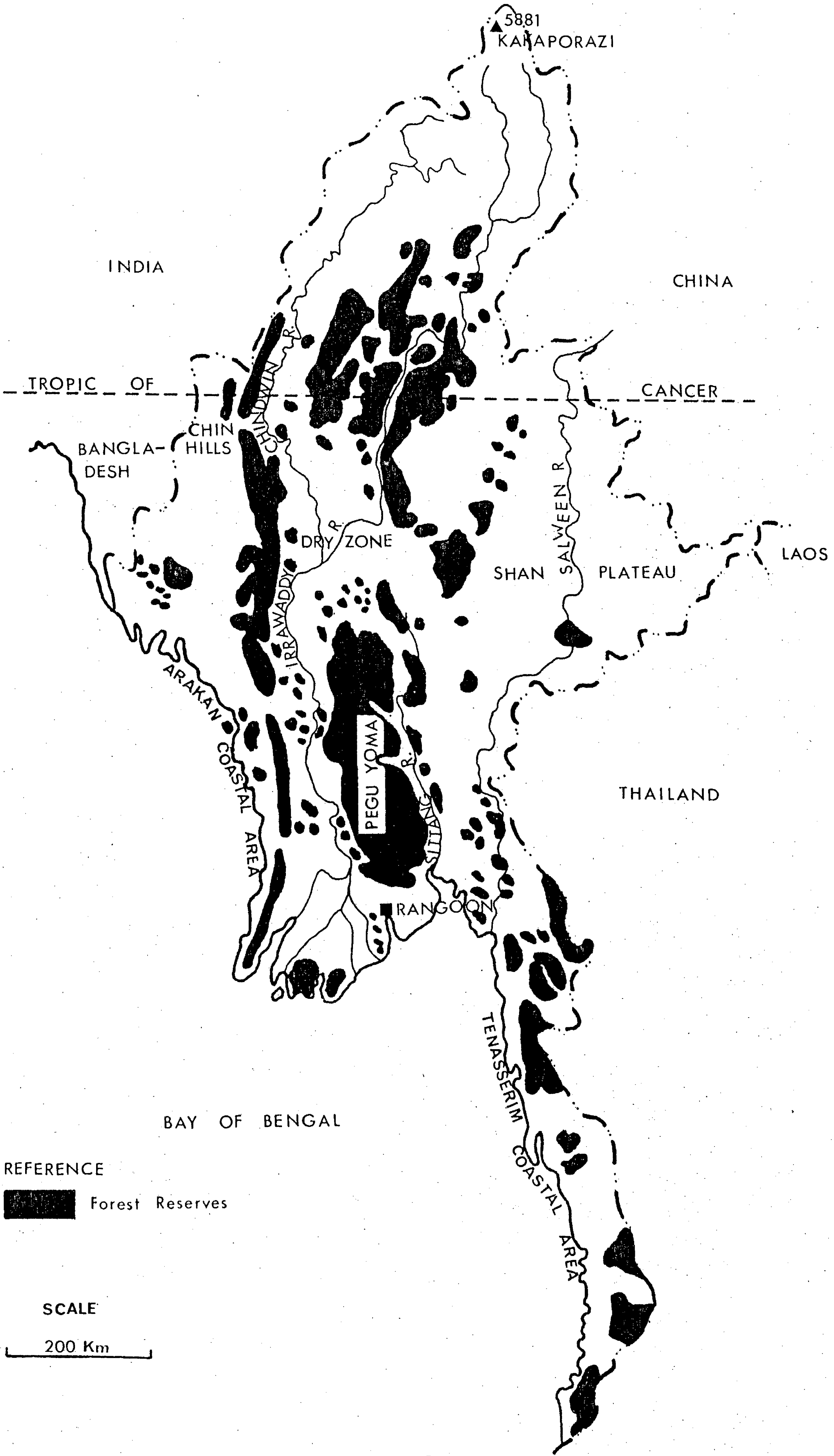

Fig. 1.1. Map showing the reserved forests of Burma

Unreserved forests are those which are not legally constituted and generally have a low production. These forests are also under the control of the Forest Department but the intensity of management and degree of control exercised in these forests are less than in the reserved forests. The local people are allowed to extract forest produce for their domestic, agricultural and piscatorial purposes from these forests, although some hardwood species including teak and certain other commodities are reserved for the Government. The local people are permitted to practise shifting cultivation in these forests, except in special circumstances.

The classification of land area in Burma is shown in Table 1.1.

Table 1.1 Classification of land area

Description of area	Area (sq km)	Percentage
Forested area		
Reserved forest	96 242	14.2
Unreserved forest	291 064	43.0
Non-forested area		
Blanks and regrowth	157 422	23.3
Cultivation etc.	131 852	19.5
Total	676 580	100.0

Source: Working Plan Division, Forest Department, Burma (1972)

The reserved forests which are very important from the protective and productive point of view form 14.2 per cent of the total land area. Over 60 per cent of the teak (*Tectona grandis* L. f.) production comes from these forests. The Government is trying to create more reserved forests for intensive management.

1.2.2 Principal forest types

As a result of the great variation in rainfall, temperature, soil and topography, there are many different forest types in Burma (Fig.1.2). Tropical evergreen forests occur over many parts of the highest rainfall areas in the south of the country. Hill and temperate evergreen forests are found in eastern, northern and western regions where elevation exceeds 900 m. The forest type changes to deciduous, then to dry and thorn forests along the transect towards the middle of the country as a result of decreasing rainfall.

The principal forest types and their relative extent are summarised in Table 1.2.

Table 1.2 The principal forest types of Burma

Forest type		Percentage of total forest area
(1) Tidal forests (2) Beach and dune forests (3) Swamp forests		4
(4) Evergreen forests		16
(5) Mixed deciduous forests		39
(6) Deciduous Dipterocarp or *indaing* forests		5
(7) Dry forests		10
(8) Hill forests		26
	Total	100

Source: Kermode *et al.* (1957)

The most important forest types from a commercial viewpoint are the evergreen, mixed deciduous and deciduous Dipterocarp forests.

Legend to Fig. 1.2

░ (1) Tidal, beach and dune and swamp forests

(2) Evergreen forests

▨ - Giant evergreen forest

▤ - Riverine and typical evergreen forests

(3) Mixed deciduous forest

▒ - Moist upper mixed deciduous forest

□ - Dry and lower mixed deciduous forest

○ (4) Dry forest

▥ (5) Deciduous Dipterocarp (*indaing*) forest

(6) Hill forests

▩ - Hill evergreen and pine forests

▧ - Dry hill forest

● - Alpine forest

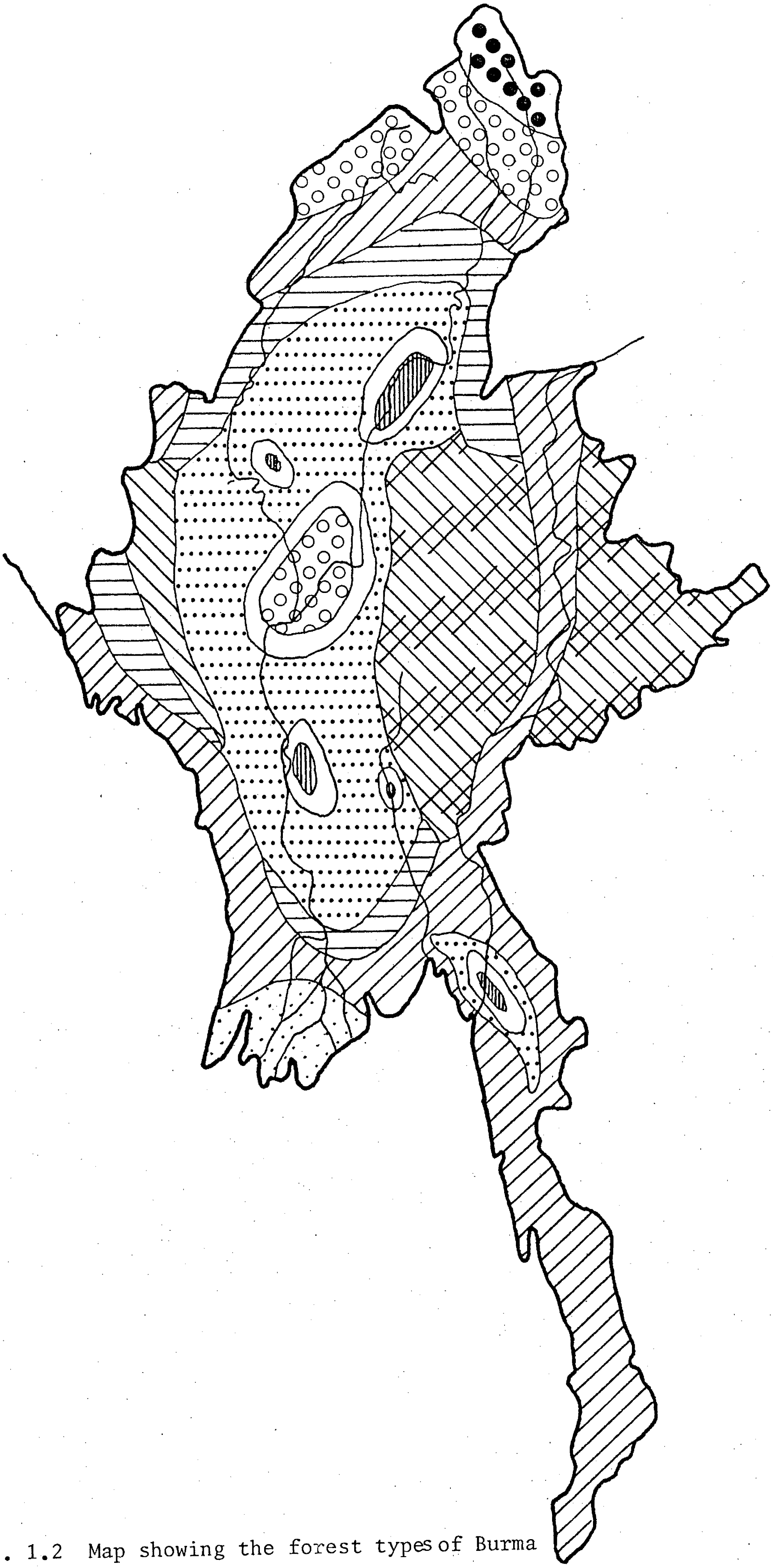

Fig. 1.2 Map showing the forest types of Burma

Evergreen forest

This type occurs in places where rainfall exceeds 3000 mm. It is also found in protected valleys and places with a moist and cool aspect where rainfall ranges from 1500 mm to 3000 mm. There are three sub-types, riverine evergreen, giant evergreen and typical evergreen forests.

The riverine evergreen forest is restricted to the banks of streams and low-lying areas in valley bottoms. It is usually found in southern Burma.

Giant evergreen forest is characterised by tall evergreen trees over a second storey of smaller evergreen trees of numerous species. This type is the common tropical evergreen forest. It usually occurs on hill slopes in the coastal area of Arakan and Tenasserim (see Fig. 1.1).

Typical evergreen forest is characterised by a dense understorey of evergreen trees or by a dense growth of bamboos such as wabomyetsangye (*Dendrocalamus hamiltonii* Nees. ex. Arn.).

Evergreen forests provide a large number of species of commercial importance, amongst which are: kanyin (*Dipterocarpus* spp.), kaunghmu (*Anisoptera scaphula* (Roxb.) Pierre), taungthayet (*Swintonia floribunda*, Griff.), thitka (*Pantace burmanica* Kurz.). Owing to the numerous species and dense undergrowth, it is not easy to carry out forest inventory in these forests.

Mixed deciduous forest

These forests are the most important forests in Burma from the economic point of view. They are divided into two types, upper and lower mixed deciduous forest, on the basis of altitude.

Upper mixed deciduous forests are situated on well drained undulating ground. This type is further subdivided into moist and dry types.

Moist upper mixed deciduous forests are distributed over the greater part of the country where rainfall reaches 1500 to 2000 mm a year. They contain the best quality teak and many other valuable species. This forest type is characterised in lower Burma by the presence of bamboos, kyathaungwa (*Bambusa polymorpha* Munro) and tinwa (*Cephalostachyum pergracile* Munro). In upper Burma, north of the dry zone, kyathaungwa (*Bambusa polymorpha* Munro) is replaced by wabomyetsangye (*Dendrocalamus hamiltonii* Nees. ex Arn.) or wapyu (*Dendrocalamus membranaceus* Munro).

Dry upper mixed deciduous forests are developed on drier soils and ridge tops. The characteristic bamboo species found in this type are myinwa (*Dendrocalamus strictus* Nees), thanawa (*Thyrsostachys oliveri* Gamble) and thaikwa (*Bambusa tulda* Roxi.). Teak is generally more abundant in this type though in smaller sizes than in the moist upper mixed deciduous forests.

Lower mixed deciduous forests are usually found at lower elevation on alluvial soils and are characterised by a scarcity or absence of bamboo. In these forests, teak often occurs in pure stands and in large size but form is usually poor.

These forests are also difficult to inventory owing to the presence of fairly thick undergrowth and bamboos.

Deciduous Dipterocarp or *indaing* forests

These forests are found over extensive tracts throughout Burma. They usually occur in localities where the soil is sandy or gravelly and on lateritic soils up to an altitude of 760 m. This type is characterised by the prevalence of 'in' (*Dipterocarpus tuberculatus* Roxb.) which tends to occur gregariously. The type varies from high forests with tall trees of good size and form to inferior forests with small trees of poor form. This forest type is the easiest to inventory as little undergrowth is present.

1.3 Importance of Forestry in the Burmese Economy

Burma is essentially an agricultural country. The Burmese economy depends very largely on the production of agricultural products, especially rice. The value of net output of each sector of the economy in 1970-71 is shown in Table 1.3.

Table 1.3 Values of net output in Burma in 1970-71

Economic sector	Value (Kyats x 10^6)[1]	Percentage
Production	5 570	52.7
Agriculture	2 897	27.4
Livestock and fishery	803	7.6
Forestry	283	2.7
Mining	93	0.9
Processing and manufacturing	1 229	11.6
Power	62	0.6
Construction	203	1.9
Services	2 278	21.6
Trade	2 709	25.7
Total net output	10 557	100.0

[1] Unit of Burmese currency 1 Kyat = A $ 0.12

Source: Report to the people by Burmese Government, 1971-72

Table 1.3 shows that 35 per cent of the total value of net output is attributed to agriculture, livestock and fishery, 11.6 per cent is from the processing and manufacturing industry, 21.6 per cent from the services sector and 25.7 per cent from trade. In comparison, the forestry sector contributes directly only 2.7 per cent of the total value of net output. The processing and manufacturing industries which contribute a substantial proportion (11.6 per cent), are based on raw materials from agriculture and forestry.

The employment provided by the various sectors is shown in Table 1.4.

Table 1.4 Labour force by economic sector (March 1974)

Economic sector	No. of working population	Per cent of working population
Agriculture	7 716 044	66.3
Livestock & fishery	151 619	1.3
Forestry	147 755	1.3
Mining	61 010	0.5
Industry	829 388	7.1
Power	13 921	0.1
Construction	173 865	1.5
Transportation	405 825	3.5
Social services	203 425	1.7
Administration	306 189	2.6
Trade	1 034 085	8.9
Unspecified	590 711	5.2
Total working population	11 633 837	100.0
Total Burma population	28 870 000	

Source: Ministry of Foreign Affairs, Burma (1974)

Agriculture is by far the most important source of employment. Only 1.3 per cent of the population is engaged in forestry. Much of the agricultural work is seasonal and in the off season many workers are engaged in other sectors, especially in the forestry sector because rural populations are close to the forests. Although the total employment in forestry is small by comparison with that in agriculture, forestry forms an essential part of the Burmese economy.

The forests of Burma supply a large amount of timber and other products such as bamboo, firewood, cane and other minor products to the local economy. Most of the houses in Burma are built from timber and bamboo and they are replaced fairly frequently. Firewood is the major heating material and a vast amount is consumed as fuel.

In developing countries, there is great need for imports of capital goods to develop industry and agriculture, and exports are essential to obtain foreign currency to purchase these goods. The forestry sector of Burma provides a very substantial proportion of the country's exports and its contribution continues to grow. Details of principal commodities exported annually from Burma during 1966-1975 are shown in Table 1.5.

Rice is the most important export. At one time, the country accounted for about 30 per cent of the total world rice export (Anon., 1971). However over recent years the country's rice exports have declined and the export of other agricultural and mining products has been irregular.

Timber has long been the second largest foreign exchange earner of the country after rice. Over recent years, timber exports have shown greater stability than those of other principal commodities. Moreover, they have grown substantially. Today, as an export commodity, they rival rice in importance. The amount of foreign exchange received in 1975 from timber, mainly teak, was 248 million kyats. It accounted for 24.8 per cent of the total export value during that year.

Table 1.5 Details of principal commodities exported annually from Burma during 1966-1975 (mill. Kyat)

Year	Rice & rice products	Other agricultural products	Timber		Mining products	Other commodities	Total
			Teak	Hardwoods			
1966	572	117	166	1	67	8	931
1967	316	106	130	2	25	8	587
1968	242	83	160	*	37	3	525
1969	321	91	147	*	61	5	625
1970	262	89	114	1	43	3	512
1971	298	111	136	3	49	6	603
1972	234	160	165	6	78	2	646
1973	89	210	232	20	118	1	670
1974	394	151	233	9	108	56	951
1975	476	173	240	8	82	22	1001

* Less than 1 million (1 Kyat = A $ 0.12)

Source: Statistical Year Book, Burma 1975

Timber production in Burma (mainly sawlog) by the State Timber Corporation during 1966-1975 is shown in Table 1.6.

Table 1.6 Timber production in Burma over the period 1966-1975 ($m^3 \times 10^3$)

Year	Teak	Hardwood	Total
1966	507	1193	1700
1967	517	1262	1779
1968	530	1178	1708
1969	499	1275	1174
1970	575	1162	1737
1971	602	1095	1697
1972	533	1176	1709
1973	664	1323	1987
1974	467	947	1414
1975	416	769	1185

Source: Statistical Year Book, Burma 1975

Timber production, both teak and other hardwoods, dropped during 1974 and 1975. However, the State Timber Corporation is endeavouring to increase the rate of timber extraction by obtaining aid from international agencies, the World Bank and Asia Development Bank (pers.comm., Forest Department, Burma).

The major difficulty in the expansion of timber production is the difficulty of expanding extraction capacity. The main means of snigging in Burma is by elephant and these animals are in short supply. Mechanical extraction of teak alone is not economical in inaccessible teak forests because the amount of exploitable timber per unit area is very low, about 2-5 exploitable teak trees per hectare (FAO, 1976).

Timber consumption in Burma is rising rapidly with the increase in population. Myint Thein (1973) predicted the demand for sawn timber in Burma in the year 2000 would be more than double that of 1980. Of the timber extracted by the State Timber Corporation, over 90% of hardwoods other than teak is utilised by the urban population (Anon., 1975). Large quantities of timber which are not included in Table 1.6 are also extracted by the rural people from nearby forests for their own housing.

Future exports of timber from Burma are very promising. As mentioned earlier, the vast majority of timber exported is teak, especially the best quality teak, the poorer quality being utilised domestically. The present demand for teak is very heavy. Its popularity is due to its attractive appearance and many other desirable properties. At present Burma is unable to meet the world demand for teak (pers.comm., State Timber Corp. Burma).

There are also possibilities for the expansion of exports of other hardwoods as international demand for wood is increasing rapidly. The world consumption of pulp and paper is also increasing rapidly. King (1975) quotes from an FAO analysis of trends in world consumption of pulp and paper that in 1985 annual consumption will be almost double that of 1973. There are many hardwood species like *Dipterocarpus tuberculatus* Roxb. which are suitable for pulp and papermaking in Burma (Anon., 1970-71). Thus, export of wood chips has good prospects.

Bamboo which can be used as industrial raw material for pulp and paper grows profusely in Burma. It is estimated that there are about 9 million ha of bamboo in pure stands and as undergrowth in Burma (FAO, 1976). One paper mill at present utilises bamboo as a raw material.

Another one is under construction and will be finished soon. The potential of bamboo would therefore be very important to the pulp and paper industry in the near future.

Burma has sufficient forest resources to greatly expand its exports. FAO (1976) estimates that the Burmese forests have the potential for an annual sustained yield of 850 000 m^3 of teak and 2 150 000 m^3 of other commercial hardwoods. At present only about 540 000 m^3 of teak and 1 258 000 m^3 of other hardwoods are extracted (Anon., 1975).

It can be seen that the forests of Burma are very important to the country's economy from the point of view of both export and internal consumption.

As discussed earlier, there is no doubt that more wood and other forest products will be extracted from the forests of Burma in the near future. This calls for more intensive management of these forests. As efficient management planning of a resource is impossible without a continuing flow of up-to-date information, and as little is known about the mixed tropical forests of Burma, efficient forest inventory is now essential.

CHAPTER 2

FOREST MANAGEMENT AND INVENTORY

2.1 Introduction

Systematic management of the forests of Burma began in 1856 when Dietrich Brandis was appointed superintendent of the forest of Pegu Yoma. Brandis inventoried the teak forests under his charge to obtain data for compiling working plans (Schlich, 1925). The number of teak trees by size classes was tallied along narrow striplines laid through the forest. The rate of diameter increment was determined by analysis of annual growth rings on the stumps of sample trees. Using these data, Brandis compiled working plans for the forests and fixed the number of teak trees to be cut annually.

A 25% subjective enumeration of each compartment for the preparation of working plans was started in about the 1880s (Blandford, 1956). The practice of collecting inventory data about teak, by a 100% enumeration during other forest operations, was started in the 1920s and is still practised today. The current method of sampling was introduced in 1963-64 to collect information for both teak and other important hardwood tree species. At present both methods are conducted simultaneously.

2.2 Forestry Administration

Control of forest administration in Burma is shared by the Forest Department and State Timber Corporation both of which come under the Ministry of Agriculture and Forests.

The Forest Department is directly responsible for the management of all forests in Burma. The Department carries out forest conservation works which include natural and artificial regeneration of important species, improvement felling[1], girdling of teak[2] and marking of other hardwoods for extraction. The Forest Department determines the annual allowable cuts for teak and other hardwoods in consultation with the State Timber Corporation. Revenues are collected from all parties engaged in extraction including the State Timber Corporation.

The organisation of the Forest Department is shown in Fig. 2.1. The Director-General heads the Department. Under him, there are eight Directors, six in charge of the territorial forest circles and two responsible for planning, research and training. Each forest circle comprises four to seven forest divisions, each headed by a Deputy Director. Each forest division includes four to six ranges depending on the intensity of management. Each range is administered by a Range Officer assisted by a number of Deputy Rangers and Foresters.[3] Within a range there are several beats. A Forester is responsible for the supervision of forest management operations in each beat.

Planning is the responsibility of a Director assisted by three Deputy Directors. Two Deputy Directors are assigned for revision of Working Plans and teak yield regulation for the whole of Burma. The third Deputy Director is responsible for inventory.

Forest research work and training are the responsibility of a Director. There are presently three research sections, namely Economics, Silviculture and Timber Research. The forest school is situated in Maymyo,

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[1] Felling of less valuable species to improve young stands of valuable species, mainly teak.

[2] Teak trees are girdled before felling and extraction

[3] Forester is the lowest rank of forest service in Burma

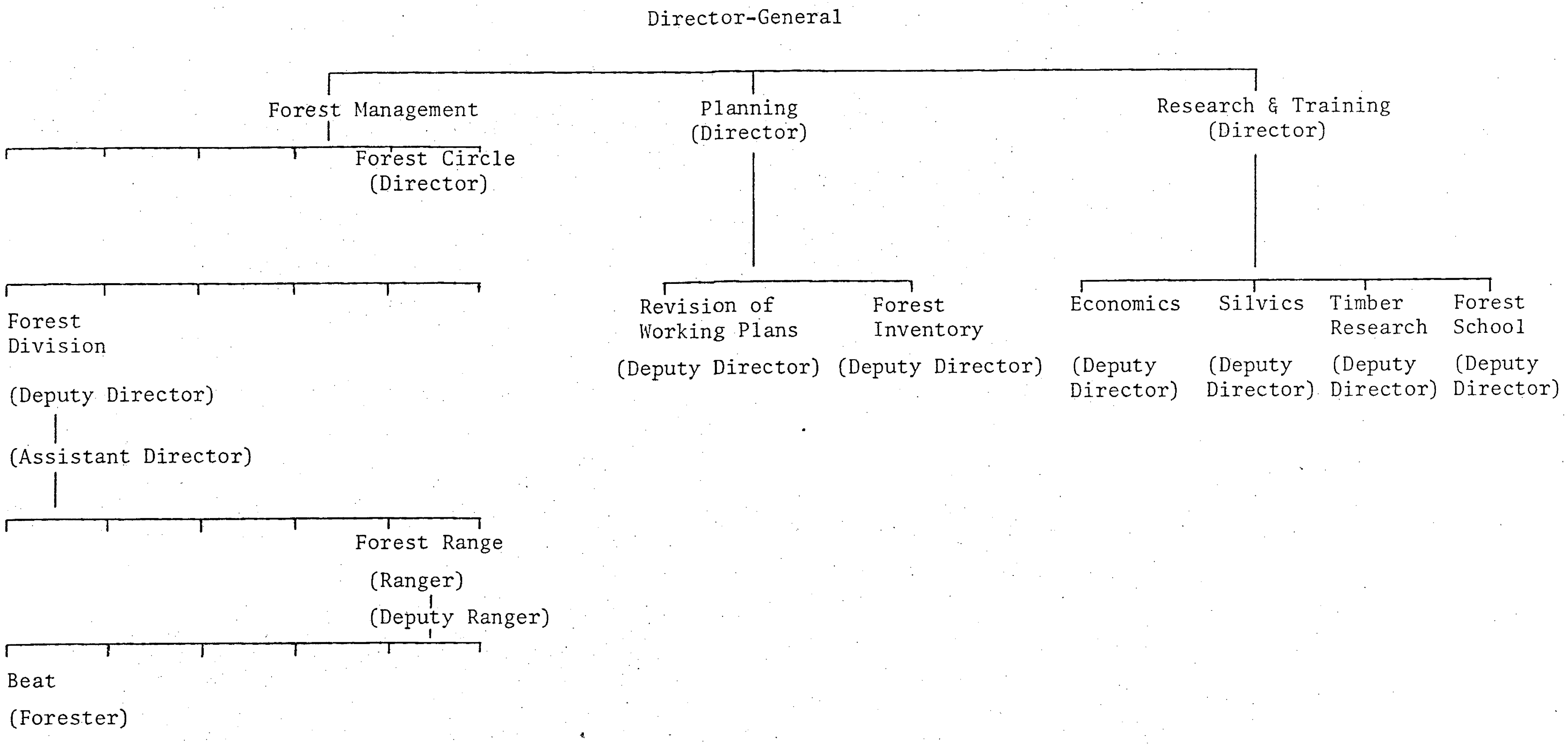

Fig. 2.1 Organisation of the Forest Department in Burma

northern Burma and trains Forest Rangers. A Forest Research Institute, currently being established in Burma with the aid of funds from the UNDP (United Nations Development Program) will be part of the Research and Training Division.

The State Timber Corporation, which is responsible for the extraction, milling and marketing of timber for both internal consumption and export, plans its operations based on information supplied by the Forest Department.

2.3 Forest Management Practice

2.3.1 Working circles

The forests in a forest division are managed under a Working Plan which generally covers three working circles, namely:

(1) teak selection working circle (TSWC)

(2) commercial supply working circle (CSWC)

and (3) local supply working circle (LSWC).

Table 2.1 summarises the area of reserved forest managed under these working circles in Burma.

Table 2.1 Classification of forest reserves into working circles (mill. ha)

Working circle	Separate from TSWC	Overlap with TSWC	Total
Teak selection working circle	-	-	5.92
Commercial supply working circle	0.90	1.53	2.43
Local supply working circle	0.32	1.65	1.97

Source: Thein, FAO, 1959

The total area of reserved forests under TSWC is 5.92 mill. ha,of which 3.18 mill. ha is overlapped with CSWC and LSWC.

The TSWC includes all teak-bearing forests. Complete extraction is possible. Teak logs from any part of the forest can be floated downstream. All teak extraction is organised under this working circle.

Forests included in the CSWC are those situated close to the main transportation routes such as railway lines, main roads and main rivers. The extraction of all marketable hardwoods other than teak is organised under this working circle.

Forests readily accessible to the local population are usually included in the LSWC, the purpose of which is to supply firewood and small timber for local consumption.

2.3.2 Timber extraction

Operations in each working circle are generally organised independently of each other. This also applies in areas where the working circles overlap.

The TSWC is generally divided into four to six felling series, each of which is again subdivided into 30 annual coupes of approximately equal yield capacity.

Harvesting is based on the selection exploitation system. All marketable teak trees which have attained the prescribed gbhob limit are measured and selected for extraction. The girth limit varies with the type of forest. In good (moist) teak forest the limit is 2.3 m and in poor (dry) teak forest, it is 2.0 m. Evergreen, moist upper mixed deciduous and lower mixed deciduous forests are considered to be good teak forest while dry upper mixed deciduous forest is considered to be poor. Some large teak trees are retained as seed bearers if natural regeneration of teak is absent. Defective teak trees which have not attained the prescribed girth limit are also selected for extraction provided they are marketable.

Teak is generally girdled 3 years ahead of felling and extraction. Girdling kills the tree and by the time of felling and extraction the wood is partly dry. This has two advantages:

(1) less damage is caused at felling;

(2) the logs float easily: this permits transport to the mill by water which greatly reduces cost.

Girdling of teak is the major operation of the Forest Department. The girdling officers explore all parts of the forest in the annual coupe looking for exploitable trees. Enumeration of ungirdled teak trees (described in Section 2.4) is usually performed at the time of the girdling operation. The girdling officer prepares a report comprising:

(1) a table giving the number of trees girdled and left in each girth class;

(2) maps showing forest types, and positions of teak trees girdled;

(3) cost of the operation;

(4) information to assist the extraction crews.

The State Timber Corporation extracts all girdled teak trees three years after girdling. The logs are snigged to streams by elephants and floated down the streams in the rainy season. They are formed into rafts at stations in the main rivers and towed by motorboats to Rangoon.

A selection system is also applied in the CSWC. Marketable species other than teak are selected on the basis of a gbhob limit which varies with species from 1.5 to 2.4 m. Selected trees are marked with a blaze and serial number and are felled and extracted the following year. The logs are trucked to nearby sawmills, railway lines or main rivers. In some areas, logs are made bouyant using bamboo and other materials and floated downstream to the mills.

Before 1963, the State Timber Corporation extracted only teak, extraction of other hardwoods being left to private agencies. In forests where the TSWC and CSWC overlapped, this extraction took place some one to three years after the teak was harvested.

Today, the State Timber Corporation extracts both teak and other hardwoods, but the two product types are still harvested separately even though simultaneous extraction would reduce costs. One reason for doing so is that there would be a shortage of food for the many elephants which are required for snigging of logs in one area, if both teak and other hardwoods were harvested at the same time.

Yield per ha of both operations is very low. FAO (1976) estimated that about 7-12 cuttable trees (29-48 m^3) per ha occur in these natural mixed teak forests of which 2-5 trees are teak (6-16 m^3).

The forests under LSWC are situated in the thickly populated areas. The silvicultural system usually adopted in these forests is coppice with standards. The Forest Department controls extraction by the local people but otherwise there is little active management.

2.3.3 Burma selection system

In both the TSWC and CSWC, silvicultural practice involves harvesting the marketable trees and undertaking improvement felling and other cultural operations. It is known as the Burma Selection System. The cultural operations include cutting climbers, thinning young overstocked stands of teak and cutting back undesirable teak stems with the object of producing straight coppice shoots. These stand improvement operations are usually carried out either at the time of girdling marketable teak or after extraction. The operations may be repeated 10-15 years later, depending on the locality and availability of funds and staff.

2.4 Forest Inventory Practice

In Burma, forest inventory for management planning is generally associated with other forest operations. Complete enumeration of all trees down to a particular gbhob limit (e.g. 1.22 m gbhob) is the usual method of inventory. It is obviously very expensive and a long time elapses before a clear picture of the whole felling series is obtained because the felling cycle is 30 years. Measuring marketable species to lower girth limits is impracticable. Consequently, forest inventory, using modern methods of sampling, has been tried in recent years.

2.4.1 Complete enumeration

In the TSWC, complete enumeration of ungirdled teak trees at the time of girdling was begun in 1920-21 (Stebbing, 1962). At first, the lower limit enumerated was 1.83 m gbhob but the limit was later reduced to 1.22 m gbhob which is the limit still in use.

A complete enumeration of marketable hardwood species above a certain gbhob limit is also made in the CSWC. However, because of the many species involved, the lower limit could not be reduced to that for teak. Only marketable hardwood species 0.3 m below the exploitable gbhob limit are measured and recorded. This is done at the time the stand is marked for felling.

When the annual girdling operation is finished, the Deputy Director of each Division compiles a summary table of the teak trees, both girdled and left, in each compartment and felling series and sends it to the Director of Planning. These data are recorded in the registers of the working plan circle for revising the working plans.

2.4.2 Partial enumeration

The information gathered at the time of tree selection by 100% enumeration in both the TSWC and CSWC under the present system has proved to be inadequate for efficient management planning because it does not cover the smaller size classes of the growing stock. More precise and up-to-date information for both teak and other hardwood species is required in a shorter time at more reasonable cost. This was recognised in the early 1960s and prompted the first trial of modern forest inventory, using stratified two-stage sampling which was conducted in 1963-64 in Minbyin forest reserve, Pyinmana Forest Division. Large second-stage sampling units of area about 100-300 ha were used. Subsequently (1964-67) large scale forest inventories, using a modified version of this design were carried out in four forest divisions, but these had theoretical and practical shortcomings (Myint Tin *et al.*,1973). Consequently, a further two-stage sampling method called 'stratified replicated sampling' was introduced in 1968-69 and is still practised. The method is described below.

<u>Stratification</u>

A forest reserve or group of reserves for which tree or stand estimates are required is stratified into blocks of equal size using the following aids:

(1) aerial photographs enabling forest type and productivity to be assessed visually;

(2) stock maps[1];

(3) previous inventory data if available;

(4) contour maps - showing topography and accessibility;

(5) general information supplied by the local forest staff.

Scales of aerial photographs available in Burma for forest inventory purposes are mostly 1:20 000 and 1:50 000 which enable non-forested areas and a few forest types to be distinguished.

Stratification based on natural features of the forest, e.g. forest type , is impossible due to the restriction that blocks must be equal in area. The average size of a block is 6000 ha and the number of blocks is usually 2-6 depending on the area of the reserve.

Selection of sampling units

A transparent grid of squares, each representing the same area as that of a first-stage unit drawn at a scale of 1:63 360, is superimposed on the map of a block of the same scale (Fig. 2.2). All possible first-stage units are marked on the grid and counted. The units are square in shape except those near the block boundary and all must be approximately the same area. The number of first-stage units counted must be equal to the theoretical number of first-stage units obtained by dividing the area of a block by the area of a first-stage unit. The required sample of first-stage units is selected at random from each block, an equal number being selected per block. The sample units together with their order of selection, are marked on the map.

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[1] Maps showing forest types and occurrence of species

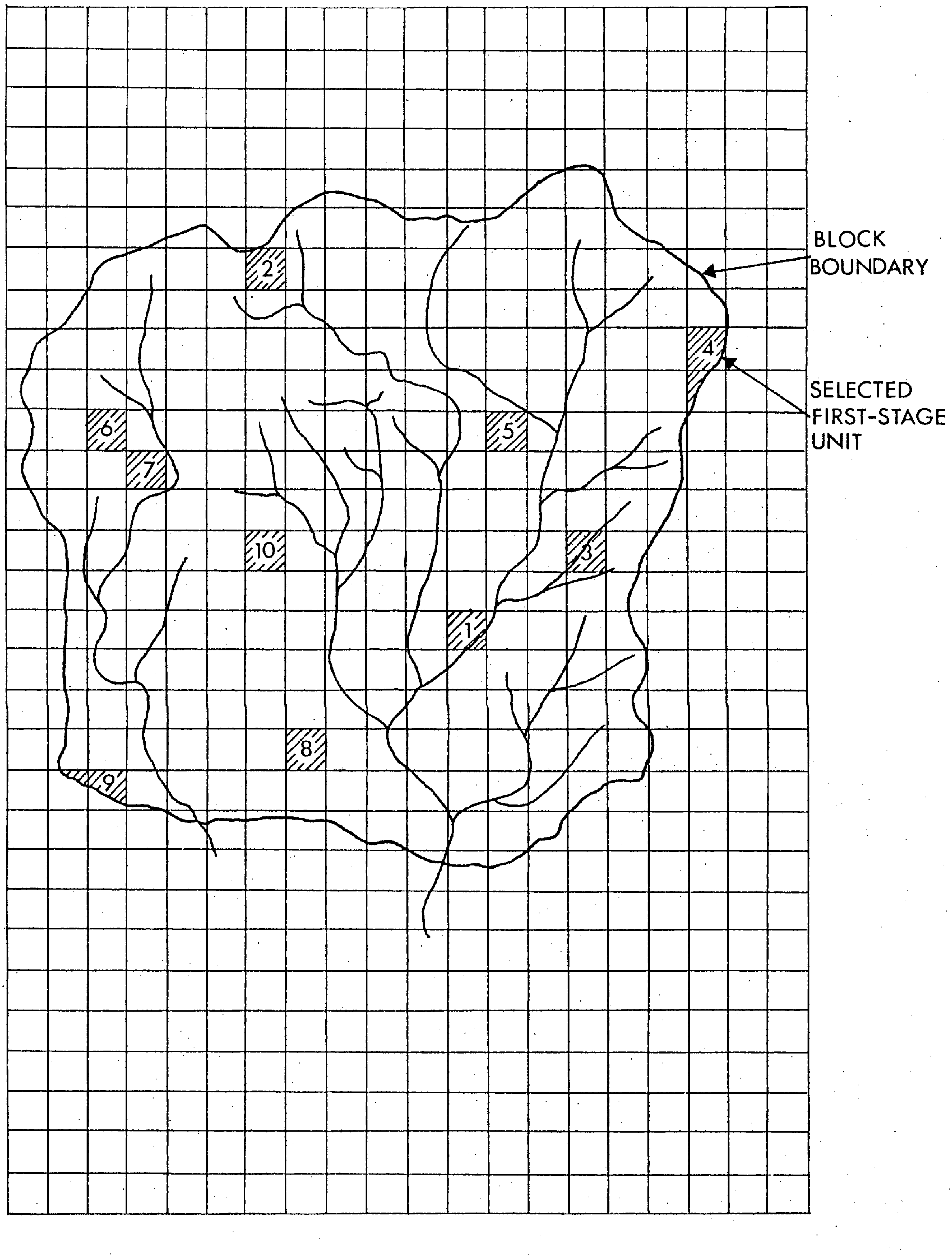

Fig. 2.2 Selection of first-stage unit

Within each first-stage unit of the sample, an equal number of circular plots of 9.1 m (30') radius is laid out systematically at 21.3 m (70') intervals along straight lines equidistant from one another (Figs. 2.3 and 2.4). The number of circular plots in a first-stage unit is varied in different forest inventories by varying the intervals between lines.

Statistical analysis

In calculating estimates of the population parameters of the forest, sampling units from different blocks are combined using the principle of a randomised block design. Units selected in the first draw from each block are combined and, similarly, those selected in the second draw, etc. Calculations (Kish, 1965) are summarised below:

Let L be the number of blocks in a reserve, X be the area of a block and N be the number of possible first-stage units in it. As the areas of the blocks within a reserve are almost equal, the number of possible first-stage units per block is equal. Out of this total of N first-stage units per block, n units are selected at random without replacement.

Let y_{ij} be the value of y (e.g. number of trees of a species in a gbhob class) in all second-stage units (circular plots) of a first-stage unit selected from the i^{th} block at the j^{th} draw.

The estimate of the total value of y in the reserve is

$$\hat{Y} = \frac{X}{nx} \sum_{i=1}^{L} \sum_{j=1}^{n} y_{ij} \qquad (1)$$

where x = the total area of second-stage units within a first-stage unit.

In calculating the variance, each combination of the draw is treated as an observation. Although the design is a two-stage sample,

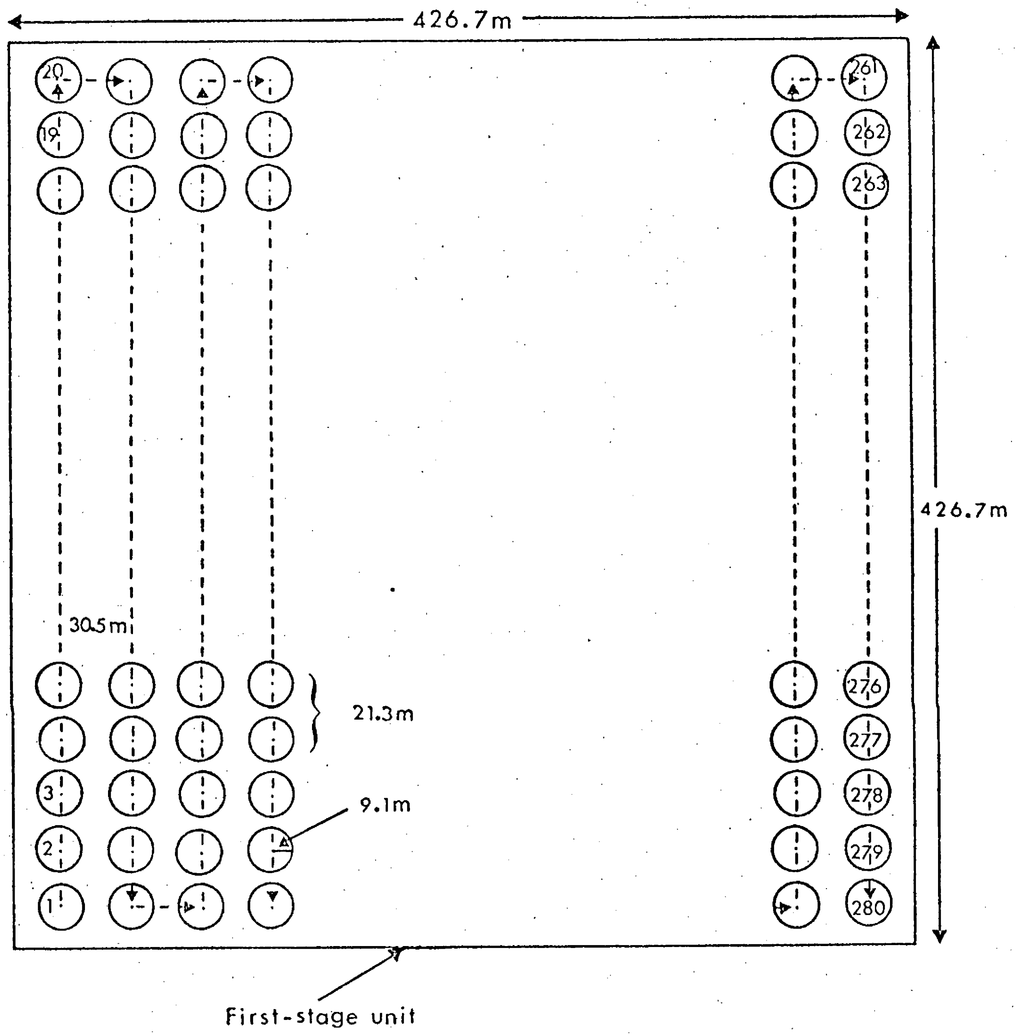

Fig. 2.3 First-stage square sample unit with circular second-stage units

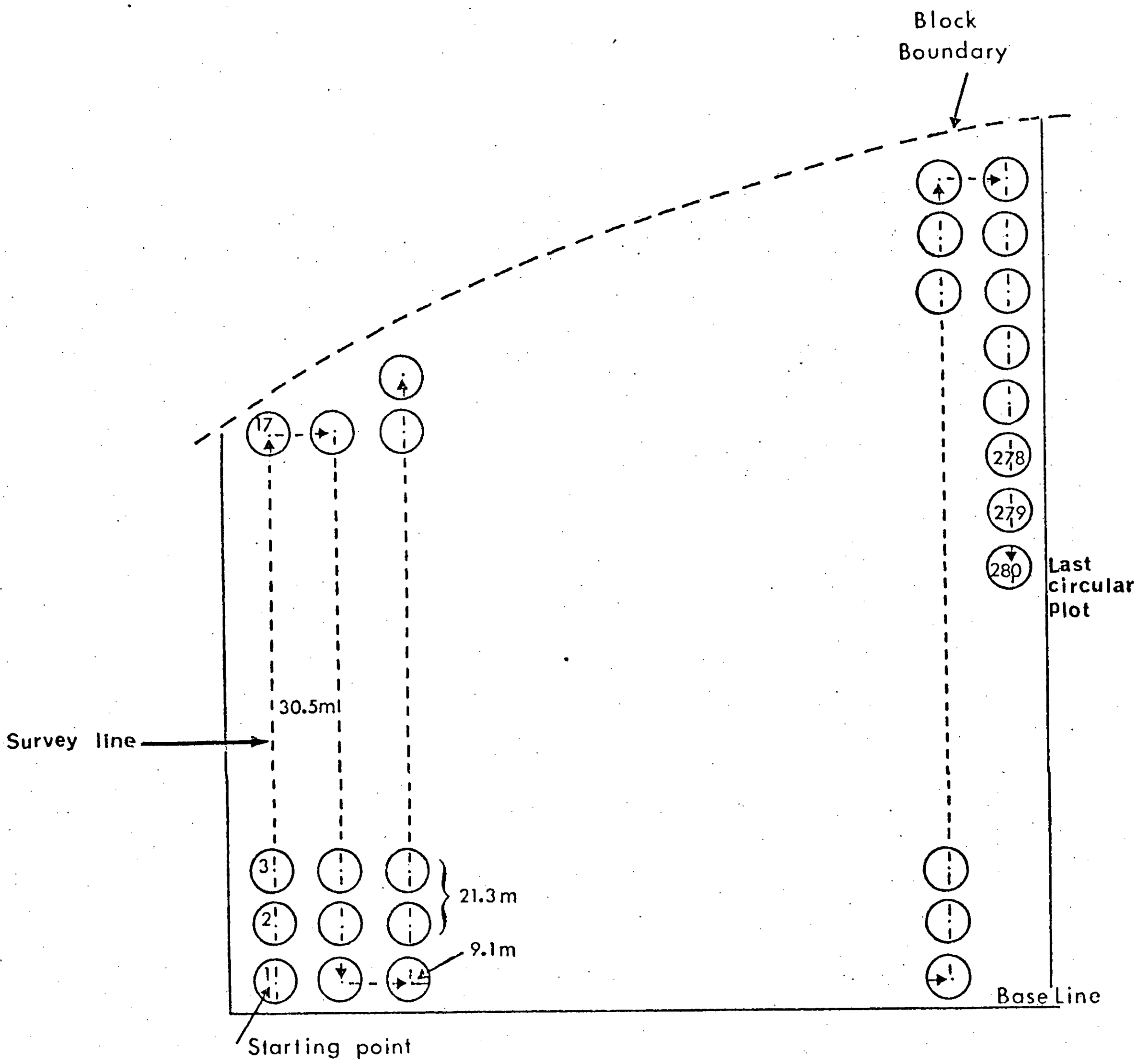

Fig. 2.4 First-stage irregular sample unit with circular second-stage units

computation of variance is carried out ignoring the variation due to second-stage sampling which is negligible because the number of second-stage units is large (Myint Tin *et al.*, 1968-69).

The estimate of the variance of the population is:

$$\hat{V}(\hat{Y}) = \left(\frac{1}{n} - \frac{1}{N}\right) \frac{L^2\, X^2}{x^2(n-1)} \sum_{j=1}^{n} (\bar{y}_{\cdot j} - \bar{y})^2 \qquad (2)$$

where $\bar{y}_{\cdot j} = \frac{1}{L} \sum_{i=1}^{L} y_{ij}$ = mean of units selected at j^{th} draw

$\bar{y} = \frac{1}{n} \sum_{j=1}^{n} \bar{y}_{\circ j}$ = grand mean

Location of units in the field

The position of the first circular plot, or starting point for enumeration in a first-stage sample unit, is located in the field by reference to prominent points on the map such as boundary pillars, junctions of streams, etc. so that it is easily identifiable on the ground. Once this point is located, the systematic grid of second-stage units is laid out either in a north-south or east-west direction as directed.

The boundaries of the first-stage units are not demarcated in the field. The number of second-stage units per line is constant in square first-stage sample units (Fig. 2.3) but varies in irregularly shaped units (Fig. 2.4). However, the total number of second-stage units is the same in each.

Procedure in each second-stage unit is as follows:

(1) all sound and unsound trees greater than 0.61 m gbhob are enumerated and grouped by species or as a combination of species (Appendix II) into 0.15 m gbhob classes;

(2) radial increment at breast height is measured by increment borer on two teak trees within each girth class, being the first trees met within the enumeration;

(3) natural regeneration of teak and other important species is assessed on four 1.8 m quadrats laid out systematically about the centre of each unit;

(4) bamboo is enumerated by species and age class.

The field work is usually done in winter between November and February. Field crews take about one day to locate the starting point of each first-stage unit and 3 to 5 days to complete the full enumeration. Cost averages about 1.19 kyats per ha for the whole inventoried area (Myint Tin *et al.*, 1968-1973).

Field organisation

At present, about 121 500 ha of Burmese forests are inventoried each year. Each field crew usually consists of a Deputy Ranger who leads the party, two foresters and 6 labourers. One of the foresters, assisted by three labourers, cuts survey lines and marks the centres of the circular second-stage units with bush pegs.

The Deputy Ranger, assisted by a forester and two labourers, follows behind recording the necessary information on each plot. One labourer remains in camp as camp attendant.

Data processing

Up to 1975, all data processing was done manually using desk calculators. Summaries of the sample data were prepared by leaders of the field parties and forwarded to the officer in charge of the field organisation. The collected data were checked thoroughly at the base camp when the annual fieldwork was finished. Estimates and their precision were calculated at the forest headquarters in Rangoon. Processing involved approximately four months' work.

In 1973, a fairly large electronic computer was installed in the Rangoon Arts and Sciences University with aid from UNESCO. Although the computer centre was set up especially for the University, other Government departments were granted access. In view of the advantages of electronic data processing, a test run using forest inventory data was carried out successfully on this computer in 1974. Since 1975, all processing of inventory data has been done using this computer.

CHAPTER 3

REVIEW OF SAMPLING DESIGNS USED IN INVENTORY OF MIXED TROPICAL FORESTS

3.1 Introduction

Tropical forests cover a total area of approximately 19 million square kilometres or 14% of the world area and slightly less than half of the world forested area (Howard and Lanly, 1975). They consist generally of a great number of species of different sizes ranging from seedlings to mature trees. Only a few species are commercially important. The stocking of the larger trees of these species (assessment of which is usually a prime object of inventory) is often low, sometimes less than five trees per hectare (Loetsch and Haller, 1964). Loetsch and Haller (1964) point out that -

> 'The simplest and safest method of making inventory of such populations is by complete enumeration, which, however, is rarely done because of the many difficulties and the high cost .... The only practical alternative .... is the application of sampling methods which are capable of producing for the least cost, a tolerable estimate of tree population'.

The choice of sampling method depends on a number of factors e.g. the purpose of the inventory, the variability of the forest to be inventoried, the precision of the estimates required and time and money available. No particular inventory design is best for all tropical forest inventories. This is borne out by the wide variety of sampling designs which have been used (Nyyssönen, 1961). Husch (1969) points out that sampling designs in use in a given tropical forest area are, to a large extent, the result of inheriting earlier methodologies developed by prior workers in the region. In this chapter, some of the common sampling designs used in tropical forest inventory are reviewed.

3.2 Simple Random Sampling

Simple random sampling or unrestricted random sampling is the basic type of sampling and, from it, many other sampling methods are developed. In simple random sampling, it is required that in choosing a sample of 'n' units out of a total of 'N' units, every possible combination of 'n' units has an equal chance of selection. In practice, the sample is drawn unit by unit and can be done with or without replacement. If the sampling unit is replaced in the population after each draw, the method is known as sampling with replacement and is equivalent to selecting from an infinite population. In sampling without replacement, a particular sampling unit is allowed to appear in the sample once only - this is equivalent to selecting from a finite population. If the ratio of sampling units selected without replacement to the total number of sampling units in the population is small there is little difference between the two methods. Most forest inventories apply sampling without replacement.

Simple random sampling gives an unbiased estimate of the population mean and of the variance of the sample mean from which an unbiased estimate of the variance of the population can be calculated. It is rarely used in mixed tropical forests which are highly variable, because at the sampling intensities which are practicable, precision of the estimates is low.

3.3 Stratified Random Sampling

In simple random sampling, it is assumed that the means of samples of the same size drawn from a population tend to be normally distributed if the samples are above a certain size, even if individuals of that population are not normally distributed. Cochran (1963) states that good sampling practice tends to make the normal approximation more valid. It will deviate from the normal approximation mostly when the population contains some extreme individuals which dominate the sample average. These extremes markedly decrease the precision. It is desirable to segregate them from the main population to improve the normal approximation and hence increase the precision. This can be done by separating the population into strata and sampling at random within each stratum. This technique is called stratified random or restricted random sampling. The basic idea of stratification is to reduce the variation of the variable of interest within each stratum and so increase the precision of the population estimate.

Stratification is commonly applied in inventory of mixed tropical forests which by nature are very heterogeneous. It is usually based on information from aerial photographs and data from previous and pilot surveys. Loetsch and Haller (1964) and Husch, Miller and Beers (1972) affirm that it is possible simply to divide large tropical forests into blocks of regular shape if a more suitable basis for stratification is not available. Geometric stratification is better than simple random sampling simply because it gives a potentially better distribution of the sampling units.

Carron (1968) states that the most effective stratification is usually one using criteria with which the characteristic under study is correlated. A major value of stratification is the possibility of weighting the sample distribution to each stratum by various criteria. Proper use of stratification reduces the cost of inventory for a given level of precision or increases the precision for a given cost compared with simple random sampling (Bickford, 1961).

Dawkins (1957, 1958) applied stratified random sampling in the tropical forests of Uganda. He found that stratification based on forest type maps and topographic maps produced from aerial photographs greatly increased the efficiency of sampling. Purposive blocks or strata, theoretically rectangles of width $\frac{2}{f}$ x 20.1 m (one chain), where f is sampling fraction, and from 0.8 to 5-6 km in length were superimposed deliberately on the map. Careful siting of the blocks was necessary to increase the total efficiency of the sampling method. The reliable minimum estimate (RME) or lower confidence limit at the 5% probability level was calculated.

In Liberia, a restricted one-stage random sampling was used in the inventory of national forests (Loetsch, 1975; Fumbah, 1975). Square blocks varying in size according to the forest conditions, were the primary units. The blocks were treated as strata. In each block, two sampling units called tracts were selected. The side length of the square tract was 400 m with 10 circular plots of 0.05 ha on each side. Hence, the total area of one sampling unit, called a satellite system, was 2 ha. In each sample plot, all trees of dbhob 10 cm and above were enumerated. A total of 90 species was recorded and classified into 7 species groups. Merchantable volume of trees greater than 40 cm dbhob in each species group was estimated.

In India, a bamboo pilot survey was tried in four compartments of Bori range, Hoshangabad division, by using the method of stratified random sampling (Chacko *et al.*, 1965). The compartments were first divided into sub-compartments which could easily be located in the field. The areas of the sub-compartments ranged from 10-48 ha. All bamboo clumps within each sub-compartment were numbered and each set of 40 or 100 clumps was treated as a separate stratum from which a sample of two clumps was selected at random. The mean number of culms per clump and its standard error were estimated for each sub-compartment and the whole area.

On the assumption that all the clumps selected at random for all the sets of 40 and 100 clumps in a sub-compartment formed a simple random sample of the total population, the estimate of the mean number of culms per clump and its standard error were recalculated. In the majority of cases, the estimates obtained by using the stratified random sampling were more precise than those obtained by simple random sampling.

3.4 Multiphase Sampling

Multiphase sampling is designed with the object of minimising the cost of inventory without affecting the precision. Two-phase sampling, also called double sampling, is commonly used in forest inventory. In the first phase, a large sample is taken for the auxiliary variable X to get a precise estimate of its population mean or total. A small sub-sample of the previous sample, where both the auxiliary and main variables X and Y are measured, is taken in the second phase. The regression between the variables X and Y is then developed and this relationship is applied to the large sample mean or total of X to obtain the estimate of the population mean or total of Y.

In Laos, a double sampling design called 'double sampling for regression' was used in the reconnaissance survey of the forests (Anon., 1969). Photo-plots were systematically spread over the whole forest and their photo parameters were observed. To determine the regression function the required parameters were measured in representative forest areas in the field. The model used was:

$y = f(x) + e$

where y = the primary variable e.g. volume per ha of a sample plot

x = the auxiliary variable - a photo-parameter of the sample plot

f = a regression function which connects the two variables

e = random component.

The volume per ha was estimated for each main forest type using the regression functions.

3.5 Multi-stage Sampling

Another modification of simple random sampling is multi-stage sampling or sub-sampling. In multi-stage sampling, the sampling units of a population are divided into smaller units, each of which in turn can be further subdivided, and so on. The sampling process is carried out in stages independently. The selection of sampling units in each stage may be at random or systematic.

The advantage of multi-stage sampling is the concentration of assessment work close to the locations of chosen primary sampling units rather than spreading it over the entire forest area to be inventoried. Besides, such a layout simplifies the planning and organising of field work and necessary supervision and control.

Two-stage sampling is also common in forest inventory. It frequently gives estimates of a required precision at lower cost than for mono-stage sampling (Husch *et al.*, 1972).

In tropical forests, it is very difficult to move from one place to another especially in rough terrain, due to both poor access and poor communications. The cost is high especially if the sampling units are widely distributed over the forest. Therefore sampling units are often clustered or grouped to minimise the cost of travel and to exercise better control of field work. In this case, each primary unit is considered to be a cluster of secondary units. The work is concentrated within the selected primary unit.

A method of forming tracts as sampling units was applied by Loetsch (1957) in inventorying the northern teak bearing forests of Thailand. Aerial photographs of average scale 1:48 000 were used in the stratification. The method is especially designed for field parties to concentrate their work around a particular camp and it is therefore called the camp-unit system. The camp was composed of seven camp-units, each unit comprising seven square tracts (400 m x 400 m) (Fig. 3.1).

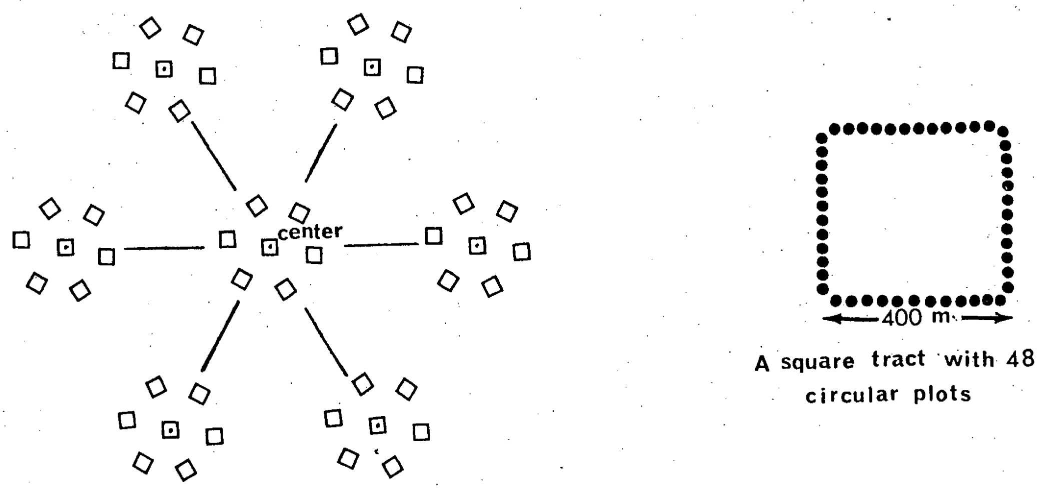

Fig. 3.1 The camp-unit system

Along the sides of each tract, 48 circular plots each of 0.05 ha (radius 12.61 m) were equally distributed. The distance from the camp centre to the furthest circular plot was 5 km and that from the centre to the first corner of a tract was 1 km. The camps were distributed throughout the forest by restricted random selection.

The national forest inventory of Cambodia was carried out using aerial photographs for forest stratification and ground measurement for tree data (Cunia, 1974). The ground sample was systematically distributed on a square grid pattern. Plots were 16 km apart and consisted of clusters of four circular sub-plots. Each sub-plot in its turn consisted of two concentric, circular sample areas. Small trees, saplings and seedlings were measured and recorded in the smaller circular plots and all trees above 30 cm dbhob were measured in the larger plots.

In India a two-stage sampling design was applied in the inventory of resources of *Boswellia serrata* in Madhya Pradesh (Mathauda, 1957). The species formed only a small proportion of the total growing stock and was distributed over an area of over 50 000 ha. In the first stage, a 10% random selection was made on the basis of compartments. Within each of the selected compartments a systematic line plot survey of 1% intensity was conducted using rectangular plots 0.2 ha in area. The intensity of sampling within the total area was only about 0.1%.

According to Cunia (1974), a two-stage cluster sampling design was applied in inventorying the large forests of French Africa (several million ha). Estimates were calculated for blocks of several hundred thousand ha. The first-stage sample consisted of square forest areas of 2 000 to 5 000 ha. Selection of sampling units was done at random in the first-stage and at random or on a systematic basis in the second stage.

In Burma, two sampling methods, (1) stratified two-stage sampling and (2) stratified replicated sampling have been applied in inventorying the natural tropical forests. Stratification in both methods is based on aerial photographs and other available information.

Stratified two-stage sampling is considered suitable for hilly areas where topographical maps of about 1:15 000 scale are available. In each stratum, first-stage units of area about 400-800 ha are formed by combining two neighbouring and, if possible, heterogenous compartments. The required number of first-stage units is selected at random. Each selected first-stage unit is divided into 8 sampling units (4 units in each compartment) with natural boundaries (topographical plot). The sampling units of average size about 80 ha are numbered from 1-4 in each of the two compartments in such a way that units which bear the same number are as heterogenous as possible (Fig. 3.2). Then, 2 out of the 8

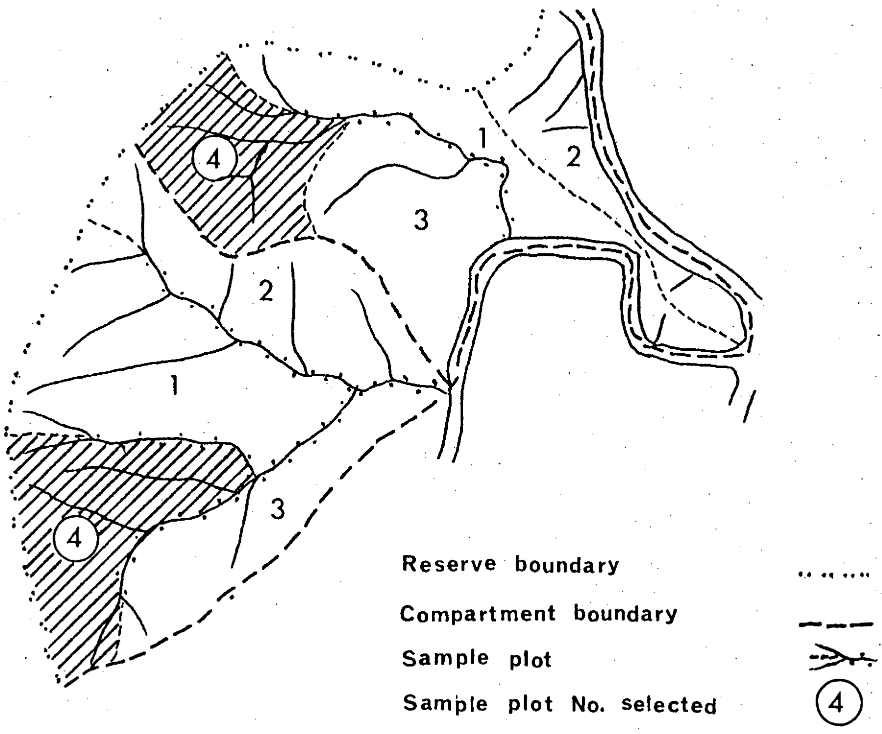

Fig. 3.2 Topographical plot

sampling units are selected for the second-stage sample by systematic sampling.

In each second-stage sampling unit, a complete enumeration of trees greater than 0.6 m gbhob is made and data are recorded by species or groups of species into 0.15 m gbhob classes. Radial increment at breast height is determined by increment borer on two teak trees in each 0.15 m class. Natural regeneration of teak is counted on two strips 3.7 m wide which have been randomly selected in each sampling unit. Bamboo is also enumerated in these strips but enumeration is confined to a 7.3 m width.

Stratified replicated sampling was discussed in Chapter 2.

3.6 Systematic Sampling

Systematic sampling involves selecting sampling units at equal intervals or according to a grid or predetermined scheme. Since the units are fixed at regular intervals there will be a fixed set of possible samples. If the sampling interval is k, there will be k possible samples. It is only required to choose the initial sampling unit in the population and then all following units will be selected at intervals of k units. If the mean of a sample selected in such a way is to be an unbiased estimate of the population mean, the initial sampling unit must be selected at random. It is usually selected from the first k units of the population.

The entire set of sampling units of a systematic sample consists of a single selection. Therefore a single systematic sample cannot provide an unbiased estimate of variance of the population mean. In spite of this shortcoming, systematic sampling remains the most popular method of forest inventory among foresters. Its advantages over random sampling are:

(i) Selecting, establishing and re-locating the units is simple.

(ii) It generally provides precise estimates of population means and totals because the sample is spread over the entire population.

Three types of systematic layout of sampling units are in common use (Loetsch and Haller, 1964):

(1) Continuous strip layout

(2) Line-plot strip layout and

(3) Layout of plots located at equal distances on a regular grid.

These methods have been applied successfully in tropical forest inventory.

About 1850, Dietrich Brandis introduced the systematic strip survey, called linear sampling, to manage teak-bearing forests in Burma. Strips were formed within compartments in such a way as to give a 5 per cent sampling intensity.

Griffith (1945, 1946) conducted a series of experiments in various types of forest in India comparing random and systematic sampling layouts with complete enumeration. He found that systematic sampling in general gave more precise estimates of population means and totals than random sampling, provided it was carried out with a full appreciation of the probable trends of fertility gradients within the forests.

In Sarawak, Malaysia, a stratified one-stage sample with clustered sampling points was used in inventory of 1.24 mill. ha of tropical forest for the preparation of plans for industrial development and forest management (FAO, 1974; Cunia, 1974). The total forest area was divided into eight inventory blocks. Pre-stratification was not carried out due to shortage of staff for photo-interpretation and lack of essential information.

In each inventory block, the positions of the sampling units were systematically located by dot grid on the aerial photographs. The sampling units used were a cluster of nine sample points arranged on a square pattern of three rows of three points each. The distance between neighbouring points in the same row or column was 80.5 m (4 chains).

Trees were counted at each sample point using a prism relascope of Basal Area Factor = 2.3 (square metre per ha). The dbhobs of all tallied trees were measured. On buttressed trees, diameter was measured 0.7 m above the buttress. Volume regression equations were developed by species groups based on felled trees.

Post-stratification was carried out using aerial photographs. Different forest types and canopy density classes for commercial forests were distinguished and forest cover maps were produced. Volume estimates for each stratum within a block and for the whole block were calculated.

In the Philippines, systematic strip sampling is commonly used in inventorying large areas of forest. Line-plot sampling is also used in regions where the forests are not contiguous (Serevo *et al.*,1962).

Systematic sampling is also practised in conjunction with a random selection of sampling units. According to Lanly (1975), systematic selection of the sampling units in one-stage sampling designs or of the secondary sampling units in two-stage sampling designs is the common practice in inventory of the French-speaking countries of Africa - Cameroons, Congo, Dahomey, Gabon, Ivory Coast, Zaire, etc.

3.7 Size and Shape of Sampling Units

The size and shape of the sampling unit may affect the cost of the survey and the precision of estimates or both. According to statistical theory, the smaller the sampling unit, the better the precision of estimate for a given sampling intensity. Thus, large-sized sampling units should not be used especially for the inventory of small forests. However, it is not advisable to use small sampling units in extensive forests of low stocking density of required species because it may result in a large proportion of the sampling units being empty (Chacko, 1962).

Another point to be considered in choosing size of sampling unit is relative cost. The larger the plot size for a given sampling intensity, the fewer will be the number of plots. Hence, less time will be involved in travelling and locating the plots. In tropical forests, the cost of cutting a path to reach the sample plots will be higher than the cost of enumeration of the plot if the plot is too small, say less than one ha. Thus the cost of travel and locating the plot is the important aspect to be considered in tropical forest inventories. Cunia (1974) points out that intensive inventories with large sampling units or clusters of sample plots or points must be considered in inventorying irregular mixed tropical forests. The choice of size of sampling unit must be a compromise between the required precision, cost and the important practical aspect of representativeness of the sample.

Selection of the shape of the sampling units is governed by forest conditions and accepted custom. Units with natural boundaries, topographical units and units with artificial boundaries (strips, rectangles and squares, circular plots and relascope plots) are all used.

3.7.1 Units with natural boundaries

A forest area to be inventoried is often divided into compartments of irregular shape with distinguishable natural boundaries like streams, roads, ridge tops, forest reserve boundaries, etc. These compartments are again subdivided into distinguishable topographical sections called sub-compartments. These sub-compartments are treated as sampling units and the area of each unit is calculated from the map by planimeter or some other area-measuring device.

This type of sampling unit is appropriate in inventorying tropical forests where the stocking of the exploitable trees of valuable species is low and the cost of cutting survey lines is high. However, the area of this type of sampling unit is usually large, 50-100 ha, because it is impossible to determine the area of small plots accurately on small scale maps, for example 1:50 000.

3.7.2 Units with artificial boundaries

The strip line has been used a great deal in tropical forest inventories and is still preferred by many foresters. Strips of width not larger than 30 m are often preferred in mixed tropical forests, i.e. 15 m on each side of the survey line in order to allow for a good control of the recording operation (Dawkins, 1958; FAO, 1973). However, Loetsch and Haller (1964) emphasise that inaccurate bearings and incorrect width of the strip are common sources of error. It is difficult to establish right angle offsets to the survey line to determine borderline trees and it is not easy to maintain correct strip width.

To avoid the above difficulties, circular plots are also used in tropical forest inventory. However, it is impractical to establish very large circular plots and measure trees in them although large sampling units are required in these forests. Consequently, small circular plots of radius about 10 m are often grouped or clustered in order to profit from the advantages of circular plots while, at the same time, constituting sufficiently large sampling units. In this case, the circular plots are the recording units. These are arranged along survey lines spaced out at equal intervals on a square or rectangular tract.

The decision on shape of the sampling units should be based mainly on practical convenience, e.g. ease of establishment and measurement. However, other factors must be considered such as type of forest, nature of terrain and precision required.

CHAPTER 4

OBJECTIVES AND CRITERIA OF FOREST INVENTORY IN BURMESE FORESTS

4.1 Introduction

Forest inventory is an important and complex part of the forest management process. Different types of inventory are required for different purposes as no single inventory can provide the required information in all circumstances.

In planning an inventory it is important as a first step to clearly define the objectives (Johnston, 1960; Husch, 1971). Several important decisions concerning the information required must then be made. Hall (1966) points out that much attention is given in planning to details of sampling design, volume estimation and measurement tools, while the objectives are overlooked. As a result, the information collected is inadequate for making management decisions.

4.2 Management Planning Requirements and Inventory Objectives

The requirement of forest inventory increases as the intensity of forest management increases and so is dependent on financial, administrative and technical resources and the demand for and value of forest products. These factors are reflected in forest policy.

A policy for the systematic management of Burmese forests was laid down in 1894 (Anon., 1960). This policy was revised after the

Second World War. In the revised policy, more attention was given to providing forest products to meet the needs of the local population.

The present forest policy of Burma was summarised at the Fifth World Forestry Congress held in the USA in 1960 (Anon., 1960). The main aims of this policy are:

1. To safeguard the forest estate for all time by State ownership and management;
2. To administer the forest estate with a scientifically trained staff for increasing productive and protective benefits consistent with the stage of social and economic development of the country;
3. To administer the forest estate not only for the benefit of the present population but also for posterity;
4. To increase the proportion of land under reserved forest cover, i.e. permanent yield forests, to at least 25%, distributed over the country as would be considered appropriate;
5. To perpetuate representative specimens of the indigenous fauna and flora; and
6. To carry out research in forestry and allied fields.

To meet these objectives in the face of a rapid rise in demand for forest produce, it has become necessary to manage the tropical forests of Burma more intensively than in the past. This requires more management planning which necessitates the collection of a range of inventory data. The information required for management planning embodies tree or stand data for each management area at a level of precision dictated by the use to which the data are to be put. The provision of this information is the responsibility of the inventory section of the Burmese Forest Department.

4.2.1 Tree and stand information

The most important information required about the mixed tropical forests of Burma is an estimate of the stocking of commercial species of merchantable size which provides the basis for calculation of the allowable cut. To permit long term management planning, it is desirable to obtain information to construct a stand table based on gbhob classes. Separate stand tables for each species or group of species are desirable.

Knowledge of growth and drain[1] of the forest is also important to allow regulation of yield. The allowable cut of a species or species group is related to the number of years it takes a tree to pass through each girth class to exploitable size. At present, this is determined only for teak by examination of growth rings. The assessment of growth of other hardwood species is much more difficult because they lack annual growth rings.

4.2.2 Area for which information is required

Inventory data are required on a continuing basis for all forests to be managed. These data could be collected separately for each forest, e.g. felling series. Management planning for a forest requires information about the general condition of the whole forest.

In Burma, inventory data for management planning are collected for those forests managed under the TSWC and CSWC. Teak only is extracted from the forests under the TSWC unless these forests overlap the CSWC and LSWC. In these cases, both teak and other hardwoods are

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[1] The drain is the loss in growing stock from both natural causes and cutting

extracted. The forests under both TSWC and CSWC are more important economically at present because some forests in the TSWC are not yet accessible for the extraction of other hardwoods. The information is required by felling series as determination of the allowable cut is carried out on that basis in each working circle.

4.2.3 Precision requirement

The degree of precision sought in the inventory estimates depends on many factors such as the intensity of management, the purpose of the inventory, variability of the forest, time, money and staff available. If precise estimates of volume or stocking of a certain species of a tropical forest are required by small compartments, then a high sampling intensity, for example 10 per cent or more, will be needed. However, if a general estimate is required for the whole forest, a lower sampling intensity will usually suffice to give the same level of precision in the estimates.

The stocking density of a forest also affects the precision of the estimates in the inventory of tropical forests. The lower the stocking density encountered the higher is the sampling error, and therefore in general a higher sampling intensity is needed for a given precision.

A large number of tree species per unit area is a characteristic of the tropical forests of Burma. Seventy species or groups of species are separately recorded in the forest inventory of Burma. Thirtyfive species are found in the deciduous Dipterocarp forest type in the Indainggon reserve and thirtyfour species in dry upper mixed deciduous forest type in Budaung, Thaw and Aukte reserves. The frequency distributions by girth class of the most dominant species encountered in

Indainggon and Budaung, Thaw and Aukte reserves are shown in Tables 4.1 and 4.2 and Figs. 4.1 and 4.2.

Although 'in' forms 45.4% of the total tree population in Indainggon reserve, the stocking per ha in the largest gbhob class (>2.2 m) is 2.2 trees. Fortunately 'in' is one of the most valuable species. The other two dominant species Thitya and Thitsi form 6.6% and 10.2% of the total population respectively and their stockings in the largest girth class are correspondingly low (0.4 and 0.1 trees respectively). Teak does not occur in this type of forest.

Teak contributes 7.7% of the total growing stock greater than 0.6 m gbhob in Budaung, Thaw and Aukte reserves. The stocking per ha of the four dominant species in the girth class greater than 2.2 m is less than one tree (0.6 trees for teak, 0.4 trees for Pyinkado, 0.1 trees for ingyin and 0.2 trees for Padauk).

The precision requirement for each species and even for each gbhob class of a species is not the same. More precise estimates are required for the more valuable species and for the larger gbhob classes. However, as the valuable species generally form a small proportion of the total population, precise estimates of this low and irregular stocking in the larger size classes cannot be expected under the general conditions of inventory.

4.3 Criteria of Forest Inventory in Burma

There are many constraints and obstacles which impede the implementation of efficient and reliable forest inventory in the mixed tropical forests of Burma. The environment is made inhospitable by humidity, insects of all kinds and dense undergrowth. Access is difficult. Field

Table 4.1 Number of stems per hectare of dominant species, Indainggon reserve

GBHOB class (m) / Species	0.6-0.9	1.0-1.2	1.3-1.5	1.6-1.8	1.9-2.1	2.2-2.4	2.5-2.7	2.8+	Total	Percentage of total
'In'	14.4	12.8	9.6	6.0	2.6	1.2	0.5	0.5	47.6	45.4
Thitya	2.9	1.8	1.0	0.5	0.3	0.2	0.1	0.1	6.9	6.6
Thitsi	5.6	2.9	1.3	0.5	0.3	0.1	-	-	10.7	10.2
Others	21.3	9.7	4.0	1.9	0.9	0.6	0.5	0.6	39.5	37.8
Total	44.2	27.2	15.9	8.9	4.1	2.1	1.1	1.2	104.7	100.0

Table 4.2 Number of stems per hectare of dominant species, Budaung, Thaw and Aukte reserves

Species \ GBHOB class (m)	0.6-0.9	1.0-1.2	1.3-1.5	1.6-1.8	1.9-2.1	2.2-2.4	2.5-2.7	2.8+	Total	Percentage of total
Teak	1.5	1.7	1.5	1.2	0.8	0.4	0.1	0.1	7.3	7.7
Pyinkado	1.3	1.0	0.9	0.7	0.3	0.2	0.1	0.1	4.6	4.9
Ingyin	6.7	4.1	2.1	1.0	0.3	0.1	-	-	14.3	15.1
Padauk	0.4	0.5	0.5	0.4	0.2	0.1	0.1	-	2.2	2.3
Others	32.3	17.4	9.0	4.3	1.7	0.7	0.4	0.5	66.3	70.0
Total	42.2	24.7	14.0	7.6	3.3	1.5	0.7	0.7	94.7	100.0

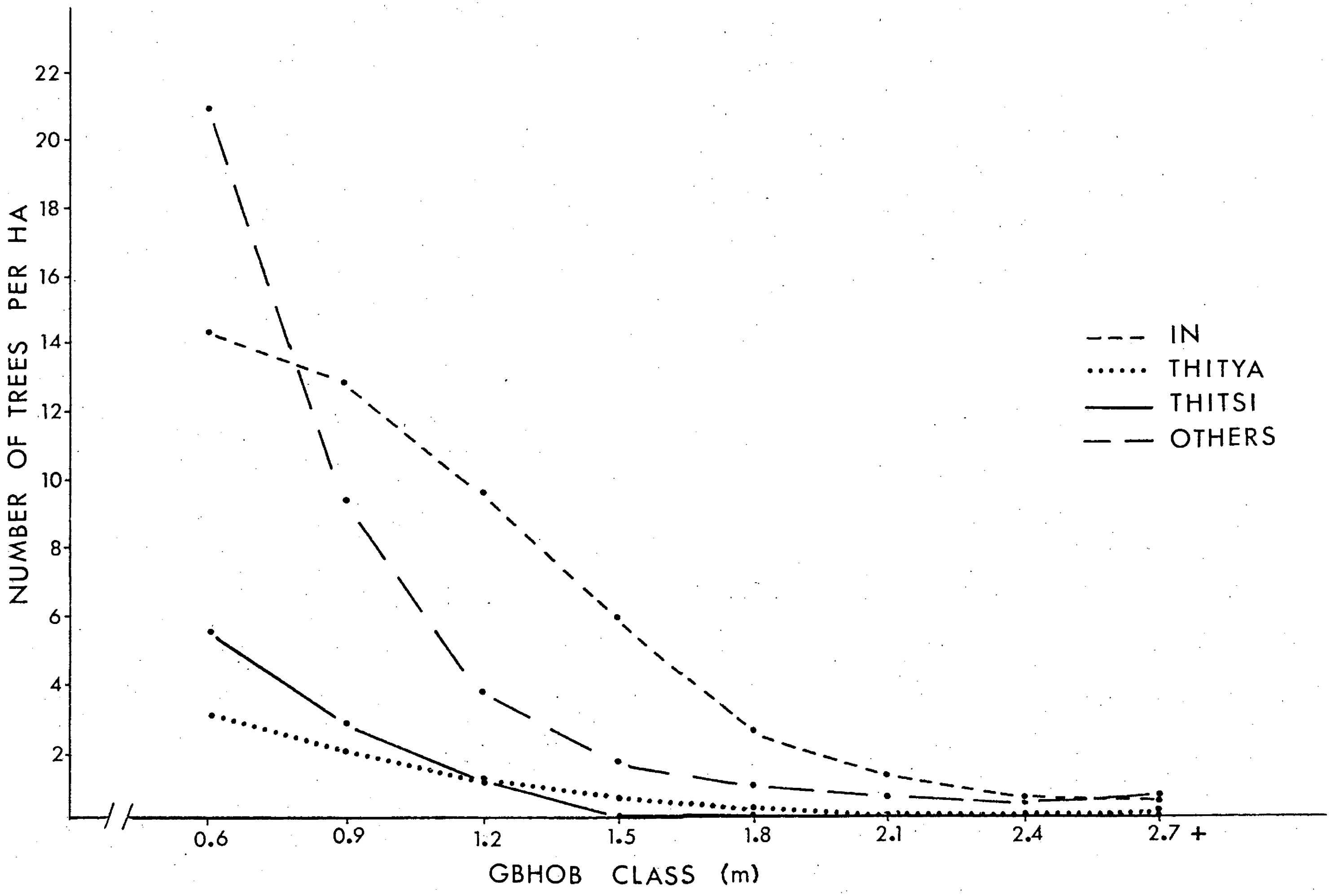

Fig. 4.1 Number of trees per ha by girth class, Indainggon reserve

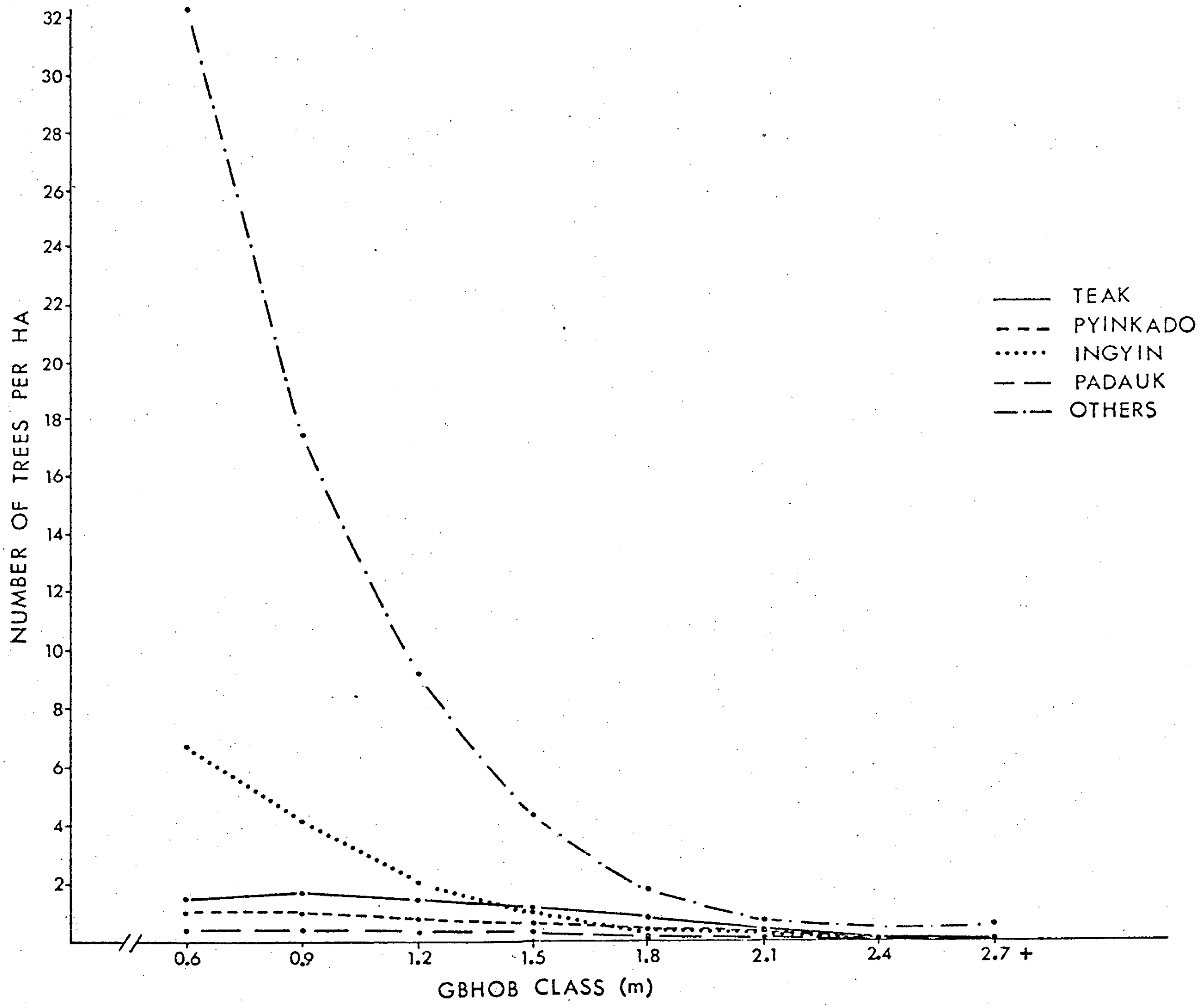

Fig. 4.2 Number of trees per ha by girth class, Badaung, Thaw and Aukte reserves

work can only be carried out in winter. The rainy season is too wet and the summer too hot for inventory.

Forest inventory, especially in the tropics, is a monotonous and tiring job. In Burma, field crews have to stay about 4 months in the jungle away from home. The author himself has spent 6 seasons supervising field parties. Field crews endeavour to complete the work as quickly as possible consistent with accuracy.

Suitable equipment and trained staff are limited. It is particularly difficult to obtain labouring staff. This must be considered in planning the inventory.

Consequently, the sophisticated sampling designs which have proved efficient for temperate forests may not be appropriate in mixed tropical forests. The inventory design must be simple and practicable. This is the most important requirement of inventory in the mixed tropical forests of Burma. However, it is desirable that the sampling design adopted be based on probability sampling to enable the precision of estimates to be calculated.

Cost of inventory is another important consideration in developing countries such as Burma. Capital resources are restricted and the required information, at the specified precision level, must be obtained at the lowest possible cost. Careful design can lead to substantial savings because inventory in the mixed tropical forests is very expensive. Efficiency of the inventory design is obviously a very important criterion of the forest inventory in Burma.

Costs are closely related to the number of sampling units used in the inventory. Hence, it is important to determine the optimum number of sampling units to give the required precision. This subject is discussed in Chapters 5 and 6.

In the tropical high forests of Uganda, an estimate of total basal area with a sampling error of ±20% at 95% confidence level is considered acceptable for forest management purposes (Dawkins, 1958). Similar criteria have been set for teak greater than 1 m gbhob in inventorying vast areas (>1 mill. ha) of teak-bearing forests in Thailand (Loetsch, 1957; Loetsch and Haller, 1964). This information was obtained with a low sampling intensity of less than 1 per cent.

In Burma, estimates of the growing stock of important species or group of species of the larger size classes (e.g. >2.0 m gbhob) are required by felling series of area about 50 000 ha each. It is difficult to achieve a sampling error of ±20% at 95% confidence level for these estimates even though the sampling intensity is increased to 2-3 per cent in the current sampling method. The sampling intensity could not be increased beyond 2-3 per cent in the inventory of large areas of tropical forest of Burma for management planning because of the many constraints mentioned earlier. Therefore, the sampling error for the estimate of teak (>2.0 m gbhob in dry teak forests and >2.3 m gbhob in moist teak forests) has been fixed by the author for this study at ±30% at 95% confidence level in the teak-bearing forests of Burma. This slightly less reliable estimate is usually sufficient for the purpose of forest management (Dawkins, 1958). For less valuable species it has been fixed at ±40%. More precise estimates using the same sampling intensity as employed in teak-bearing forests are achieved for 'in' in the deciduous Dipterocarp forest type because 'in' forms about half of the total population, and more than this in some areas (Myint Tin *et al.*, 1971-72).

CHAPTER 5

THE OPTIMUM SAMPLE SIZE FOR ONE SPECIES SUBPOPULATION

5.1 Introduction

Size of sample has a considerable bearing on both the precision and cost of inventory. The larger the sample, the greater will be the precision of estimates but cost will also be greater. The optimum sample size is that which provides the greatest precision per unit cost or alternatively the least cost per unit precision.

Stratified replicated sampling or stratified two-stage sampling using circular plots as second-stage units (described in Chapter 2) has been shown to be suitable for the forest inventories in Burma (Myint Tin *et al.*, 1975). In this type of two-stage sampling design, the precision of estimate obtained relative to the cost is dependent not only on the total sample size but also on the relative number of first and second-stage units. Determination of the best combination of these types of units is a very important phase of inventory design.

In most forest inventories, information is collected simultaneously for several subpopulations, e.g. different species and size classes. However, for simplicity, the optimum sample size is usually calculated using data of the most important subpopulation. In this chapter, the optimum number of first and second-stage units will be calculated using the data for teak and 'in' from two different forest areas for which appropriate data were available.

5.2 The Study Area

Each of the forest areas is part of a large area inventoried in Upper Chindwin/Myittha and Shwebo Forest Divisions in 1971-72 and 1972-73 respectively.

The first study area consists of the Indainggon reserve in Upper Chindwin/Myittha Forest Division. The topography of the area is generally undulating. The forest type is deciduous Dipterocarp which is dominated by the species 'in'.

The second area includes a group of forest reserves,viz.: Budaung, Thaw and Aukte reserves (BTA reserves) in Shwebo Forest Division. The topography of the area is similar to that of the first study area. However, the dominating forest type is dry upper mixed deciduous forest. Poor types of deciduous Dipterocarp forests are found on some hill tops and in the drier areas (Myint Tin *et al.*, 1972-73). Teak occurs in mixture with other marketable species throughout the forest but is generally of second-class quality.

The total area and number of blocks in each study area are in Table 5.1 (Myint Tin *et al.*, 1971-72, 1972-73).

Table 5.1 Details of Study Area

Forest reserve	Total area (ha)	No. of blocks	Average area of each block (ha)
Budaung, Thaw and Aukte	55 912	5	11 182
Indainggon	31 834	6	5 306

5.3 Sampling Method

The general sampling method applied to the two study areas was as outlined in Chapter 2. However, there are some minor differences in detail. The size of the first-stage unit (FSU) was 28.5 ha in Indainggon reserve and 18.2 ha in the BTA reserves. The radius of each circular plot (9.1 m), the distance between circular plots along the survey lines (21.3 m) and the number of lines in a square FSU (14) were the same in both areas. However, the distance between the survey lines differed, being 38.1 m on Indainggon reserve and 30.5 m in the BTA reserves. As a result, the number of circular plots in a FSU was 350 in Indainggon reserve and 280 in the BTA reserves.

A block in each study area was divided into FSUs of equal area. The required number of FSUs was selected independently of the other blocks. Hence a block can be treated as a stratum. Within each selected FSU, 14 second-stage units (SSU-lines with a fixed number of circular plots) were sampled systematically. Thus the sampling method can be treated as stratified two-stage sampling.

The total number of possible FSUs and the number of FSUs selected in both study areas are shown in Table 5.2 (Myint Tin *et al.*,1971-2, 1972-3). The sampling intensity at the first-stage is the number of selected FSUs expressed as a per cent of the total number of possible FSUs for the forest. That of the second-stage is the area of all circular plots measured, expressed as a per cent of total forest area.

Table 5.2 Number of first-stage units selected

Forest reserve	No. of blocks	No. of possible FSUs	Selected FSUs in each block	Total FSUs for whole forest	Sampling intensity %	
					FSUs	SSUs
Budaung Thaw & Aukte	5	3 065	20	100	3.26	1.32
Indainggon	6	1 116	10	60	5.38	1.73

5.4 Data

Data were recorded for each line of circular plots (25 circular plots equivalent to 0.65 ha in Indainggon reserve and 20 circular plots equivalent to 0.53 ha in the BTA reserves) within each square FSU. Each line-plot is a recording unit. In irregular-shaped FSUs, the number of circular plots per line varies. In this case, 25 (or 20) circular plots are still taken as a recording unit which might require combining circular plots from adjacent lines (Fig. 5.1). It was therefore necessary and convenient to treat each line-plot or set of circular plots (25 in Indainggon or 20 in BTA reserves) as a SSU.

The data available for all SSUs in both study areas consist of the number of trees greater than 0.61 m gbhob in 0.15 m girth classes for a variety of species and groups of species. The number of trees of teak in BTA reserves and of 'in' in Indainggon reserve greater than exploitable girth size by lines are shown in Appendix III. The total numbers of species or groups of species recorded were 34 and 35 for the BTA and Indainggon study areas respectively.

5.5 Resources Used

In both main inventories, 25 field crews were employed. These were divided into five groups and one supervisor was made responsible for each group. Each crew was assigned 9-10 FSUs in the BTA reserves and 8-9 FSUs in the Indainggon reserve.

The average time spent by each crew on the various phases of work within each forest division in which the study areas are located is summarised in Table 5.3 (Myint Tin *et al.*, 1971-72, 1972-73).

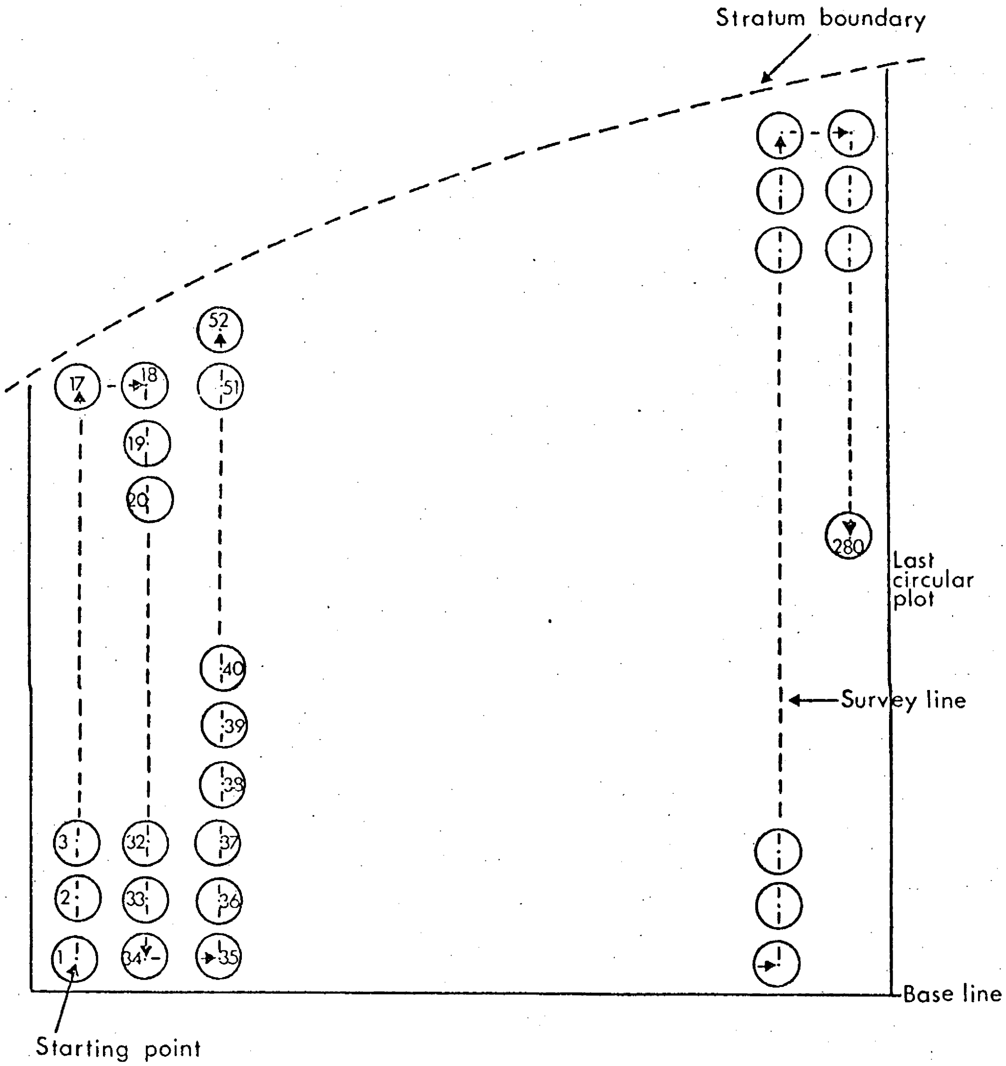

Fig. 5.1 First-stage irregular sampling unit with circular second-stage units

Table 5.3 Time study of activities of inventory crew

Field work	Shwebo Forest Division (crew days)	Upper Chindwin/Myittha Forest Division (crew days)
Starting point location	6	6
Enumeration of trees	35	27
Camp organisation	5	4
Rest	8	7
Total	54	44

Detailed costs of inventory are not available for either of the study areas. However, the average cost per FSU and SSU for each category of field work can be estimated from the total costs for each division (Table 5.4). These average costs are used in subsequent analyses assuming that the costs of inventory on each forest division are similar.

The following points should be noted in relation to Table 5.4.

1. All costs are based on actual field wages paid to inventory staff and hired labourers. Office costs (planning, checking of inventory data, etc.) are not included.
2. The costs of locating the starting points and of enumeration were not kept separate. Costs for each operation have been extracted from the time study data of Table 5.3.
3. To find the relationship between travel cost and sample size n (where n = number of FSUs) in a forest of area A, it is assumed that the average distance between all pairs of consecutive FSUs is $\sqrt{\frac{A}{n}}$ (Hansen *et al.*, 1953; Kish, 1965). Therefore the total distance of travel for n FSUs is

approximately $\sqrt{An}$. As A is constant for all sample sizes, then c_o = total travel cost/$\sqrt{n}$ may be described as the average travel cost per FSU.

Table 5.4 Cost (A$) of field inventory

Category	Shwebo Forest Division	Upper Chindwin/ Myittha Forest Division
1. Transportation cost		
Average cost of travel per FSU (c_o)	100.22	93.73
2. Cost of camp organisation and locating starting points		
Average cost per FSU (c_1)	4.54	5.63
3. Cost of enumeration, camp attendant and miscellaneous		
Average cost per SSU (c_2)	2.05	2.12

5.6 Statistical Analyses and Results

5.6.1 Calculation of sample mean and variance[1]

For a stratum

Let y_{ij} = the number of trees in the j^{th} line in the i^{th} FSU

N = total number of FSUs

n = number of FSUs sampled

M = total number of SSUs in each FSU

m = number of SSUs sampled in each FSU

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[1] All formulae quoted are based on Cochran (1963) unless otherwise indicated

An unbiased estimate of the population mean per SSU in the i^{th} FSU is thus:

$$\bar{y}_{i.} = \sum_{j=1}^{m} \frac{y_{ij}}{m} \tag{5.1}$$

An overall sample mean per SSU of a stratum is:

$$\bar{\bar{y}} = \sum_{i=1}^{n} \frac{\bar{y}_{i.}}{n} = \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{y_{ij}}{nm} \tag{5.2}$$

An unbiased estimate of the variance of $\bar{\bar{y}}$ is:

$$\mathrm{var}_{(\bar{\bar{y}})} = (1 - f_1) \frac{s_1^2}{n} + f_1(1 - f_2) \frac{s_2^2}{nm} \tag{5.3}$$

where $f_1 = \frac{n}{N}$ = sampling fraction in the first stage

$f_2 = \frac{m}{M}$ = sampling fraction in the second stage

$s_1^2 = \frac{\sum_{i=1}^{n} (\bar{y}_{i.} - \bar{\bar{y}})^2}{n-1}$ = sample variance among the FSU means

$s_2^2 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} (y_{ij} - \bar{y}_{i.})^2}{n(m - 1)}$ = sample variance among the SSUs within the FSUs

Second-stage units are assumed to be selected at random.

For large N, Equation 5.3 becomes

$$\mathrm{var}_{(\bar{\bar{y}})} = \frac{s_1^2}{n} \tag{5.4}$$

$$= \frac{s_u^2}{n} + \frac{s_2^2}{nm} \tag{5.5}$$

where $s_u^2 = s_1^2 - \frac{s_2^2}{m}$ = component of variance between the FSU means

For the whole forest, the unbiased estimate of the population mean is:

$$\bar{\bar{y}}_{st} = \frac{\sum_{h=1}^{L} N_h \; M_h \; \bar{\bar{y}}_h}{\sum_{h=1}^{L} N_h \; M_h} \tag{5.6}$$

$$= \sum_{h=1}^{L} W_h \; \bar{\bar{y}}_h \tag{5.7}$$

where h = h^{th} stratum

L = number of strata

$W_h = \dfrac{N_h \; M_h}{\sum_{h=1}^{L} N_h \; M_h}$ = relative size of a stratum in terms of SSUs

An unbiased estimate of the variance of $\bar{\bar{y}}_{st}$ is:

$$\text{var}_{(\bar{\bar{y}}_{st})} = \sum_{h=1}^{L} W_h^2 \left[(1-f_{1h}) \; \frac{s_{1h}^2}{n_h} + f_{1h} \; (1-f_{2h}) \; \frac{s_{2h}^2}{n_h \; m_h} \right] \tag{5.8}$$

Assuming that N is large in all strata, then:

$$\text{var}_{(\bar{\bar{y}}_{st})} = \sum_{h=1}^{L} W_h^2 \; \frac{s_{1h}^2}{n_h} \tag{5.9}$$

$$= \sum_{h=1}^{L} W_h^2 \left[\frac{s_{uh}^2}{n_h} + \frac{s_{2h}^2}{n_h \; m_h} \right] \tag{5.10}$$

and, with proportional allocation to all strata,

$$n_h = W_h \; n^* \tag{5.11}$$

where $n^* = \sum_{h=1}^{L} n_h$

Assuming also that the areas of the FSUs and SSUs are the same in all strata, then substituting n_h in Equation 5.10, we get:

$$\text{var}(\bar{\bar{y}}_{st}) = \sum_{h=1}^{L} W_h \left[\frac{s_{uh}^2}{n^*} + \frac{s_{2h}^2}{n^* m_h} \right] \qquad (5.12)$$

If now, m SSUs in each FSU are taken in every stratum, then

$$\text{var}(\bar{\bar{y}}_{st}) = \sum_{h=1}^{L} W_h \left[\frac{s_{uh}^2}{n^*} + \frac{s_{2h}^2}{n^* m} \right] \qquad (5.13)$$

5.6.2 Cost function

The determination of optimum sample size depends on the type of cost function. As travel costs between FSUs are important in the inventory of mixed tropical forests, the following cost function (Hansen *et al.*, 1953) will be used in the subsequent analyses.

$$C = c_o\sqrt{n} + c_1 n + c_2 nm \qquad (5.14)$$

where C = total cost of inventory

c_o = average cost of travel per FSU

c_1 = average cost of locating and establishing each FSU: this cost varies directly with the number of FSUs included in the sample.

c_2 = average cost of measuring the SSUs: this cost varies with the number of SSUs included in the sample

When applied to the cost data for the two study areas, the estimated cost functions are:

BTA reserves: $C = 100.22\sqrt{n} + 4.54\ n + 2.05\ nm$ (5.15)

Indainggon Reserve: $C = 93.73\sqrt{n} + 5.63\ n + 2.12\ nm$ (5.16)

5.6.3 Optimum sample sizes for a single subpopulation with proportional allocation

To determine the optimum number of sampling units in each stage, preliminary estimates are required of the variability of the subpopulation of interest,e.g. a size class of a desired species and the unit costs at each stage. In some areas, these estimates can be obtained from former inventories and in others from a small pilot survey. Estimates from similar forest areas might be used as a guide in determining the optimum number of sampling units for a forest area to be inventoried.

In this section, optimum number of FSUs and SSUs will be determined to achieve the required precision of a single subpopulation assuming proportional allocation of FSUs to different strata.

The optimum number of first and second-stage units can be calculated in two different ways:

(i) by substitution of successive values and

(ii) by explicit formula.

(i) Calculation of optimum by substitution of successive values

If the required precision is set for a particular subpopulation, the different numbers of FSUs and SSUs that satisfy the set precision can be calculated from the variance function. The total cost for each pair of FSUs and SSUs is then obtained by substituting the numbers of the corresponding FSUs and SSUs in the cost function. The pair which yields the minimum cost is the optimum.

The subpopulation of most interest in the BTA reserves is the number of teak trees greater than 2.0 m gbhob. The precision of this estimate was fixed in Chapter 4 at 30% sampling error at the 95%

confidence level (approximately 15% standard error) or less. The inventory shows that for teak greater than 2.0 m gbhob in the BTA study area, the estimate of the population mean (number of trees greater than 2.0 m gbhob per SSU (line)) is, according to Equation 5.7: $\bar{\bar{y}}_{st} = 0.50$.

The required maximum acceptable variance is therefore $(0.50 \times 0.15)^2 = 0.005\ 625$

In addition, $\sum_{h=1}^{L} W_h\, s_{uh}^2 = 0.375\ 447$ and

$$\sum_{h=1}^{L} W_h\, s_{2h}^2 = 0.799\ 231$$

Therefore the variance function, according to Equation 5.13, is:

$$0.375\ 447/n^* + 0.799\ 231/n^*m = 0.005\ 625$$

The finite population correction was ignored because the sampling fraction in the first-stage in all strata was small, i.e. 0.03.

The cost function according to Equation 5.15 is

$$C = 100.22\ \sqrt{n^*} + 4.54\ n^* + 2.05\ n^*m$$

The values of n* and m that satisfy the required variance function, and the corresponding cost of inventory, are shown in Table 5.5.

Table 5.5 Values of n* and m and corresponding cost of inventory

n*	m	Cost of inventory (A$)
209	1	2826.17
138	2	2369.64
114	3	2288.72**
102	4	2316.19
95	5	2381.87
90	6	2466.37
87	7	2578.22
85	8	2703.88
83	9	2821.22
81	10	2930.22
80	11	3063.59
79	12	3192.83

** Minimum cost

From Table 5.5, the combination that yields the minimum cost comprises 114 FSUs and 3 SSUs.

For Indainggon reserve, the most important subpopulation is the 'in' trees greater than 2.1 m gbhob. The objective adopted was to obtain the estimates of that population with a sampling error of 30% at the 95% confidence level. The optimum combination of FSUs and SSUs required to achieve the above criterion was calculated as being 64 and 2 respectively.

In Figure 5.2, the total cost is plotted against number of SSUs for the two study areas. If the number of SSUs varies between 2 and 5 for the BTA reserves and between 2 and 4 for the Indainggon reserve then the cost of inventory will be within 10 per cent of the optimal cost. The optimum number of FSUs and SSUs can also be calculated by fixing the total cost and minimising the variance in a way similar to that described above.

The optimum combination of FSUs and SSUs and the corresponding costs of inventory to obtain an estimate of the total number of trees of the two most important species (teak and 'in') of exploitable size with 30% sampling error at the 95% confidence level for the two study areas are shown in Table 5.6. The optimum values are compared against the values used in the actual inventory.

Table 5.6 Optimum and actual number of FSUs and SSUs and total cost of inventory

Forest reserve	Area (ha)	Optimum values			Actual inventory		
		FSU	SSUs per FSU	Cost ($A)	FSU	SSUs per FSU	Cost ($A)
BTA	55 912	114	3	2288.72	100	14	4326.20
Indainggon	31 834	64	2	1381.52	60	14	2844.63

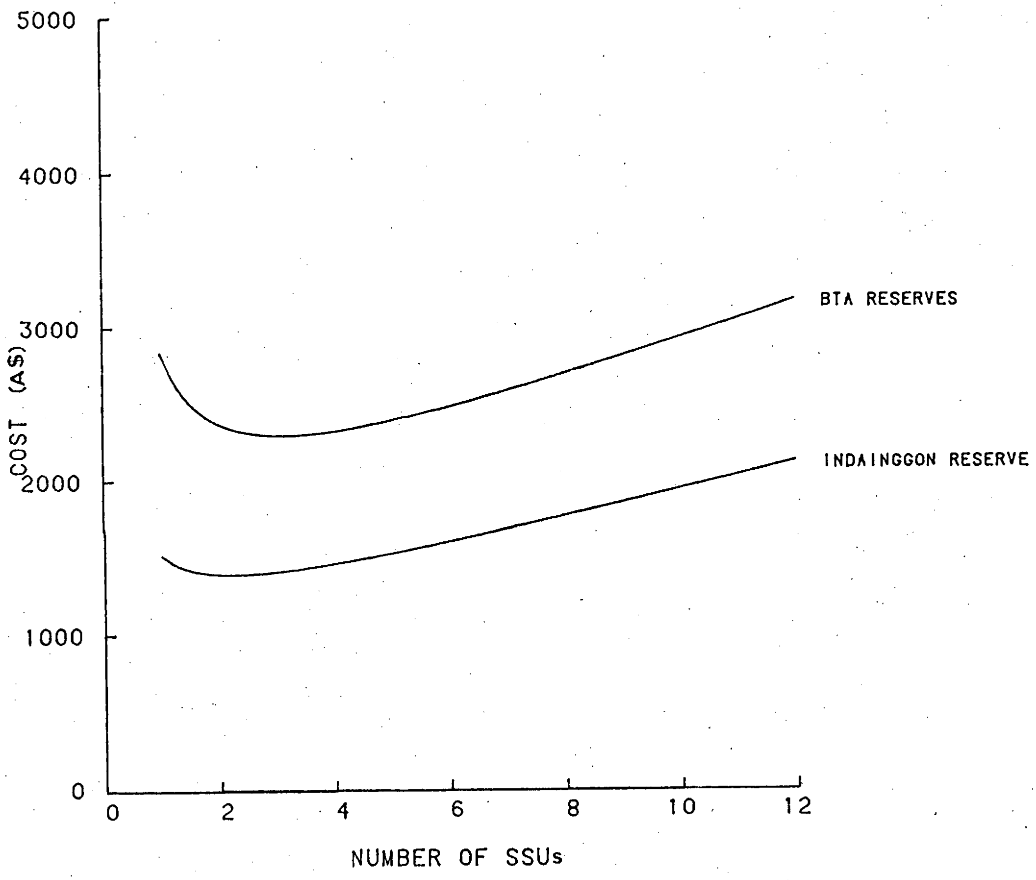

Fig. 5.2 Number of SSUs and total cost of inventory

Although the number of FSUs used in both forest areas is a little less than the optimum, the number of SSUs per FSU greatly exceeds the optimum. Consequently, the costs of inventory are about twice the costs of the optimal costs in both areas.

(ii) Explicit formula for optimum FSUs and SSUs

The optimum number of FSUs and SSUs can also be obtained from the explicit formula instead of calculating by the method of successive substitution (Hansen *et al.*, 1953; Kish, 1965). The optimum number is that which minimises the cost for a fixed variance or *vice versa*.

With the cost function (Equation 5.14), the estimate of the number of optimum SSUs is

$$m_{opt} = \frac{s_2}{s_u} \left(\frac{c_0/2\sqrt{n_{opt}} + c_1}{c_2} \right)^{\frac{1}{2}} \qquad \text{(Hansen } et\ al.\text{, 1953)} \qquad (5.17)$$

where n_{opt} = optimum number of FSUs.

The formula cannot be readily used to define the optimum m because it depends on n_{opt}. However, the optimum m can easily be calculated by a successive approximation method (Hansen *et al.*, 1953). Once the optimum m is calculated, the optimum n can be computed by substituting the value of m in Equation 5.17 or in the given cost or variance functions.

The optimum number of SSUs increases as c_1 increases in relation to c_2. However, it is not very sensitive to changes in the ratio of c_1/c_2 because it varies with the square root of the ratio.

The optimum number of SSUs also increases as s_2^2 (variability between the SSUs within the FSUs) increases and decreases as s_u^2 (variability between the FSUs) increases. The travel cost between the

FSUs (c_o) affects the optimum m in the same way as c_1 does. However, as the sample size increases this relative effect of travel becomes less since c_o is divided by $\sqrt{n_{opt}}$.

The relationship between n_{opt} and m_{opt} in the BTA and Indainggon reserves is shown in Fig. 5.3. Provided n_{opt} is greater than 30, there is little change in m_{opt} assuming the cost of inventory and the variability of the forest are kept constant.

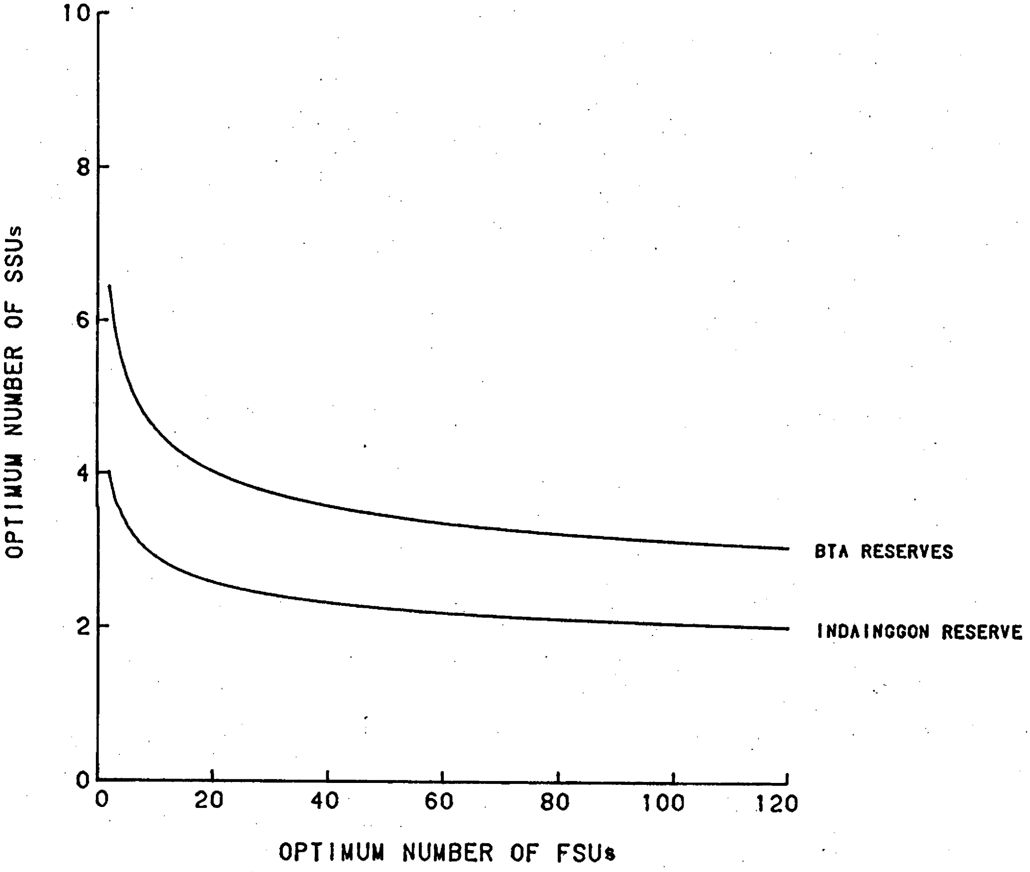

Fig. 5.3 Relationship between n_{opt} and m_{opt}

CHAPTER 6

THE OPTIMUM SAMPLE SIZE FOR SEVERAL SPECIES SUBPOPULATIONS

6.1 Introduction

The variability of tropical forests and the difficulties experienced in inventorying them (described in Chapter 3), complicate the determination of the most efficient sample design because many species have to be considered simultaneously. An allocation of sampling units in each stage, such that the cost of collecting information at the required precision for one species or group of species is minimised, is unlikely to be suitable for some other species or species groups because of differences in variability and distribution among species. A compromise must be made to achieve the required precision for important species of interest at minimum cost.

For inventories designed to deal with only one subpopulation of interest, calculation of the optimum number of sampling units in each stage is straightforward. However, large-scale forest inventories deal with multiple objectives. Estimates of a number of subpopulations with specified precision at minimum cost are generally required. In this case,an optimum will minimise the inventory cost while simultaneously satisfying precision requirements for all subpopulations of interest.

In this Chapter, the optimum sample size to achieve the required precision of several subpopulations of interest is investigated using both proportional and optimum allocation of FSUs (equal number of SSUs per FSU) to the strata.

6.2 Optimum Sample Sizes with Proportional Allocation

Suppose the various subpopulations (e.g. most important species of larger size classes) can be defined on each sampling unit.

With stratified two-stage sampling, let $\bar{\bar{y}}_{j(st)}$ be the unbiased estimate of the number of trees per line for a desired subpopulation j (j = 1,2,..........,p) with sampling variance:

$$\mathrm{Var}_j(\bar{\bar{y}}_{st}) = \sum_{h=1}^{L} W_h^2 \left[\left(\frac{1}{n_h} - \frac{1}{N_h}\right) S_{uhj}^2 + \left(\frac{1}{n_h m_h} - \frac{1}{N_h M_h}\right) S_{2hj}^2 \right] \tag{6.1}$$

where S_{uhj}^2 = component of the variance among FSUs in the h^{th} stratum for the j^{th} subpopulation

S_{2hj}^2 = variance among SSUs between FSUs in the h^{th} stratum for the j^{th} subpopulation.

The other terms are the same as given in Section 5.6.1.

For large N and proportional allocation of FSUs to each stratum with an equal number of SSUs per FSU, Equation 6.1 becomes:

$$\mathrm{Var}_j(\bar{\bar{y}}_{st}) = \sum_{h=1}^{L} W_h \left[\frac{S_{uhj}^2}{n^*} + \frac{S_{2hj}^2}{n^*m} \right] \tag{6.2}$$

$$\text{Let } x_1 = \frac{1}{n^*} \text{ and } x_2 = \frac{1}{n^*m} \tag{6.3}$$

Then Equation 6.2 becomes:

$$\mathrm{Var}_j(\bar{\bar{y}}_{st}) = \sum_{h=1}^{L} W_h \left[S_{uhj}^2 x_1 + S_{2hj}^2 x_2 \right] \tag{6.4}$$

Since $1 \leqslant n^* \leqslant \sum_h N_h$ and $1 \leqslant m \leqslant M$, then

$0 < x_1 \leqslant 1$ and $0 < x_2 \leqslant x_1$, although Kokan (1963) states that the upper bound of x_2 is 1.

Let the cost function be as in Equation 5.14. Thus:

$$C = c_o\sqrt{n^*} + c_1 n + c_2 n^* m \tag{6.5}$$

$$= c_o/\sqrt{x_1} + c_1/x_1 + c_2/x_2 \tag{6.6}$$

If we fix a maximum acceptable sampling variance for $\text{Var}_j(\bar{\bar{y}}_{st})$ and call it v_j, then the problem becomes one of minimising the objective function ϕ where:

$$\phi = c_o/\sqrt{x_1} + c_1/x_1 + c_2/x_2 \tag{6.7}$$

subject to the constraints

$$\begin{array}{c}
\sum_{h=1}^{L} W_h\left[S^2_{uh1}\,x_1 + S^2_{2h1}\,x_2\right] \leqslant v_1 \\[1em]
\sum_{h=1}^{L} W_h\left[S^2_{uh2}\,x_1 + S^2_{2h2}\,x_2\right] \leqslant v_2 \\
\begin{array}{cccc} \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \end{array} \\
\sum_{h=1}^{L} W_h\left[S^2_{uhp}\,x_1 + S^2_{2hp}\,x_2\right] \leqslant v_p
\end{array} \tag{6.8}$$

$$\text{where } 0 < x_1 \leqslant 1 \text{ and } 0 < x_2 \leqslant x_1 \tag{6.9}$$

The objective function 6.7 is nonlinear and is minimised subject to a number of nonlinear and linear constraints (6.8 and 6.9 respectively). There are (p + 4) constraints in the above problem. There is no simple analytical solution when several subpopulations are considered simultaneously as above. However, nonlinear mathematical programming techniques can be used to solve such problems.

Nonlinear mathematical programming

Dalenius (1957) suggested that nonlinear mathematical programming could be used to solve the allocation problems in sample surveys and Kokan (1963) outlined how this could be carried out for three common sampling designs. Hazard and Promnitz (1974) proposed a nonlinear technique for determining the allocation of sampling units in successive forest inventories with multiple objectives.

Unlike linear models, nonlinear models can only be solved by approximate iterative algorithms in which feasible starting values are successively modified until a desired accuracy is achieved. There are several such algorithms (Marquardt, 1963; Taha, 1971; Sadler, 1975) for different model structures. No general algorithm exists that will efficiently handle all nonlinear models.

NLPE (Nonlinear Parameter Estimation), a nonlinear programming package developed by Bard (1967), was used to solve the above problem. The program provides two alternative methods viz., modified Gauss-Newton and the Davidson-Fletcher-Powell method, and is amply described in the extensive documentation. The program should be most efficient if the minimum is at an interior point of the feasible region and the objective function is highly nonlinear. As minimisation of the objective function proceeds in an iterative way, termination criteria must be used. The criteria suggested by Marquardt (1963) are used in NLPE. The first and second derivatives of the objective function and first derivatives of the constraint functions must be coded by the user. Feasible starting values must also be supplied.

The program is relatively simple to use for the present problem as the objective function is nonlinear and the single minimum is generally an interior point of the feasible region. The solution provides the optimum values in real numbers. Rounding these off to their near integer values may be suboptimal due to the rounding error. However, an integer programming package was not available. In the present study, the optimum number of SSUs in each FSU was not very sensitive to small changes (see Section 5.6.3) and hence the small rounding error is unlikely to be serious.

Analysis of the BTA reserves

In the BTA reserves, separate estimates were required for several species with varying exploitable girth and precision (Table 6.1).

Table 6.1 Exploitable girth and precision requirements for various species - BTA reserves

Species	Exploitable gbhob (m)	Precision required (standard error %)
Teak	2.0	15
Pyinkado	2.0	20
Padauk	2.0	20
Ingyin	1.8	20
Other commercial species	2.0	20

The estimates of the five subpopulation means $\bar{\bar{y}}_{j(st)}$ and their unbiased estimates of variance are obtained according to Equations 5.7 and 5.13. For each subpopulation, the maximum acceptable variance (v_j) is calculated based on the required precision and the estimated mean. Thus, the cost function -

$$C = 100.22/\sqrt{x_1} + 4.54/x_1 + 2.05/x_2 \tag{6.14}$$

is minimised subject to the constraints:

Teak	$0.375\,447\ x_1 + 0.799\,231\ x_2 \leqslant 0.005\,625$
Pyinkado	$0.062\,267\ x_1 + 0.287\,583\ x_2 \leqslant 0.002\,500$
Padauk	$0.020\,944\ x_1 + 0.114\,341\ x_2 \leqslant 0.000\,484$
Ingyin	$0.053\,324\ x_1 + 0.351\,429\ x_2 \leqslant 0.001\,936$
Other commercial species	$0.306\,450\ x_1 + 1.058\,352\ x_2 \leqslant 0.027\,556$

$$0 < x_1 \leqslant 1 \quad \text{and} \quad 0 < x_2 \leqslant x_1$$

The solution was $x_1 = 0.009\,790$ and $x_2 = 0.002\,438$. The corresponding sample size from Equation 6.3 is n* = 102.15 and m = 4.02. The value of m is rounded to the nearest integer and the corresponding n* value is obtained by substituting the rounded value of m in the critical constraint functions (Fig. 6.1). The resulting values of n* and m are 102.1 and 4.0 respectively. If the value of m is retained as 4, the value of n* must be increased to 103 to satisfy all constraints. The optimum combination of FSUs and SSUs per FSU is therefore 103 and 4 respectively.

Since we have applied proportional allocation to each stratum, and since there are five strata of equal size, then 20.6 FSUs i.e. 21 FSUs with 4 SSUs each are required per stratum in the BTA reserves.

The desired variance functions for each species and the optimum cost function are plotted against the values of n* and m in Fig. 6.1. In this case the minimum inventory cost to satisfy all specific levels of precision occurs at the intersection (4,102.1) of the constraints teak and padauk. The other constraints are not involved in determining this optimum point as they fall outside the feasible region.

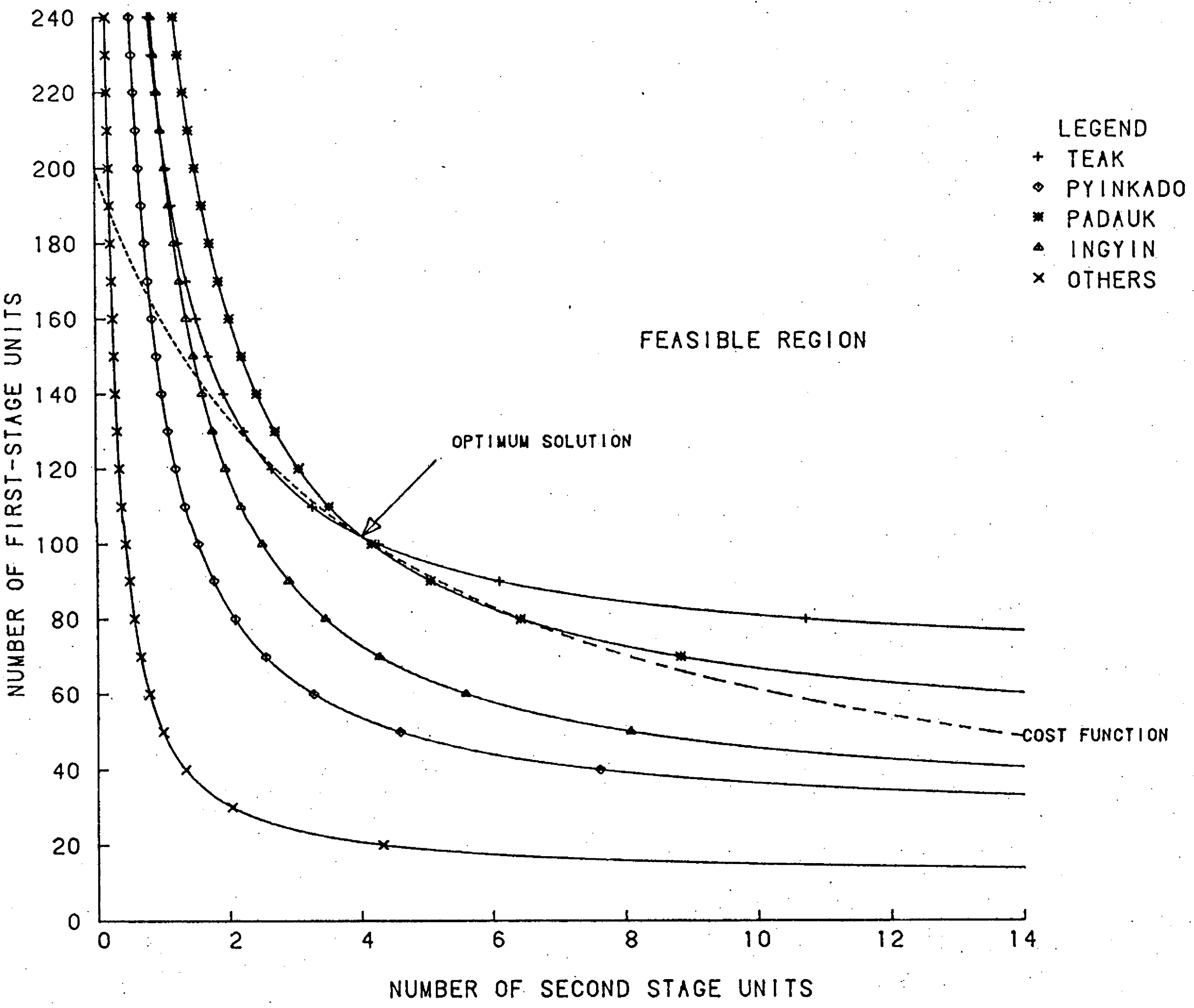

Fig. 6.1 Optimum number of sampling units, Budaung, Thaw and Aukte reserves

Analysis of Indainggon reserve

The most important and dominant species in Indainggon reserve are shown in Table 6.2 together with their exploitable girths and the required precision.

Table 6.2 Exploitable girth and precision requirements for various species - Indainggon reserve

Species	Exploitable gbhob (m)	Required precision (standard error %)
'In'	2.1	15
Thitsi	1.5	20
Thitya	1.5	20
Other commercial species	1.5	20

Apart from 'in', thitsi and thitya, other minor commercial species are combined in a fourth category. To achieve the set precision for these subpopulations, 62.19 FSUs with 2.20 SSUs in each would be required for the whole forest. If the number of SSUs is rounded to 2, then the number of FSUs required to achieve the set criteria would be 64.

With proportional allocation, 11 FSUs each consisting of 2 SSUs would be required in each of the 6 strata. Fig. 6.2 illustrates the desired variance functions of the different subpopulations and the optimum cost function which gives the optimum number of FSUs and SSUs. The optimum solution occurs at the point where the cost function is tangent to the variance function of the key species, in this case 'in'. The sole solution always occurs at the extremity of the feasible region as shown in Figs. 6.1 and 6.2.

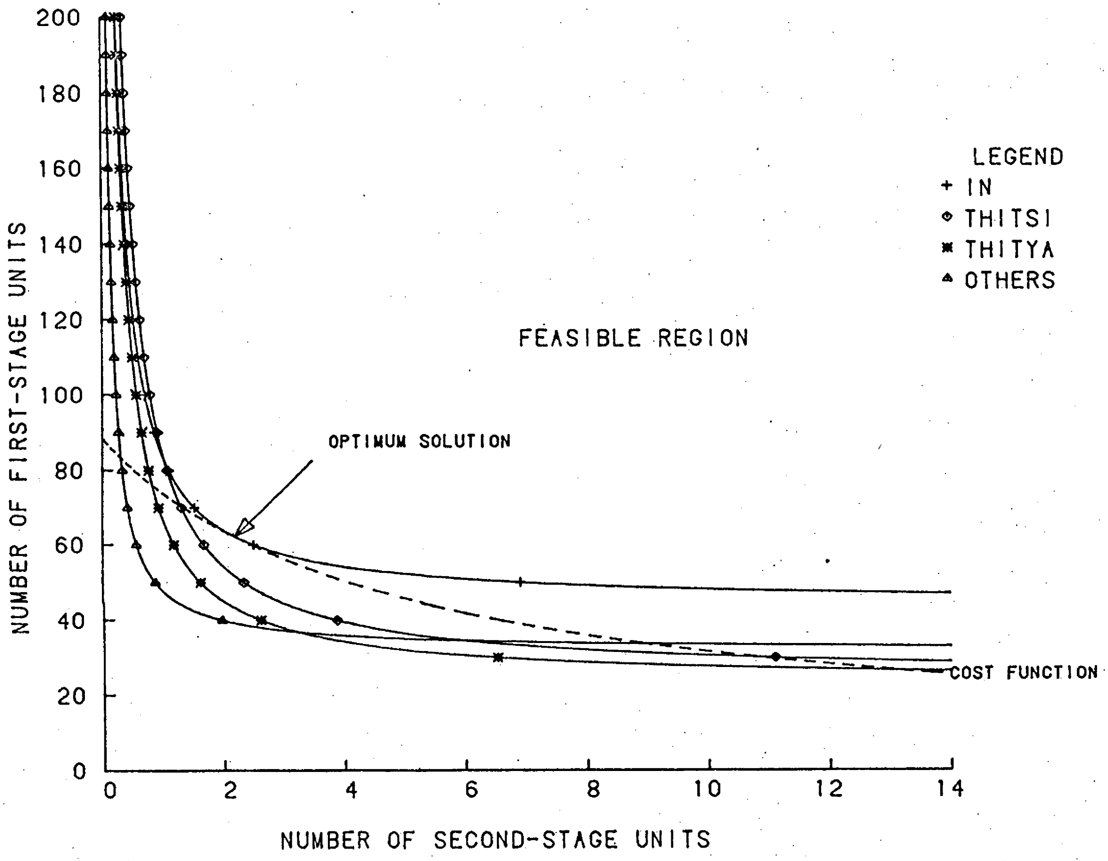

Fig. 6.2 Optimum number of sampling units, Indainggon reserve

Sensitivity of solution to changes in desired precision

The optimum will vary if the variances between the FSUs and SSUs or the precision requirements are changed assuming the inventory cost is kept constant. Table 6.3 illustrates this for different sub-populations of species or species groups and size classes.

For the BTA reserves, if a 15% standard error had been the desired precision for all 5 species then the number of FSUs required would have been 161. On the other hand, the number of FSUs would have been reduced to 90 if the precision had been set to 20% for all species. A 15% standard error could be achieved with 43 FSUs each of 5 SSUs if the girth limit for all species is reduced to 1.5 m (the minimum merchantable girth limit of hardwood species other than teak).

For the same reserve, all commercial species apart from teak were combined into groups according to the classification used for royalty assessment, as detailed in Appendix IV. One hundred and three FSUs each of 5 SSUs would be enough to achieve a 15% standard error for teak and the other species groups greater than exploitable girth.

For Indainggon reserve, 2 to 4 SSUs per FSU are needed for all alternatives considered in Table 6.3. The variability between the SSUs within the FSUs is larger for the BTA reserves than for Indainggon reserve, indicating that the FSUs in the BTA reserves are internally heterogeneous. Therefore more SSUs are required per FSU in the BTA reserves.

For Indainggon reserve, the optimum number of sampling units to achieve 15% standard error for all set species in two different size classes, exploitable girth and greater than 1.5 m gbhob, is the same because the exploitable girth of other species apart from 'in' was set

Table 6.3 Optimum number of sampling units

Area	Species	Size class	Required precision (standard error %)	Optimum number of FSUs	Optimum number of SSUs per FSU
BTA reserves	5 species*	exploitable girth +	) 15% for teak) 20% for others	) 103)	) 4)
	"	"	15% for all spp.	161	5
	"	"	20% "	90	5
	"	1.5 m gbhob +	15% "	43	5
	5 spp. groups	exploitable girth +	15% for all groups	103	4
Indainggon	4 species✱	exploitable girth +	) 15% for 'in') 20% for others	) 64)	) 2)
	"	"	15% for all spp.	70	4
	"	"	20% "	40	4
	"	1.5 m gbhob +	15% "	70	4

* Teak, pyinkado, padauk, ingyin, other commercial species

✱ 'In', thitsi, thitya, other commercial species at 1.5 m gbhob. In both cases 'in' is not involved in determining the optimum number of sampling units.

6.3 Optimum Sample Sizes with Optimum Allocation

In Sections 5.6.3 and 6.2, proportional allocation of FSUs to each stratum with equal number of SSUs per FSU was assumed. If rough estimates of the means and variances of the various subpopulations of interest and the cost of the inventory for the two different stages for different strata were available from the pilot survey then the optimum allocation of FSUs with equal numbers of SSUs could be determined.

For example, let the cost function be:

$$C = \sum_{h=1}^{L} \left[c_{oh} \sqrt{n_h} + c_{1h} n_h + c_{2h} n_h m \right] \tag{6.10}$$

where n_h = number of FSUs in the h^{th} stratum

m = number of SSUs per FSU in all strata.

The variance function for stratified two-stage sampling for the j^{th} subpopulation is:

$$\mathrm{Var}_j(\bar{\bar{y}}_{st}) = \sum_{h=1}^{L} W_h^2 \left[\frac{S_{uhj}^2}{n_h} + \frac{S_{2hj}^2}{n_h m} \right] \tag{6.11}$$

where S_{uhj}^2 = component of the variance between FSUs in the h^{th} stratum

S_{2hj}^2 = variance between SSUs within a FSU in the h^{th} stratum.

Let $x_{1h} = \frac{1}{n_h}$ and $x_2 = \frac{1}{m}$, and then

$0 < x_{1h} \leqslant 1$ and $0 < x_2 \leqslant 1$

Then the problem is to minimise the objective function

$$\phi = \sum_{h=1}^{L} \left[c_{oh}/\sqrt{x}_{1h} + c_{1h}/x_{1h} + c_{2h}/(x_{1h}\ x_2) \right] \qquad (6.12)$$

subject to the constraints:

$$\begin{array}{l}
\sum_{h=1}^{L} W_h^2 \ (S_{uh1}^2 \ x_{1h} + S_{2h1}^2 \ x_{1h} \ x_2) \leqslant v_1 \\
\sum_{h=1}^{L} W_h^2 \ (S_{uh2}^2 \ x_{1h} + S_{2h2}^2 \ x_{1h} \ x_2) \leqslant v_2 \\
\vdots \\
\sum_{h=1}^{L} W_h^2 \ (S_{uhp}^2 \ x_{1h} + S_{2hp}^2 \ x_{1h} \ x_2) \leqslant v_p
\end{array} \qquad (6.13)$$

$$0 < x_{1h} \leqslant 1 \quad \text{and} \quad 0 < x_2 \leqslant 1$$

where v_j = maximum fixed sampling variance for the required j^{th} subpopulation ($j = 1,2,\ldots\ldots,p$).

If there are L strata, there will be L values of FSU and one value of SSU to be estimated and the number of constraints will be $(2(L+1)+p)$.

The optimum number of FSUs and SSUs for each stratum is calculated using the inventory data of the two study areas. Although costs may vary between strata, the costs in this instance are assumed to be the same because separate data for each stratum were not available.

The species, size classes and required precision levels in Tables 6.1 and 6.2 in Section 6.3 were used in the calculation of the optimum number of FSUs (with equal number of SSUs) for different strata with optimum allocation. Unbiased estimate of S^2_{uh} and S^2_{2h} for each subpopulation were obtained from Equation 5.10. The optimum number of FSUs and SSUs in each stratum and the corresponding total cost of inventory for both study areas were then calculated and these are listed in Table 6.4. These values are also compared with the values from proportional allocation and the actual inventories.

With optimum allocation, the optimum number of FSUs varies between strata in both study areas. In this study, as the cost of inventory is assumed to be the same in all strata for each study area, the optimum number of FSUs depends on the variability between the FSUs of the key subpopulations in each stratum.

Although the optimum number of SSUs per FSU is more for optimum allocation than proportional allocation, the total number of FSUs in the optimum allocation decreases appreciably in both study areas. Consequently, the total cost of inventory reduces slightly with the optimum allocation.

In the actual inventory, although the number of FSUs used was near optimum, the number of SSUs per FSU was much higher than the optimum. Therefore, the total costs of inventory were much higher than was necessary.

Optimum allocation is desirable if the required data for each stratum are available from previous inventory or from pilot survey, as it is more efficient.

Table 6.4 Optimum number of FSUs and SSUs for each stratum and total cost

Reserve	Stratum No.	Optimum allocation			Proportional allocation			Actual inventory		
		Optimum number		Total cost (A$)	Optimum number		Total cost (A$)	Number of		Total cost (A$)
		FSUs	SSUs per FSU		FSUs	SSUs per FSU		FSUs	SSUs per FSU	
BTA	1	16	6	2310.77	21	4	2364.65	20	14	4326.20
	2	12	6		21	4		20	14	
	3	17	6		21	4		20	14	
	4	13	6		21	4		20	14	
	5	25	6		21	4		20	14	
		83			105			100		
Indainggon	1	6	4	1221.36	11	2	1412.89	10	14	2844.63
	2	10	4		11	2		10	14	
	3	7	4		11	2		10	14	
	4	3	4		11	2		10	14	
	5	14	4		11	2		10	14	
	6	3	4		11	2		10	14	
		43			66			60		

CHAPTER 7

DETERMINATION OF ALLOWABLE CUT AND ITS PRECISION

7.1 Introduction

The general object of management of the mixed tropical forests of Burma is to achieve maximum sustained yield, whether for local consumption or for export, while improving the capital value of the forests (Anon., 1957). Under ideal conditions with the optimum level of growing stock, maximum allowable cut should be set equal to the current growth of the forest. At present, allowable cut is determined as the number of trees reaching an exploitable size.

The allowable cut for teak is usually calculated using data from complete enumeration (Section 2.4) collected in other forestry operations. In recent years, the allowable cut has also been calculated for a few forests from data obtained by sampling.

Since a number of estimates, for example a stand table and growth and mortality data, involved in this calculation of allowable cut are each subject to sampling error, the estimate of allowable cut will be subject to error. It is desirable that the forest manager be able to calculate these sampling errors so that he can calculate the reliability of the estimate of the allowable cut.

7.2 Allowable Cut Using Data from Complete Enumeration

The allowable cut is calculated by felling series for which the felling cycle is usually fixed at 30 years in both the TSWC and CSWC. Experience has shown that a 30-year cycle allows sufficient trees of exploitable size to accumulate thus enabling the areas girdled each year to be utilised profitably (Anon., 1957).

In the TSWC, the allowable cut of teak is determined from data gathered during the last girdling operation and is usually defined as the number of trees of exploitable size. Most of these trees are those in the girth class 0.3 m below the exploitable girth limit at the last enumeration.

Data for the whole felling series are seldom available when the allowable cut is calculated or revised. In areas where there is no information, the allowable cut is estimated from adjacent areas of the felling series which have already been logged (Anon., 1957). The allowable cut is adjusted when more information is available, generally at intervals of less than five years. Essentially, the yield regulation method for teak in Burma is by area control, subject to a volume check based on the number of trees exceeding a fixed girth limit. Yield calculations are revised frequently to avoid violent fluctuations (Kyi, 1961).

In the CSWC, the allowable cut for other hardwoods is generally determined by area control because detailed information on stocking is generally not available.

7.3 Allowable Cut Using Data from Sampling

7.3.1 Data

The following estimates for teak can be derived from current forest inventory data based on sampling:

1. Stand table by 0.15 m gbhob classes
2. Precision for each class of the table

3. Sampling covariance of the estimates of the number of trees in the various girth classes
4. Time of passage through the girth classes, obtained by increment boring

The relevant data for teak in the BTA reserves are shown in Tables 7.1 and 7.2.

Arbitrary values of survival per cent for each girth class have been adopted*.

Table 7.1 Number of trees per ha and time of passage through various girth classes - BTA reserves

Gbhob class (m)	Number of trees per ha	Survival (%)	No. of trees per ha reaching exploitable size	Mean time of passage (yrs)	Variance** of time of passage
2.26+	0.36	97	0.35	exploitable size class	
2.11-2.25	0.27	97	0.26	18	0.8100
1.96-2.10	0.33	95	0.32	17	0.7225
1.81-1.95	0.47	85	0.40	17	0.7225
1.66-1.80	0.54	75	0.41	17	0.7225
1.51-1.65	0.62	65	0.40	17	0.7225
1.36-1.50	0.70	57	0.40	16	0.6400
1.21-1.35	0.79	50	0.39	16	0.6400
1.06-1.20	0.87	43	0.37	16	0.6400

*Since there is no information available about survival per cent, the author has adopted what appears to be a realistic estimate.

**This column is derived from the data on mean time of passage through a girth class and assumes that the standard error of the time of passage is 5% of the mean for all classes.

7.3.2 Determination of the allowable cut (yield)

These data (Tables 7.1 and 7.2) may then be used to determine the

Table 7.2 Variance-covariance matrix of number of trees per ha which can reach exploitable size (2.26 m gbhob+) from different girth classes for the BTA reserves

Gbhob class (m)	2.26+	2.11-2.25	1.96-2.10	1.81-1.95	1.66-1.80	1.51-1.65	1.36-1.50	1.21-1.35	1.06 1.20
2.26+	.0043								
2.11-2.25	.0017	.0012							
1.96-2.10	.0012	.0007	.0014						
1.81-1.95	.0008	.0007	.0007	.0012					
1.66-1.80	.0006	.0008	.0007	.0009	.0014				
1.51-1.65	.0008	.0008	.0007	.0009	.0011	.0013			
1.36-1.50	.0003	.0006	.0005	.0008	.0012	.0009	.0017		
1.21-1.35	.0003	.0004	.0002	.0005	.0008	.0006	.0010	.0011	
1.06-1.20	.0004	.0005	.0002	.0005	.0009	.0007	.0012	.0010	.0013

allowable cut by stand-table projection in which the following assumptions are made:

1. The trees of a girth class are evenly distributed within that class and move through a class at the same rate.
2. The survival per cent for each girth class remains constant in a felling cycle period.

Allowable cut is calculated at the beginning of the felling cycle.

Let i denote the i^{th} girth class in descending order of size i to 0, where 0 represents the class of exploitable size.

x_i = number of trees per unit area in the i^{th} girth class

s_i = survival per cent in the i^{th} girth class to reach the exploitable girth class

y_i = number of trees of the i^{th} girth class per unit area which reach the exploitable size

t_i = time of passage to pass through the i^{th} girth class to the next higher class

T_i = cumulative total of time of passage from the first to the i^{th} girth class, i.e. $T_i = \sum_{k=1}^{i} t_k$,

$T_i = 0$ if $i \leqslant 0$

n = number of girth classes

The above values are illustrated in Table 7.3.

Let p be the number of years in a felling cycle. Assuming that the whole felling series is worked over in p years in the j^{th} felling cycle, i.e. each successive annual coupe is logged in its due year, then $\sum_{i=1}^{n} a_{ij} y_i$ trees would exceed the exploitable girth. The coefficient a_{ij} is defined as follows:

Table 7.3 Information available to determine the allowable cut

Gbhob class (m)	Number of trees per unit area	Survival (%)	Number of trees per unit area which can reach exploitable class	Time of passage (yrs)	Cumulative total of time of passage (yrs)
2.26+	x_0	s_0	y_0		exploitable girth limit
2.11-2.25	x_1	s_1	y_1	t_1	T_1 $(= \sum_{k=1}^{1} t_k)$
1.96-2.10	x_2	s_2	y_2	t_2	T_2
|	|	|	|	|	|
|	|	|	|	|	|
|	|	|	|	|	|
|	|	|	|	|	|
|	|	|	|	|	|
|	|	|	|	|	|
|	|	|	|	|	|
0.61-0.75	x_n	s_n	y_n	t_n	T_n $(= \sum_{k=1}^{n} t_k)$

(i) If $T_i \leqslant (j-1)p$, $a_{ij} = 0$ (7.1)

(ii) If $T_{i-1} \leqslant (j-1)p \leqslant T_i$ (7.2)

and if $T_i \leqslant jp$; then $a_{ij} = \dfrac{T_i - p(j-1)}{t_i}$

but if $T_i > jp$; then $a_{ij} = \dfrac{p}{t_i}$

(iii) If $(j-1)p < T_{i-1} \leqslant jp$ (7.3)

and if $T_i \leqslant jp$; then $a_{ij} = \dfrac{T_i - T_{i-1}}{t_i}$

but if $T_i > jp$; then $a_{ij} = \dfrac{jp - T_{i-1}}{t_i}$

(iv) If $T_{i-1} \geqslant jp$; $a_{ij} = 0$ (7.4)

Although $\sum_{i=1}^{n} a_{ij}\, y_i$ trees would exceed the exploitable girth, only half of them are assumed to occur in that felling cycle period. All the trees reaching the exploitable girth could not be found in that felling cycle as cutting proceeded annually from the 1^{st} to the p^{th} coupe. In other words, the number of trees cut on the annual coupe in the middle of the felling cycle constitutes the average annual cut for the cycle. Therefore the total yield for the first cycle is:

$$\text{Yield for FC}_1 = y_0 + \tfrac{1}{2} \sum_{i=1}^{n} a_{i1}\, y_i \qquad (7.5)$$

For the second and later cycles, the total yield will be one half of the recruitments in the current and previous cycles, i.e.

$$\text{Yield for FC}_j \text{ cycle} = \tfrac{1}{2} \sum_{i=1}^{n} (a_{ij-1} + a_{ij}) y_i \qquad (7.6)$$

7.3.3 Precision of the estimate of allowable cut (yield)

If the time of passage and survival per cent of each girth class are known accurately, and the variances and covariances of the number of trees per unit area in each girth class can be estimated, then the variance of the total yield (allowable cut) in the first cycle is:

$$\text{var}\ (FC_1\ \text{yield}) = \text{var}\ (y_0) + \tfrac{1}{4} \sum_{i=1}^{n} a_{i1}^2\ \text{var}\ (y_i) + \sum_{i=1}^{n} a_{i1}\ \text{cov}(y_0,y_i)$$

$$+ \tfrac{1}{4} \sum_{i \neq}^{n} \sum_{k}^{n} a_{i1}\ a_{k1}\ \text{cov}\ (y_i,y_k) \qquad (7.7)$$

Similarly, the variance of the estimated yield for the second and later cycles is:

$$\text{var}\ (FC_j\ \text{yield}) = \tfrac{1}{4} \sum_{i=1}^{n} (a_{ij-1} + a_{ij})^2\ \text{var}\ (y_i)\ +$$

$$\tfrac{1}{4} \sum_{i \neq}^{n} \sum_{k}^{n} (a_{ij-1} + a_{ij})\ (a_{kj-1} + a_{kj})\ \ \text{cov}\ (y_i,y_k) \qquad (7.8)$$

The confidence limit for the calculated yield is:

$$\text{Yield for } j^{th} \text{ cycle} \pm t_{0.05}\ \sqrt{\text{var (yield for } j^{th} \text{ cycle)}}$$

where $t_{0.05}$ = tabulated value of the 't' statistic at 95% confidence level.

In Equations 7.7 and 7.8, the coefficients a_{ij} depend on the t values (time of passage) of those girth classes which are larger than the i^{th} girth class. The time of passage values are not known exactly. The estimated time of passage of teak for each girth class is obtained by ring counting following increment boring. Teak trees for ring counting are sampled for each girth class enabling the sampling error of the time of passage for each class to be calculated. This error should be allowed for in calculating the confidence limits of the estimated yield. However, including it complicates the problem even though survival per cents are assumed to be free of sampling error because, since y and t are random variables, the calculated yield is also a random variable and the probability distribution of the yield is a function of the probability distribution of y and t. If t is also subject to sampling error, the sampling error of the estimate of yield cannot be derived directly by analytical methods because of the complex relationship of yield and the variables y and t. So, for this study, a Monte Carlo approach was used to derive the sampling error of the estimate of yield.

Monte Carlo method I

Let us first assume that t_is (times of passage through the various girth classes) are independently and normally distributed with mean $\mu_i(t)$ and variance $\sigma_i^2(t)$. Then, if we write

$$t_i = \sigma_i(t)\ Z_i + \mu_i(t) \tag{7.9}$$

where $i = 1, 2, \ldots\ldots\ldots\ldots, n$

then the Z_is are independently and normally distributed with zero mean and unit variance. If we select a set of random values of Z using a random number generator, then for each such set, a corresponding set of values of t can be obtained by Equation 7.9. For each such set of t values, the corresponding set of 'a' coefficients can be calculated by Equations 7.1-7.4. Once a large number of sets of the 'a' coefficient are available, then the variances and covariances of 'a' can be estimated.

As it is assumed that the variances and covariances of y (number of trees per unit area in each girth class) are known already together with the variances and covariances of the a's, the variance of the yield can be estimated from Equations 7.10 and 7.11. These equations are based on a Taylor series expansion of the expression for estimating yield, but dropping terms beyond the first order (Kendall and Stuart, 1958).

The variance of the estimated yield for the first cycle is:

$$\text{var }(FC_1 \text{ yield}) = \text{var}(y_0) + \sum_{i=1}^{n} a_{i1} \text{ cov}(y_0,y_i) + \frac{1}{4} \sum_{i=1}^{n} \sum_{k=1}^{n} a_{i1} a_{k1} \text{ cov}(y_i,y_k) + \frac{1}{4} \sum_{i=1}^{n} \sum_{k=1}^{n} y_i y_k \text{ cov }(a_{i1},a_{k1}) \qquad (7.10)$$

The variance of the estimated yield for the second and later cycles is:

$$\text{var }(FC_j \text{ yield}) = \frac{1}{4} \sum_{i=1}^{n} \sum_{k=1}^{n} \text{cov}(y_i,y_k)(a_{ij} + a_{ij-1})(a_{kj}+a_{kj-1}) + \frac{1}{4} \sum_{i=1}^{n} \sum_{k=1}^{n} y_i y_k \left\{ \text{cov }(a_{ij},a_{kj}) + \text{cov}(a_{ij},a_{kj-1}) + \text{cov}(a_{ij-1},a_{kj}) + \text{cov}(a_{ij-1},a_{kj-1}) \right\} \qquad (7.11)$$

where $\text{cov}(a_{ij},a_{kj}) = \text{var}(a_{ij})$, if $i=k$.

Monte Carlo method II

The neglect of higher order terms from the Taylor series expansion inevitably casts some doubts on the accuracy of Equations 7.10 and 7.11. However, we can also apply the Monte Carlo method in another way to get the sampling error of the estimated yield by generating the probability distribution of yield. For this, we generate a large number of values of the random variable t, as in the above case, and also of the random variable y by an extension of the technique of Tocher (1969, Sec. 2.7), viz:

Assuming that the y's are multinormally distributed with means $\mu_i(y)$, $(i = 1, \ldots\ldots, n)$ and variances and covariances $\sigma_{ij}(y)$, $(i,j = 1, \ldots\ldots, n)$ then:

$$y_1 = \alpha_{11}U_1 + \mu_1(y)$$

$$y_2 = \alpha_{21}U_1 + \alpha_{22}U_2 + \mu_2(y)$$

$$\begin{matrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{matrix}$$

$$y_n = \alpha_{n1}U_1 + \ldots\ldots + \alpha_{nn-1}U_{n-1} + \alpha_{nn}U_n + \mu_n(y)$$

$$\text{In general } y_j = \sum_{k=1}^{j} \alpha_{jk} U_k + \mu_j(y) \qquad (7.12)$$

$$\text{where } \alpha_{ii} = \sqrt{(\sigma_{ii} - \sum_{k=1}^{i-1} \alpha_{ik}^2)}$$

$$\alpha_{ij} = \frac{\sigma_{ij} - \sum_{k=1}^{j-1} \alpha_{ik}\alpha_{jk}}{\alpha_{jj}}, \quad i > j$$

The U's are independently and normally distributed with zero mean and unit variance. So, if we generate a large number of values of the random variable U, the corresponding sets of values of the y's will be obtained by Equation 7.12. And for each set of values of the random variables t and y generated in this way, the corresponding yield can be calculated by Equations 7.1-7.4. Finally, the variance of the estimated yield can be calculated from a large number of random estimates of yield.

Both Monte Carlo methods were applied in determining the sampling error of the estimated yield and gave essentially the same result.

7.3.4 Results

The BTA reserves were treated as a felling series. A felling cycle of 30 years and an exploitable girth of 2.26 m for teak were used in subsequent calculations.

(a) Treating the time of passage as a fixed variable

The total yield for different felling cycles and the associated confidence limits were calculated using Equations 7.5-7.8. The results are summarised in Table 7.4.

Table 7.4 Estimated yield (number of trees greater than 2.26 m gbhob) in the BTA reserves

Felling cycle	Estimated yield per ha & 95% confidence limits	Half-interval as % of estimated yield
FC1 (0-30 yrs)	0.59 ± 0.171	29.0
FC2 (31-60 yrs)	0.58 ± 0.101	17.4
FC3 (61-90 yrs)	0.70 ± 0.110	15.7
FC4 (91-120 yrs)	0.73 ± 0.116	15.9

The immediate concern is the yield for the first felling cycle. The confidence interval for yield in this cycle is the widest because there is greater variation in the number of trees in the larger girth classes per unit area than in the number of trees in the smaller girth classes per unit area, and it is from the larger girth classes that the yield of the first felling cycle is derived. However, this is the most important felling cycle and the most precise estimates of yield are required for it. The estimated yields for the later cycles (2nd, 3rd, etc.)

are calculated only to illustrate the possible trend in these cycles. Although the yields increase in the 3rd and 4th cycles, they are subject to many sources of error especially in estimating survival per cent in the smaller size classes over a long period.

(b) Treating time of passage as a stochastic variable

The variance of the estimated yield was also calculated by Monte Carlo methods taking into account both the variabilities of the number of trees in the stand table and the time of passage through the girth classes. Then, the 95% confidence limits of the estimated yield for different cycles can be calculated as follows:

$$\mu_j \pm 1.96\ \sigma_j$$

where μ_j = estimated yield

σ_j^2 = variance of the estimated yield.

The 95% confidence limits of the estimated yield were calculated for each of several different levels of sampling error of time of passage and the results are summarised in Table 7.5 and also presented in Fig. 7.1.

In the first felling cycle, the confidence limits of the estimated yield increases very little (3.5% at 95% confidence level) with increase in standard error of time of passage from 0-20%. This is due to the fact that the number of trees above exploitable size are not affected by the time of passage in the yield calculation for this cycle. In the later cycles, the standard error of time of passage has a greater effect and increases the 95% confidence limits of the estimated yield by 8.5% to 13.1% in different felling cycles.

The yield for species other than teak cannot be calculated in the same way as neither time of passage nor growth data are available from current inventory.

Table 7.5 Estimated yield (number of trees/ha greater than 2.26 m gbhob) and 95% confidence limits

Felling cycle	Estimated yield per ha (No. of trees)	Without sampling error of time of passage	Standard error (%) of time of passage			
			5%	10%	15%	20%
1	0.59	±0.171 (29.0%)	±0.174 (29.5%)	±0.177 (30.0%)	±0.183 (31.0%)	±0.192 (32.5%)
2	0.58	±0.101 (17.4%)	±0.108 (18.6%)	±0.126 (21.7%)	±0.151 (26.0%)	±0.180 (30.5%)
3	0.70	±0.110 (15.7%)	±0.118 (16.9%)	±0.135 (19.3%)	±0.160 (22.9%)	±0.189 (27.0%)
4	0.73	±0.116 (15.9%)	±0.122 (16.7%)	±0.136 (18.6%)	±0.156 (21.4%)	±0.178 (24.4%)

Note: Half confidence intervals in per cent of the estimated yield are shown in brackets.

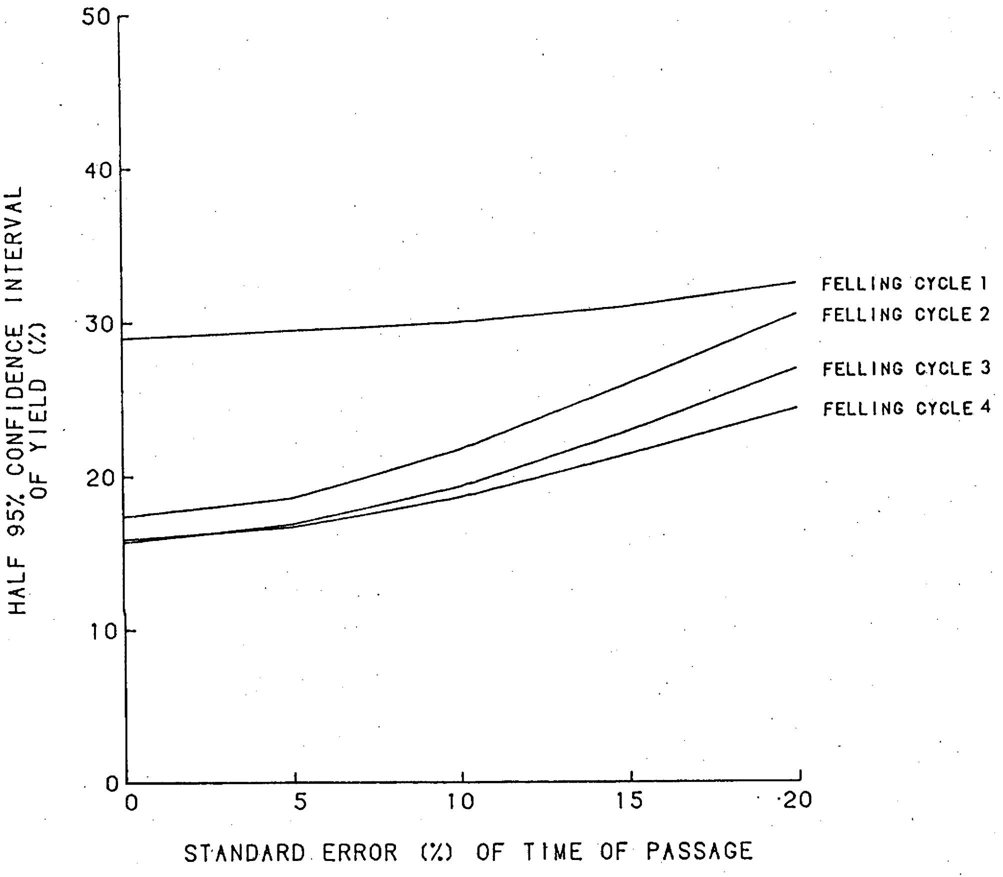

Fig. 7.1 Relationship between standard error of time of passage and sampling error of yield

CHAPTER 8

FUTURE FOREST INVENTORY IN BURMA

8.1 Introduction

The mixed tropical forests of Burma play such an important role in the country's economy that they must be managed skilfully if maximum sustained yield is to be achieved in perpetuity. Up-to-date stand table information for both teak and other important species of hardwoods is necessary for sound management planning. A 100% enumeration of teak above a defined girth limit (1.2 m (4 feet)) and other hardwoods marginally below the exploitable girth limit, carried out during other forest operations, does not and cannot provide the required information. Such enumerations cover only a small area and are carried out annually as a forerunner to extraction. They are therefore essentially operational inventories.

8.2 Management Inventory by Sampling

Management inventory is needed to collect up-to-date and precise information of the whole forest within a short period for long term planning. The most important consideration of forest management for timber production is the allowable cut. This, of necessity, is an estimate since growth and mortality cannot be determined exactly due to numerous stochastic influences,e.g. climatic fluctuations. It is obvious that such information can be obtained efficiently by sampling due to its advantages such as reduced cost, greater speed, greater scope, and so on.

The main problem in planning a forest inventory by sampling on a large scale is deciding the type of information required. The general tendency in a developing country like Burma is to collect as much information as possible as so little is known about the resource. However, inventory is expensive and any data collected should have a use. The cost of obtaining information which has no immediate use can be substantial. Moreover, recording procedures become more complicated which increases the possibility of non-sampling errors being introduced.

Possible methods of estimating allowable cut and its precision for different felling cycles were analysed in Chapter 7 using available inventory data. Sampling errors of the stand table and of the time of passage of teak through various girth classes were considered in calculating the precision of the cut estimate. The results showed that, in the first felling cycle, the confidence intervals for the estimated allowable cut were wider than in later cycles due to the larger sampling errors attached to stocking in the larger girth classes (Table 7.4). However, this felling cycle is the most important because cutting is imminent and more precise estimates are required for it.

Owing to the uncertainty of the survival per cent in the smaller size classes, the allowable cuts in the 2nd and later cycles cannot be determined precisely. Therefore the sampling errors of the smaller size classes tend to be of little significance in determining the precision of the allowable cut estimate, i.e. it is pointless obtaining more precise estimates for these classes when other errors are so significant. Lesser precision in the smaller size classes will suffice than in the larger size classes. A better approach to reduce the cost of inventory is to decide on the required precision for each species and girth class and design an inventory to meet these precision requirements.

8.3 Efficiency of Sampling Methods

The available resources of the organisation have an important bearing on inventory design. A compromise between theoretical or desirable statistical requirements and practical execution within the limits of available resources must be reached. Therefore, forest inventory must be designed to collect as much information of the required precision as possible consistent with the resources (money, time, labour) available.

8.3.1 Stratification

The statistical advantages of stratification are well known and have been discussed in Chapter 3. Stratification is usually carried out utilising any available information about the forest to be inventoried. Aerial photographs are extremely useful for inventorying extensive areas of tropical forest because the cost of ground survey is so expensive due to the character of the forests, the climate and lack of communication. Aerial photos are used for both stratification as a preliminary to sampling and ground location of the sampling units.

In Burma, stratification is generally carried out from aerial photographs and from forest type maps compiled during other forest operations. Owing to the shortage of skilled interpreters, and the poor quality and scale of the photos (1:50 000 and 1:20 000), only non-forested areas and a few forest types can be distinguished. Teak trees can be recognised if the photos are taken in the flowering season. The criteria used to define the various strata are therefore broad forest type and the stocking of the forest.

In the replicated sampling method described in Chapter 2, the blocks (strata) must be equal in area for convenience in calculating the precision of the estimates. Therefore, information from aerial photos and forest type maps is only used as a guide in fixing the boundaries of the blocks. Even with this limited stratification, the variabilities between the strata were considerable as the optimum number of FSUs required for each stratum varied from 12 to 25 in the BTA reserves and from 3 to 14 in Indainggon reserve (Table 6.4). Had the forests been stratified purely on the basis of natural features (e.g. forest type, stocking, topography) interpreted from aerial photos, it is likely that the variation within each stratum would have been reduced even further and that between strata increased. Consequently, a higher precision of estimate would be possible at the same sampling intensity or, conversely, a lower sampling intensity would achieve the same precision of the estimate. The calculation of the estimates and their precision becomes more complicated with stratification into blocks of unequal size but this is a less serious problem in Burma today with the increasing availability of modern computing facilities. Therefore, future stratification of the forests of Burma should be based on natural features using aerial photographs and forest type maps. This should reduce the cost of inventory for a given precision of estimate.

8.3.2 Optimum number of sampling units

Analysis of the optimum number of sampling units in stratified two-stage sampling with FSUs of equal size was described in Chapters 5 and 6 for teak-bearing and deciduous Dipterocarp forests. Assuming that the cost of inventory is the same in all strata, the number of FSUs varies with both the precision required and the variability of the key species. In both forest types, it was found that the number of SSUs could be reduced from 14 to 2-6 to achieve a standard error of the estimate of 15% for teak and 15-20% for less important but dominant hardwood species.

With an optimum number of FSUs and SSUs and proportional allocation of FSUs to different strata, the current cost of inventory could be reduced by about 45% and 48% in the BTA and Indainggon reserves respectively while achieving the required precision of the estimate for all species as set out in Chapter 6. With optimum allocation of FSUs to the strata, the reduction in the cost of inventory increases to 47% and 57% respectively in the two reserves mentioned.

This investigation has provided a lead in determining optimum sample size to achieve the required precision of estimate for various species and girth classes of interest. It is patently more efficient to determine the optimum number of FSUs and SSUs using an optimum allocation of FSUs to the strata. However, such allocation requires, in addition to information on area of the various strata, preliminary estimates of means and variances of the subpopulations of interest within each stratum. The optimum number of FSUs and SSUs using proportional allocation as determined in this study can be used as a guide for inventory of forests similar to those in the BTA and Indainggon reserves for which area estimates alone are available. However, extrapolation to other forest areas would depend on the similarity of these forests to those in the BTA and Indainggon reserves. As no two forests are exactly the same, caution should be exercised.

8.3.3 Variable sample size

Inventories are usually carried out to collect information for various subpopulations,e.g. different species and size classes. The stocking and variability of these subpopulations differ. Hence, the precision obtained for different subpopulations will also differ at the same sampling intensity. Larger size classes,e.g. those of exploitable size, are the most important and more precise estimates are required for these classes than for smaller classes. However, the stocking of larger size classes per unit area is low and the distribution is also heterogeneous. Consequently, to achieve the same precision a larger sample is required for the larger size classes than for the smaller size classes.

The size of sample needed to give the required precision in the larger size classes would give a precision in the smaller classes which might be much greater than is needed. For example, in Section 6.2 (Table 6.3) 165 FSUs with 5 SSUs each are required in the BTA reserves to achieve standard error of 15% for the exploitable size class (1.8 and 2.0 m+) of 5 important species. However, only 43 FSUs with 5 SSUs each are required to achieve the same precision if the exploitable size of these same species is reduced to 1.5 m. Different sampling intensities (i.e. varying number of FSUs, e.g. fewer FSUs in the smaller size classes) for the various size classes, or sampling with probability proportional to size, would therefore reduce the cost of inventory while achieving the required precision for each class. The reduced cost of measuring fewer trees in the smaller size classes might not be great because travelling to and establishing a FSU in tropical forests is much more time consuming than measuring trees on it. However, all possible ways of reducing the cost of inventory should be considered as inventory in tropical forests is very expensive.

8.4 Future Research

8.4.1 Volume tables

In Burma, the allowable cut is generally calculated as a number of trees, the corresponding volumes being computed by rule-of-thumb methods because volume tables (equations) generally do not exist. Construction of volume tables for teak and other important hardwood species or species groups is therefore needed to improve volume estimates of the allowable cut.

8.4.2 Growth and mortality data

If the forest is to be managed on a sustained yield basis, then information on growth and mortality is essential both as a measure of effect of silvicultural treatment and a basis for estimating future growth.

One method of estimating growth is by ring counts on cores obtained by increment boring. In Burma, however, hardwood species other than teak generally do not produce well defined annual rings. Therefore there is no substitute for some form of re-measurement of the forest. Moreover, Cunia (1968) points out that growth estimated by ring counting is commonly biased because one of the main components of net growth, namely mortality, is not measured and selection of sample trees is usually not at random.

Sampling on successive occasions seems appropriate in the design of inventories of the mixed tropical forests of Burma in order to collect essential information required for long term management planning. In some forests, it has been shown that the most efficient method of obtaining estimates of current state and past growth is by sampling with partial replacement (Cunia, 1976). The optimum number of old permanent plots to be measured and number of temporary new plots to be established can be calculated in order to achieve the required precision at minimum cost (Hazard and Promnitz, 1974). No work has been done in Burma on this aspect yet, but the potential gains in efficiency are such that the matter should be investigated.

Based on growth data collected from measurement of the forest, future growth can be predicted using appropriate methods assuming stocking, weather and treatments are unchanged.

8.4.3 Growth and yield models

Some accessible mixed tropical forests of Burma must be managed intensively by heavy selective logging and silvicultural treatment to improve long term productivity. Although in less intensively managed forests future short term yields can be estimated based on the immediate past increment data from measurements of successive occasions, this is unlikely to suffice for intensively managed forests. It is desirable to know the volume yields at different stages under a wide range of silvicultural strategies to justify the heavy investment. Long term yield will depend on the growth response of stands managed under a particular silvicultural strategy. Therefore, establishment of experimental or research plots is essential to monitor growth trends under various strategies. Growth and yield models, developed from the data on stand and forest dynamics collected from the experimental plots are very useful in stand and forest simulations under present day intensive forest management. Once the growth and yield models have been developed, an inventory of the present state of the forest is all that is required to predict possible future yield following specific treatment of the forest.

8.5 Conclusion

With the increasing demand in Burma for wood and wood-based products for both local consumption and export and the tremendous pressure on forest land for expanding the agricultural base to allow for a fast-growing population, the relatively under-developed mixed tropical forests of Burma are becoming more important than ever before. Old concepts and techniques in forest management practice must give way to new outlooks and methodologies to cater for advances in technology and new utilisation trends. Management inventory in Burma must be planned and carried out utilising, wherever possible, modern remote sensing techniques, biometric and mensuration methods and electronic computers, to collect and process more efficiently the data required by management.

The mixed tropical forests of Burma have been managed for over a hundred years and management and inventory procedures have been developed to meet management needs. However, the efficiency of these procedures and techniques must be examined from time to time. In this study, ways of improving the efficiency of sampling methods currently applying in the mixed tropical forests of Burma have been examined. Ways to calculate precision of allowable cut of teak using currently available inventory data have also been investigated. Wider use of modern techniques of sampling is needed in Burma to obtain up-to-date and precise estimates of the forest populations at minimum cost.

REFERENCES

Anon (1957). Working plans manual, Burma. Govt. Printing, Rangoon, Burma: 177pp.

Anon (1960). Policy and economic problems in the conversion of old-growth forests to management stands in Asia. Proc. Fifth World For. Congr., USA 1960: 1019-1023.

Anon (1969). Reconnaissance survey of lowland forests, Laos. Report prepared for the Royal Lao Government by CAID and USAID, Vientiane: 95pp.

Anon (1970-71). Pulpwood survey, 'in', Shwebo Forest Division. Report to the Ministry of Agri. and For., Forest Dept., Burma: 28pp.

Anon (1971). Burma's rice export problem. Economic division, Ministry of Foreign Affairs, Rangoon, Burma: 8pp.

Anon (1971-72). Report to the people by the Burmese Government. Table 10, pp.15 Central Press, Rangoon, Burma.

Anon (1972). Classification of land in forest circle, division, civil division and township. Working Plans Division, Forest Dept., Burma. Unpublished.

Anon (1974). Leaflet published by the Ministry of Foreign Affairs, Rangoon, Burma.

Anon (1975). Statistical Year Book. Central Statistical Organisation, Rangoon, Burma.

Avery, T.E. (1975). Natural resources measurements. 2nd ed. McGraw-Hill, New York: 339pp.

Bard, Y. (1967). Nonlinear parameter estimation and programming. Contributed programming library. IBM, New York: 154pp.

Bickford, C.A. (1961). Stratification for timber cruising. J.For. 59(10): 761-3.

Blandford, H.R. (1956). Highlights of one hundred years of forestry in Burma. Bur. For. VI(1): 12-22.

Carron, L.T. (1968). An outline of forest mensuration with special reference to Australia. ANU Press, Canberra, 224pp.

Chacko, V.J. (1962). Sampling in forest inventories. Ind. For. 88(6): 420-7.

Chacko, V.J., Rawat, A.S., Dave, P.C. and Singh, S. (1965). Bamboo pilot survey in Bori, Hoshangabad Forest Division. Ind. For. 91(7): 481-97.

Cochran, W.G. (1963). Sampling techniques. 2nd ed. John Wiley, New York: 413pp.

Cunia, T. (1968). Management inventory (CFI) and some of its basic statistical problems. J. For. 66(4): 342-50.

Cunia, T. (1974). Forest inventory sampling designs used in countries other than the United States and Canada. Inventory design and analysis. Proc. Soc. Am. For., Inventory Working Group, meeting Colo. State Univ. July 23-25, 1974: 76-110.

Cunia, T. (1976). Statistical advances in the methodology of forest inventory. Proc. 16th IUFRO Congr., Div. 4, Group 2, Norway: 128-39.

Dalenius, T. (1957). Sampling in Sweden. Contributions to the methods and theories of sample survey practices. Almqvist and Wiksell, Stockholm: 247pp.

Dawkins, H.C. (1957). Some results of stratified random sampling of tropical high forests. Paper presented to Brit. Comm. For. Conf. Canberra & New Zealand: 4pp.

Dawkins, H.C. (1958). The management of natural tropical high-forest with special reference to Uganda. Imp. For. Inst., Univ. of Oxford:155pp.

FAO (1973). Manual of forest inventory with special reference to mixed tropical forests. FAO, Rome: 200pp.

FAO (1974). The mixed Dipterocarp forests of Sarawak and their potential for development. FAO:DP/MAL/72/009 Tech. Rept. 7, FAO, Rome: 142pp.

FAO (1976). Forest resources in the Asia and Far East region. FAO, Rome: 40-41.

Ferguson, I.S. (1963). Inventory techniques in relation to management practices. M.F. thesis, School of For., Yale Univ. Unpublished: 71pp.

Fumbah, D.F. (1975). National forest inventory of Liberia. Report on the second FAO/SIDA training course, Nigeria. FAO, Rome: 188-90.

Griffith, A.L. (1945-46). The efficiency of enumerations. Ind.For.Serv. Leaflets 83-93, Dehra Dun.

Hall, O.F. (1966). Planning the inventory to meet management needs. Measuring southern forests. 15th annual For. Symp. Louis. State Univ.: 105-20.

Hansen, M.H., Hurwitz, W.N. and Madow, W.G. (1953). Sample survey methods and theory. Vol. 1 Methods and applications. John Wiley, New York: 638pp.

Hazard, J.W. and Promnitz, L.C. (1974). Design of successive forest inventories: Optimisation by convex mathematical programming. For. Sci. 20(2): 117-27.

Howard, J.A. and Lanly, J.P. (1975). Remote sensing for tropical forest surveys. Unasylva 27(108): 32-7.

Husch, B. (1969). Mensuration problems in tropical forest inventory. Proc. IUFRO Section 25, Working Group on mensuration of forest inventory in tropical countries. Reinbek, Germany: 235-44.

Husch, B. (1971). Planning a forest inventory. FAO For. & For. Products Studies No.17, FAO, Rome: 120pp.

Husch, B., Miller, C.I. and Beers, T.W. (1972). Forest mensuration. 2nd ed. Ronald Press, New York: 410pp.

Johnston, D.R. (1960). Problems of yield control and inventory in British forestry. For. 33(1): 19-36.

Johnston, D.R., Grayson, A.J. and Bradley, R.T. (1967). Forest planning. Faber and Faber, London: 541pp.

Kendall, M.G. and Stuart, A. (1958). The advanced theory of statistics. Vol. 1, Chapter 10, Charles Griffin, London: 433pp.

Kermode, C.W.D., Thein, Tin Htut and Aung Din (1957). The forest types of Burma. Bur. For. VII(1): 6-38.

King, K.F.S. (1975). It is time to make paper in the tropics. Unasylva 27(109): 2-5.

Kish, L. (1965). Survey sampling. John Wiley, New York: 643 pp.

Kokan, A.R. (1963). Optimum allocation in multivariate surveys. J. Roy. Stat. Soc. Series (A)126: 557-65.

Kyi, U. (1961). Teak yield regulation in Burma. Bur. For. XI(2): 109-15.

Lanly, J.P. (1975). Forest inventories in the Francophone countries of Africa. Report on the second FAO/SIDA training course on forest inventory, Nigeria. FAO, Rome: 178-87.

Loetsch, F. (1957). A forest inventory in Thailand. Unaslyva 11(4): 174-80.

Loetsch, F. and Haller, K.E. (1964). Forest inventory, Vol. 1, BLV Verlagsgesellschaft, Munich: 436pp.

Loetsch, F. (1975). An inventory of natural forests in Liberia. Report on the second FAO/SIDA training course, Nigeria. FAO, Rome: 191-8.

Marquardt, D.W. (1963). An algorithm for least squares estimation of nonlinear parameters. J. Soc. Ind. & App. Math. 11(2): 431-41.

Mathauda, J.S. (1957). Methods of forest surveys in India. Paper pres. to 7th Brit. Comm. For. Conf. Canberra & New Zealand: 5pp.

Myint Thein (1973). An economic review of forestry in Burma. M.Sc. thesis, ANU, Unpub. 214pp.

Myint Tin, Than Myint, Shwe Kyaw and Pe Thein (1968-69). Experiments on replicated sampling and related problems. For. Dept. Burma: 47pp.

Myint Tin, Than Myint, Shwe Kyaw and Pe Thein (1968-73). Forest inventory reports. For. Dept. Burma.

Myint Tin, Than Myint, Shwe Kyaw and Pe Thein (1971-72). Forest inventory report for Upper Chindwin/Myittha and West Katha Forest Divisions (In Burmese). For. Dept., Burma: 45pp.

Myint Tin, Than Myint, Pe Thein and Saw Win (1972-73). Forest inventory report for Shwebo Forest Division. (In Burmese). For. Dept., Burma: 40pp.

Myint Tin, Than Myint, Shwe Kyaw and Pe Thein (1973). A review of forest inventory in Burma 1963-72. For. Dept. Burma: 112pp.

Myint Tin, Than Myint, Shwe Kyaw, Pe Thein and Kyaw Tint (1975). A review of forest inventory in Burma. Comm. For. Rev. 54, 3/4: 305-9.

Nyyssonen, A. (1961). Survey methods of tropical forests. FAO, Rome: 71pp.

Sadler, D.R. (1975). Numerical methods for nonlinear regression. Qld. Univ. Press: 89pp.

Schlich, W. (1925). Schlich's manual of forestry, vol. III. Bradbury, Agnew, London: 397pp.

Serevo, T.S., Asiddas, F. and Reyes, M.R. (1962). Forest resources inventory in the Philippines. Phil. J. For. 18(1-4): 1-19.

Stebbing, F.P. (1962). The forests of India. Vol. IV. Oxford Univ. Press: 485pp.

Taha, H.A. (1971). Operation research. An introduction. Macmillan, New York: 703pp.

Thein, U. (1959). Fuelwood situation in Burma. Report prepared for the Asia-Pacific For. Comm. FAO, Rome: 115pp

Tocher, K.D. (1963). The art of simulation. The English Univ. Press, London: 184pp.

APPENDIX I

Area of reserved forests by forest circles and divisions

Serial No.	Forest circle/division	Area of reserved forest (sq. km)
1	Mandalay	
	1. Myitkyina	3124
	2. Bhamo	2080
	3. Mandalay/Maymyo	3457
	4. Meiktila	2276
	5. Dry zone	51
	6. Yamethin	1988
	7. Pyinmana	1909
	Total Mandalay circle	14 885
2	Eastern	
	1. Northern Shan State	1216
	2. Southern Shan State	4049
	3. Mongmit	2860
	4. Kayah	-
	Total Eastern circle	8125
3	Maritime	
	1. Henzada/Bassein	4342
	2. Delta	2860
	3. Arakan	1672
	4. Thaton/Ataran	1896
	5. Tavoy	11 654
	6. Pa-an	1330
	7. Kawkaraik	2867
	Total Maritime circle	26 621

APPENDIX I (cont)

Serial No.	Forest circle/division	Area of reserved forest (sq km)
4	Pegu	
	1. Prome	2719
	2. Zigon	1172
	3. Tharrawaddy	895
	4. South Pegu	2310
	5. North Pegu	2223
	6. South Taungoo	2567
	7. North Taungoo	1552
	8. Insein	1219
	Total Pegu circle	14 657
5	Magwe	
	1. Magwe	1703
	2. Yaw	3077
	3. Minbu	3731
	4. Thayetmyo	1538
	5. Chin Hills	1436
	Total Magwe circle	11 485
6	Sagaing	
	1. East Katha	2200
	2. West Katha	3442
	3. Shwebo	3901
	4. Lower Chindwin	2806
	5. Upper Chindwin	8120
	Total Sagaing circle	20 469
	Total Burma	96 242

APPENDIX II

List of species and groups of species separately recorded in the inventory of Burmese forests

Burmese name	Scientific name
1. Teak or Kyun	*Tectona grandis* Linn. f.
2. Pyinkado	*Xylia dolabriformis* Benth.
3. Anan	*Crypteronia pubescens* Blume.
4. Aukchinsa	*Diospyros chretioides* Wall.
5. Binga	*Mitragyna rotundifolia* O.Ktze.
6. Bonmeza	*Albizzia chinensis* (Osbeak) Merr.
7. Chinyok	*Garuga pinnata* Roxb.
8. Dahat	*Tectona hamiltoniana* Wall.
9. Hnaw	*Adina cordifolia* Hook.f.
10. In	*Dipterocarpus tuberculatus* Roxb.
11. Ingyin	*Pentacme siamensis* (Miq.) Kurz.
12. Kanyaung	*Dipterocarpus pilosus* Roxb.
13. Kanyin	*Dipterocarpus* spp.
14. Karawe	*Cinnamomum inunctum* Meissn.
15. Kaunghmu	*Anisoptera scaphula* (Roxb.) Pierre
16. Kokko	*Albizzia lebbek* Benth.
17. Kuthan	*Hymenodictyon excelsum* Wall.
18. Kyana	*Xylocarpus moluccensis* Lam.
19. Kyettuywesa	*Cratoxylon prunifolium* Dyer.
20. Kyilan	*Shorea assamica* Dyer.
21. Laukya	*Schima wallichii* Choisy
22. Leza	*Lagerstroemia tomentosa* Presl.
23. Linlum	*Sapium baccatum* Roxb.
24. Lunbo	*Buchanania lanzan* Spreng.
25. Maniauga	*Carallia brachiata* Merr.
26. Nabe	*Lannea grandis* Eng.
27. Nyan	*Quercus serrata* Thumb.
28. Odein	*Ailanthus triphysa* (Dennst)Alston.
29. Padauk	*Pterocarpus macrocarpus* Kurz.
30. Panga	*Terminalia chebula* Retz.
31. Peinnebo	*Palaguum polyanthium* Benth. & Hook
32. Petshut	*Grewia scabrophylla* Roxb.
33. Petwun	*Berrya ammonilla* Roxb.

APPENDIX II (cont)

Burmese name	Scientific name
34. Pinlekanazo	*Heritiera fomes* Buch.
35. Pyinma	*Lagerstroemia speciosa* Pers.
36. Sakawa	*Michelia champaca* Linn.
37. Sandawa	*Cardia fragrantissima* Kurz.
38. Sha	*Acacia catechu* Willd.
39. Sit	*Albizzia procera* Benth.
40. Talainggaung	*Bassia latifolia* Roxb.
41. Tamalan	*Dalbergia oliveri* Gamble.
42. Taukkyan	*Terminalia tomentosa* W. & A.
43. Taungpeinne	*Artocarpus chaplasha* Roxb.
44. Taungthayet	*Swintonia floribunda* Griff.
45. Tawthayet	*Mangifera caloneura* Kurz.
46. Thabye	*Eugenia* spp.
47. Thadi	*Protium serratum* Engler
48. Than	*Terminalia oliveri* Brandis
49. Tharapi	*Calophyllum amoenum* Wall
50. Thingadu	*Parashorea stellata* Kurz.
51. Thingan	*Hopea odorata* Roxb.
52. Thinwin	*Millettia pendula* Benth.
53. Thite	*Quercus* spp.
54. Thitka	*Pantace burmanica* Kurz.
55. Thitkado	*Cedrela toona* Roxb.
56. Thitkya	*Juglans regia* Linn.
57. Thitmagyi	*Albizzia odoratissima* Benth.
58. Thitpayaung	*Neonauclea excelsa* Blume.
59. Thitsi	*Melanorrhoea usitata* Wall.
60. Thitya	*Shorea oblongifolia* Thw.
61. Tinshu	*Pinus* spp.
62. Yamane	*Gmelina arborea* Roxb.
63. Yindaik	*Dalbergia cultrata* Grah.
64. Yingatgyi	*Gardenia coronaria* Ham.
65. Yinma	*Chukrasia tabularis* A.Juss.
66. Yon	*Anogeissus acuminata* Wall.
67. Zinbyun	*Dillenia pentagyna* Roxb.

APPENDIX II (cont)

Burmese name	Scientific name
68. Matchwood spp.	
(1) Didu	*Salmalia insignis* Schott & Endl.
(2) Letpan	*Salmalia malabarica* Schott & Endl.
(3) Sawbya	*Pterocymbium tinctorium* (Blanco) Merr.
(4) Kokhe	*Salmalia anceps* Schott & Endl.
(5) Ma-ulettanshi	*Anthocephalus cadamba* Miq.
69. Packing case spp.	
(1) Baing	*Tetrameles nudiflora* R. Br.
(2) Ma-ukadon	*Nauclea orientalis* Linn.
(3) Myauklok	*Artocarpus lakoocha* Roxb.
(4) Myaukngo	*Daubanga grandiflora* (Roxb.)Walp.
(5) Taungmeok	*Alstonia scholaris* R.Br.
(6) Gwe	*Spondias pinnata* (Linn.)
(7) Letkok	*Pterygota alata* (Roxb.) R.Br.
(8) Setkadon	*Trewia nudiflora* Linn.
(9) Wetshaw	*Firmiana colorata* Br.
70. Other spp.	

Bamboos

1. Kyathaungwa	*Bambusa polymorpha* Munro
2. Myinwa	*Dendrocalamus strictus* Nees.
3. Thaikwa	*Bambusa tulda* Roxb.
4. Thanawa	*Thyrsostachys oliveri* Gamble
5. Tinwa	*Cephalostachyum pergracile* Munro
6. Wabo	*Dendrocalamus brandisii* Kurz.
7. Wabomyetsangye	*Dendrocalamus hamiltonii* Nees.ex Arn.
8. Wapyu	*Dendrocalamus membranaceus* Munro
9. Wapyugyi	*Gigantochloa macrostachya* Kurz.

APPENDIX III

Number of trees per line (0.53 ha)

Species In

Size class 2.1 m+ gbhob

Indainggon reserve

Line no

Block	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1	4	1	0	1	0	0	1	0	0	0	0	0	10
	2	2	3	1	0	1	2	0	2	0	0	0	0	0	13
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	5
	0	1	0	0	0	0	0	0	0	2	2	1	1	1	8
	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
	5	6	7	8	2	6	2	3	4	4	6	3	0	3	59
II	4	7	4	11	6	7	7	1	9	1	6	4	4	2	73
	0	1	1	0	0	1	1	1	2	0	0	0	0	2	9
	1	0	0	1	2	1	2	1	0	2	2	1	0	1	14
	3	4	1	0	0	0	0	0	0	0	0	0	0	0	8
	0	1	0	0	2	0	0	0	1	1	0	0	0	0	5
	3	1	2	2	3	5	5	5	6	12	12	3	6	4	69
	3	2	1	2	4	3	1	0	0	0	0	1	1	0	18
	9	1	1	2	5	2	6	3	1	2	2	3	0	3	40
	4	6	2	2	1	1	1	0	1	0	1	0	0	1	20
	4	3	5	2	5	3	4	4	5	3	3	3	3	1	48
III	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
	1	0	3	2	3	0	3	4	1	9	6	6	4	7	49
	2	2	5	3	1	1	3	2	3	3	0	2	2	0	29
	2	2	4	2	2	0	1	1	3	2	1	0	1	3	24
	0	3	2	3	4	3	2	0	2	2	2	2	0	1	26
	8	1	4	4	2	5	2	1	2	2	3	5	3	3	45
	1	0	1	0	4	0	3	2	0	0	6	3	2	1	23
	0	0	0	1	1	0	0	0	1	0	0	1	0	5	9
	7	12	2	4	3	1	3	5	2	1	2	0	3	2	47
	2	4	5	4	1	1	4	3	4	5	5	4	3	5	50

APPENDIX III (cont)

IV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1	1	5	2	1	2	0	0	1	1	3	0	2	21
	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	1	1	1	0	0	3	1	3	2	0	0	2	14
V	6	5	4	9	7	5	6	6	3	5	2	7	3	5	73
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	6	2	3	7	4	5	4	9	3	5	6	6	5	68
	8	5	5	5	7	10	8	8	7	6	4	6	6	5	90
	7	4	4	7	1	4	3	5	1	6	4	3	4	3	56
	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	10	4	3	5	4	3	3	3	5	2	0	1	0	3	46
	4	7	3	4	6	6	5	4	6	3	10	2	4	1	65
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
VI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	0	0	0	0	2	0	1	0	0	0	0	6
	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2
	2	2	0	2	0	0	1	0	0	0	0	0	0	0	7
	3	3	1	2	1	1	0	1	0	0	1	0	0	0	13
	1	7	5	3	1	0	1	1	1	4	1	1	0	0	26
	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	1	0	1	0	1	2	2	2	9
	1	1	2	1	0	1	0	2	1	1	1	0	2	1	14

APPENDIX III (cont)

Number of trees per line (0.53 ha)

Species Teak

Size class 2.0m+ gbhob

Budaung,Thaw & Aukte reserves

Line no

Block	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
I	0	0	2	1	1	2	1	0	0	0	0	4	0	1	12
	1	1	0	2	1	1	0	1	1	0	0	0	3	1	12
	2	1	4	2	1	0	0	0	0	0	2	3	7	0	22
	1	0	1	2	1	0	0	0	1	0	1	0	2	0	9
	0	0	0	1	0	1	2	2	1	2	4	3	4	1	21
	2	1	1	1	6	1	0	1	0	1	2	2	2	0	20
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	1	1	1	0	0	2	1	0	0	2	3	3	2	16
	4	5	1	2	1	1	2	0	1	1	1	0	0	0	19
	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
	3	4	1	0	2	0	1	0	0	0	1	0	0	1	13
	1	3	1	0	4	0	1	1	2	0	1	1	0	0	15
	0	1	3	1	0	1	1	2	1	3	0	2	1	0	16
	0	0	2	1	0	0	0	0	0	0	1	1	1	1	7
	0	0	0	0	0	0	0	0	0	0	1	1	1	0	3
	3	3	0	0	0	1	3	1	1	1	1	1	1	2	18
	0	0	0	0	0	0	0	0	0	1	0	0	0	2	3
	1	0	1	1	0	1	2	0	0	0	0	0	0	0	6
	1	0	1	1	0	0	0	0	0	1	0	1	0	0	5
	1	0	0	1	0	1	1	3	0	1	0	1	0	5	14

APPENDIX III (cont)

II	0	0	0	0	0	0	0	1	0	0	2	0	0	0	3
	0	0	0	1	2	0	0	0	1	0	1	0	0	0	5
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	2	1	1	0	0	4
	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
	2	1	0	5	3	0	1	1	0	0	3	2	1	0	19
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2
	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
	2	1	0	1	0	0	1	0	0	2	0	1	1	0	9
	0	1	0	1	0	0	0	0	0	1	1	3	3	5	15
	0	0	0	2	2	0	0	0	1	0	0	0	0	0	5
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	1	0	2	0	2	1	0	0	1	1	1	9
	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	8	1	1	1	0	1	3	2	2	1	0	2	1	1	24
	0	2	2	0	0	0	1	0	0	0	0	0	0	0	5
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
III	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
	0	0	0	0	0	2	0	0	0	0	0	0	2	0	4
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	0	0	0	0	0	0	1	1	2	0	1	1	0	1	7
	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
	0	2	0	0	0	1	0	1	0	1	0	0	0	0	5
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX III (cont)

IV	0	0	1	0	0	0	0	1	0	0	1	0	0	1	4
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	5	1	2	3	0	1	0	0	0	1	13
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	1	0	2	1	0	0	0	0	0	0	0	0	0	4
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	2	5	1	3	2	3	0	3	0	2	0	2	25
	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	1	3	4	3	4	1	2	2	1	1	2	2	2	4	32
	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	1	0	1	0	1	1	0	4
V	0	0	0	0	0	1	2	0	2	0	2	1	1	1	10
	1	3	0	3	3	2	1	1	3	1	1	0	1	1	21
	0	0	0	0	0	4	0	0	1	0	3	0	0	0	8
	7	6	9	3	8	10	11	5	4	3	0	1	0	0	67
	1	0	1	2	3	0	0	0	0	0	0	0	0	0	7
	1	2	0	2	1	0	1	1	0	1	1	2	2	3	17
	1	0	0	0	0	0	0	0	0	0	3	1	1	0	6
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	1	0	1	0	0	0	0	0	1	0	1	1	1	1	7
	2	0	1	2	0	1	0	0	0	0	1	1	0	0	8
	1	0	0	1	0	1	1	0	0	0	0	0	0	0	4
	1	2	1	1	0	0	0	1	1	0	0	2	3	1	13
	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2
	0	0	0	1	1	1	1	1	1	0	0	1	0	0	7
	6	2	8	7	0	4	6	0	1	1	0	0	6	1	42
	0	0	0	0	0	0	0	0	0	2	1	0	0	0	3
	0	1	2	1	0	0	0	0	0	0	2	2	0	0	8
	0	1	0	0	1	0	0	0	0	2	2	0	2	1	9
	0	0	1	0	1	2	0	0	0	0	1	0	4	2	11

APPENDIX IV

Classification of species groups for royalty assessment

Group (1)

	Burmese name	Scientific name
1.	Pyinkado	*Xylia dolabriformis* Benth.
2.	Padauk	*Pterocarpus macrocarpus* Kurz.
3.	Thingan	*Hopea odorata* Roxb.

Group (2)

1.	Thitya	*Shorea oblongifolia* Thw.
2.	Ingyin	*Pentacme siamensis* (Miq.)Kurz.
3.	Kokko	*Albizzia lebbek* Benth.
4.	Thitmagyi	*Albizzia odoratissima* Benth.
5.	Sit	*Albizzia procera* Benth.
6.	Thitka	*Pantace burmanica* Kurz.
7.	Thitkado	*Cedrela toona* Roxb.
8.	Sakawa	*Michelia champaca* Linn.
9.	Karawe	*Cinnamomum inunctum* Meissn.
10.	Anan	*Crypteronia pubescens* Blume.
11.	Kyana	*Xylocarpus moluccensis* Lam.

Group (3)

1.	In	*Dipterocarpus tuberculatus* Roxb.
2.	Kanyin	*Dipterocarpus* spp.
3.	Pyinma	*Lagerstroemia speciosa* Pers.
4.	Kaunghmu	*Anisoptera scaphula* (Roxb.)Pierre
5.	Thadi	*Protium serratum* Engler
6.	Thinkadu	*Parashorea stellata* Kurz.
7.	Yinma	*Chukrasia tabularis* A.Juss.
8.	Yamane	*Gmelina arborea* Roxb.
9.	Hnaw	*Adina cordifolia* Hook.f.
10.	Binga	*Mitragyna rotundifolia* O.Ktze.
11.	Peinnebo	*Palaguun polyanthium* Benth.& Hook.
12.	Kyettuywesa	*Cratoxylon prunifolium* Dyer.
13.	Tharapi	*Calophyllum amoenum* Wall
14.	Kanyaung	*Dipterocarpus pilosus* Roxb.
15.	Tamalan	*Dalbergia oliveri* Gamble
16.	Thinwin	*Millettia pendula* Benth.
17.	Sandawa	*Cardia fragrantissima* Kurz.
18.	Pinlekanazo	*Heritiera formes* Buch.
19.	Talainggaung	*Bassia latifolia* Roxb.

Group (4)

1.	Didu	*Salmalia insignis* Schott. & Endl.
2.	Letpan	*Salmalia malabarica* " "
3.	Sawbya	*Pterocymbium tinctorium*(Blanco)Merr.
4.	Ma-Ulettanshe	*Anthocephalus cadamba* Miq.
5.	Kokhe	*Salmalia anceps* Schott & Endl.
6.	Other matchwood spp.	

Group (5)

Other remaining species