MANAGEMENT INVENTORY OF IRREGULAR BROAD-LEAVED FORESTS OF AUSTRALIA

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DECLARATION OF ORIGINALITY

I certify that the work reported herein is entirely my own except where due acknowledgement is given in the references cited. The joint paper with Dr. R.G. Florence is based on class exercises in silviculture devised by him. My contributions to that work were in the planning and execution of the inventory of the demonstration area, in programming the computer processing of results, in sharing in the tree-marking in the field and in contributing to the final discussion and editing.

K.J. PHILLIS

CORRIGENDA

Page 30	4 lines from bottom	Read *Toona australis* for *Cedrela australis*.
Page 42	Table 8	Against Pine Creek read 1215 for 2197.
Page 43	Line 10	Read 700 c.ft for 200 c.ft of pulpwood logs.
Page 55	10 lines from bottom	Read adjusted for graduated.
Page 77	12 lines from bottom	At start of new sentence read gully for ridge.
Page 79	Line 9	Delete reference to flooded gum example.
Page 185	Line 11	Read regression coefficient for regression constant.

ABSTRACT

It is firmly established that the broad-leaved forests of Australia are vitally important in timber production, catchment control, recreation, environmental preservation and many other uses. There is a developing conflict between the urgent need to supply the nation's wood requirement and the demands of a public becoming increasingly aware of the desirability of preserving environmental values. Some of this conflict would be resolved if it were possible to increase production from native forests while retaining an irregular structure. Inventory is needed to provide the supporting information for management towards this objective.

Under Australian conditions all management inventory must involve sampling. Techniques for sampling both the present growing stock and the rates of various changes within the growing stock are discussed. Definitions of variables for the quantitative description of eucalypts and a study of the efficiency of several estimation techniques are also presented.

The value of any information obtained by sampling and estimation depends upon the utility of its application. Most management inventory information finds its application in some aspect of yield regulation. The utility of data currently obtained in irregular eucalypt forest is discussed in terms of various methods for determining the allowable cut, the order of working and the cutting prescription.

One of the most difficult mensurational problems in eucalypt forest is the assessment of internal defect and the estimation of merchantable nett volumes. The usefulness of developing an inventory technique for assessing current levels of internal defect and rates of change in internal defect is explored by means of a simple tree growth simulation model incorporating the sawlog stumpage appraisal system of the Forestry Commission of NSW. This study has given the additional benefit of casting new light on the financial productivity of irregular eucalypt forests in general.

ACKNOWLEDGEMENTS

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Many people have taken time to listen to my thoughts on the subject of inventory and to offer technical advice. Of these I should especially like to thank the Forests Commission of Victoria for their generous assistance. From among my colleagues and former colleagues of the Forestry Commission of NSW, many of whom have offered encouragement, inspiration and technical advice, I must particularly thank Dick Curtin, Brian Furrer and Brian Turner. And from the staff of the Forestry Department of the A.N.U. there is hardly a one who has not at some time made my day a little brighter or the way a little easier. Most notable of these is Mr. E.D. Parkes.

My thanks go also to Pam Harrington for typing the draft in fine style and, finally, to my wife, Dierdre, for her cheerful endurance of the long months as a 'thesis-widow'.

INDEX

TABLES

FIGURES

APPENDICES

INTRODUCTION

In order that a work of this length may be kept in proper perspective it is essential that the implications of the title be well understood and the importance of the problem be given due emphasis. In essence the problem is one of forest inventory. The confining of the study to 'the irregular, broad-leaved forests of Australia' is an important qualification since these forests differ markedly from the even-aged, or regular, conifer forests of North America for which much has been done in recent years to develop new inventory techniques, aided by remarkable advances in computer technology. The Australian irregular forests also differ from irregular forests of western Europe because of differing management objectives and also by virtue of the different hardwood species of which they are composed. Moreover, a scarcity of wood in many European countries demands a very high level of utilisation, giving the forests a much higher value than those in Australia and therefore permitting expenditure on very intensive inventory. Chapter 1 will deal in detail with the nature of the Australian forests and their role in the Australian economy.

The second qualification embodied in the title is that the study is to be of management inventory. It is difficult to define precisely the limits implied by this qualification but it is intended to suggest that something of the potential of the forest has already been accepted and that the information obtained from the inventory will be used to assist in active management for the realisation of that potential. In emphasis it therefore differs somewhat from the earlier phase of 'resource inventory' which aims to provide, in rather less detail, a general assessment of the overall potential of a large forested area such as the forest resource of a State. If the inventory is to be the servant of management, its design will be affected by the objectives of management. These objectives, in turn, will be affected by the basic silvicultural characteristics of the forest, the effects of past management, and present and foreseeable social and economic considerations. Chapter 2 looks at these problems.

It may be expected, after 100 years of exploitation and up to 70 years of active management, that inventory techniques for Australian forests would already be established, and indeed, they are. Why, then, is a study of this nature of importance? It is desirable that any procedure should be reviewed from time to time with a view to improvement. In this case the forests are of undoubted importance since, as a national goal, it is aimed to eliminate the present timber import costs of over $200 million per annum by having in production 3,000,000 acres of planted conifers and 25,000,000 acres of native forest by the year 2000. The management of the greater part of these forests rests in the hands of the State Forest Services. It is often difficult for the officers of these organisations to detach themselves from the constraints of established procedures to examine the problem in broad perspective as this thesis aims to do. Moreover, such a review of management and management inventory seems particularly timely as it becomes apparent that after 70 years of management, at least the time of a sawlog rotation the native forest is still only realising a commercial productivity generally less than one tenth of the productivity expectation for planted conifer stands. A second factor demanding a review of techniques is the rapid development of computing facilities during the last fifteen years. Summaries of data and mathematical calculation can now be performed with greatly increased speed and convenience so that it is now possible quickly to examine established procedures, test alternatives and move to new techniques where, previously, manual data processing would have been impractical.

Measurement and assessment of various characteristics of the forest always involves the possibility of error, both in bias and in mistakes caused by operator error. Moreover, unlike some European situations, almost all Australian forest inventory involves sampling. Sampling may not only introduce bias, but also sampling error, due to the variability of the population from which the sample is taken. Much of the problem of forest inventory is concerned with the minimising of the combined error for a given cost or with minimising the cost in producing estimates within a given limit of maximum expected error. Chapter 3 deals with these concepts of error. Chapters 6, 7 and 8 discuss aspects of measurement and assessment for various forest characteristics giving particular emphasis to errors and costs. Chapter 9 deals with the role of the computer, and of other electronic aids in the recording and processing of data collected in the field. Chapters 4 and 5 are concerned with errors and costs associated with different sampling procedures.

There is no simple criterion, however, for judging the efficiency of individual components of an inventory system apart from all other components. The real test is the extent to which all types of information obtained can interact to form the basis of sound management decision-making. For this reason, Chapter 10 deals with management applications of inventory data, particularly in yield regulation, and illustrates the effects of various error sources in combination. One of the most difficult and pressing problems to emerge from this survey of the whole spectrum of inventory in irregular broad-leaved forests of Australia is the means of determining which trees are merchantable and, of these, what proportion is merchantable. Chapter 11 is therefore devoted entirely to the problem of merchantability, leading eventually to an illustration of the importance of its assessment when financial values are to be taken into account. Chapter 12 offers some conclusions and recommendations.

In summary, the tenor of the thesis is not so much to present a few new techniques as to provide a critical examination of a wide variety of existing procedures in use in Australia and overseas and to evaluate them in the light of present and foreseeable management requirements. Its originality stems from the attempt to draw the many aspects of inventory together to give a proper perspective for the management of Australian native forests, particularly through the use of modern computing techniques.

CHAPTER 1

THE ROLE OF THE BROAD-LEAVED FORESTS

1.1 The extent of the broad-leaved forests of Australia

The importance of a study of inventory techniques in the broad-leaved forests rests partly on present deficiencies in knowledge in the subject and partly on the importance attached to the management of the forests themselves. This chapter emphasizes the very great importance of these forests, not only as timber producers, but also in water production, soil protection, environmental preservation and recreation.

Forests form only part of the native Australian vegetation. Williams (1955) describes the nature and distribution of six principal vegetation forms, namely:-

a) Rainforest
b) Sclerophyll forest
c) Woodland
d) Savannah
e) Scrub
f) Grassland.

Trees are dominant in the first four of these forms. Savannah, comprising grasslands with widely scattered trees, is managed almost exclusively for grazing rather than for generally accepted 'forestry' purposes, and is not considered in this thesis. Rainforests generally present many peculiar management problems and are not specifically treated in the thesis, although much of the discussion may incidentally be applicable to them.

The distinction between sclerophyll forest and some forms of woodland is not always sharp, as the definitions given by Williams (op.cit.) will show:

Woodland

> 'Communities dominated by low to tall trees characterised by crowns which form an open to almost continuous canopy, and by boles, the length of which is not usually greater than the depth of the crown.'

Sclerophyll forest

> 'A closed community dominated by sclerophyllous trees of medium to tall height, characterised by flat-topped crowns which usually form an interlacing canopy, and by boles, the length of which is equal to or greater than the depth of the crowns.'

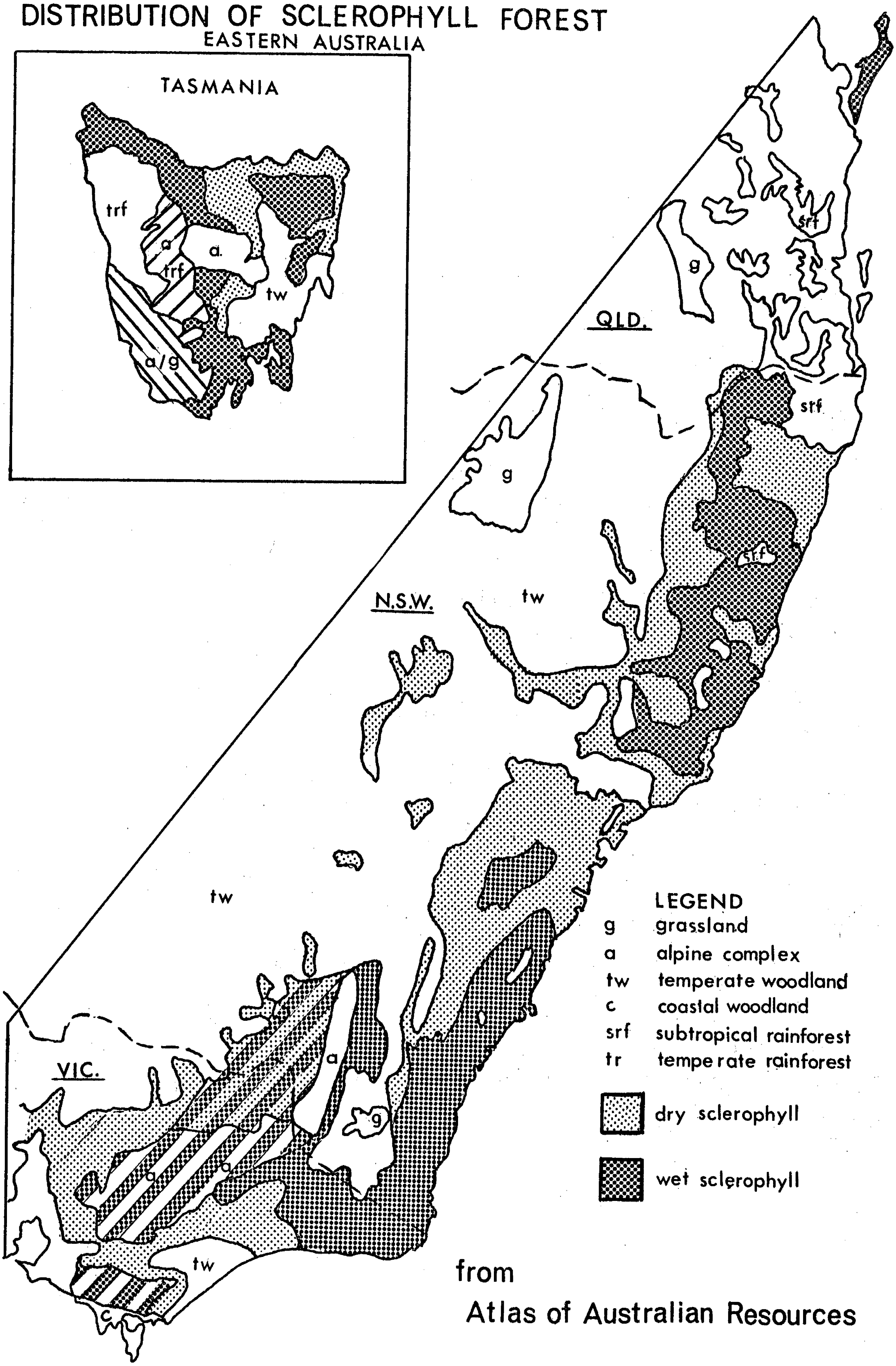
In many instances, species which occur in one form can occur in the other, the development of the particular form being governed by climatic, edaphic and other factors. Moreover, both have been used in timber production, depending upon local conditions of supply and demand, but it is the more productive sclerophyll forest that has usually attracted the attention of forest managers and which is the object of this study. The distribution of sclerophyll forest is illustrated in Figure 1. (The distinction of wet and dry sclerophyll will be drawn in Chapter 2.) In general, sclerophyll forest occurs in much of the area lying south of the Tropic of Capricorn and receiving more than 20-25 inches of rain per annum.

Complete details of the extent of Australian forests are difficult to obtain. There has never been a national inventory of Australian resources and the few details that are available are often difficult to reconcile because of conflicting definitions. A large proportion of the tree-covered area of the continent is commercially unproductive and little trouble is taken to collect information on these areas. Moreover, few private landholders engage in active forest management and therefore few records of forest holdings are kept even though private owners may realise on naturally accumulated timber values from time to time. The Official Year Book of the Commonwealth of Australia, (Commonwealth Bureau of Census and Statistics, 1969), gives the following general information: 'The area of land in Australia suitable for the production of timber as a primary crop is very small in comparison with the size of the continent. Broad-leaved forests (hardwoods) cover 97 per cent of the total forested area, and approximately 94 per cent of the broad-leaved forest area is occupied by eucalypts.'

Figure 1

DISTRIBUTION OF SCLEROPHYLL FOREST

EASTERN AUSTRALIA



from

Atlas of Australian Resources

TABLE 1

AUSTRALIAN LAND CATEGORIES AT 30.6.65

(Thousands of Acres)

	NSW	VIC	QLD	TAS	OTHERS	TOTAL
Forest Land						
Exploitable	10322	5488	12680	2855	5842	37187
Not Exploitable	4085	3215	11600	960	19178	39038
Unstocked Forest	4800	0	4590	85	1980	11455
Woodlands	4765	8077	184570	3840	310758	512010
Agric. & Grazing	21735	34535	7240	1833	186952	252295
Other Land	149361	4385	206200	7228	663283	1030457
Total Land	195068	55700	426800	16801	1188073	1882442
Water Area	2969	546	+	84	13421	17020
Total Area	198037	56246	426800	16885	1201494	1899462

\+ Area included with surrounding land area

From "Compendium of Australian Forest Products Statistics"
Forestry and Timber Bureau 1969.

Table 1, summarised from The Compendium of Australian Forest Products Statistics (Forestry and Timber Bureau, 1969) indicates that the bulk of the timber production load falls upon 37,187,000 acres of exploitable forest land. Of this area 3,021,000 acres are stocked with conifers, both native and exotic, and approximately 2,700,000 acres are rainforest, leaving about 31.5 million acres of broad-leaved sclerophyll forest. Of the total of 37,187,000 acres it is stated that 23,837,000 acres are publicly-owned and 13,350,000 acres are privately owned. Figures elsewhere in the same publication suggest that only 4.2 per cent of private forest land is owned by industrial enterprises, the remainder being part of farm holdings.

The importance of broad-leaved sclerophyll forest in publicly-owned forests can be drawn from Table 2 showing the areas of State Forest in Australia at 31.3.67. This table is also drawn from The Compendium of Australian Forest Product Statistics, (op.cit.), and shows that 83 per cent of dedicated State Forest is sclerophyll forest, described generally as eucalypt forest.

1.2 Timber production in the broad-leaved forests

The legislation governing the management of publicly owned forest will be considered in Chapter 2, but it is true to say that, over the 50-60 years of their existence, the principal management endeavours of the State Forest Services have been directed towards timber production. Notable exceptions have been the preservation of some catchment forests in Victoria and the leasehold grazing in the western forests of New South Wales and Queensland. This accent on timber production has not necessarily been to the detriment of other possible uses but their realisation has tended to be incidental to commercial production of wood.

The paramount importance of the broad-leaved forests in current Australian production is indicated by Table 3 giving the major usage of Australian grown timbers. The most striking feature of Table 3 is the preponderance of

TABLE 2

AREAS OF STATE FOREST IN AUSTRALIA AT 31.3.67

(Thousands of Acres)

	NSW	VIC	QLD	TAS	OTHER	TOTAL
Eucalypt	5427	4028	6516	1430	4149	21550
Rainforest	214	0	816	460	0	1490
Native Conifer	1175	9	1208	0	0	2392
Planted Conifer	121	71	124	27	222	565
Total	6937	4108	8664	1917	4371	25997

TABLE 3

MAJOR USAGE OF AUSTRALIAN GROWN TIMBER

1965-66

(thousands of cu.ft round measure)

Usage	Forest Type		Ownership Source		
	Broad-leaved	Coniferous	Crown	Private	Total
Sawlog	258,664	62,814	219,504	101,974	321,478
Peeling and slicing	4,498	1,660	-	-	6,158
Pulpwood	40,814	12,799	33,269	20,344	54,613
Other major products*	-	-	14,063	16,949	31,012

* Includes fencing and mining timber, poles and piles and *E. wandoo* used for tanning. A large proportion would be eucalypts despite the increasing use of preservative treated softwood.

Information collated from Compendium of Australian Forest Products Statistics. (Australian Forestry and Timber Bureau, 1969)

TABLE 4

AUSTRALIAN SAWLOG PRODUCTION 1965/66

(Thousands of cubic feet gross true volume)

	NSW	VIC	QLD	TAS	OTHER	TOTAL
Crown Land						
Rainforest Hardwood	4645	0	8088	1372	0	14105
Other Hardwood	39092	46186	10911	23896	40480	160565
Exotic Conifer	6096	4905	3863	417	19490	34771
Native Cypress	3682	0	2985	0	131	6798
Other Conifer	385	0	2592	288	0	3265
Total	53900	51091	28439	25973	60101	219504
Private Property						
Rainforest Hardwood	539	0	2833	0	0	3372
Other Hardwood	25360	13893	18649	11903	10817	80622
Exotic Conifer	96	3823	0	803	7127	11849
Native Cypress	3343	0	2346	0	0	5689
Other Conifer	85	0	355	2	0	442
Total	29423	17716	24183	12708	17944	101974
Grand Total	83323	68807	52622	38681	78045	321478

Compendium of Australian Forest Products Statistics (Australian Forestry and Timber Bureau, 1969).

broad-leaved sawlogs in the total yield and it is interesting to note that approximately two thirds of this yield is drawn from Crown lands. This is an important point to note, since it will be shown later that most of the irregular broad-leaved forest is State-owned and it is in these forests that management is most active and most in need of inventory data. Table 4 is provided to give a more detailed account of the sawlog material and to illustrate that already the planted exotic conifers do play an important part in this market. Much of the sawnwood finds its way into home construction and, with the continuing expansion of the nation's economy, the demand for sawlogs can be expected to extend well into the future despite increasing competition from other building materials, including reconstituted wood products.

The role of the broad-leaved forests in pulpwood production is currently a topic of considerable importance. Of the total pulpwood production in 1965-66, 73 per cent was used in the making of paper and paper products and, of this, 81 per cent was of broad-leaved timbers, principally from Tasmania and Victoria. Much of this output has been in the form of newsprint from Australian Newsprint Mills Ltd in Tasmania. Very often the input for paper pulp has been high quality Mountain Ash (*E. regnans*), which would have been well suited to sawing. On the other hand, input to other pulp-using industries, including the manufacture of fibre board, has often been in the form of waste material, early thinnings and small eucalypts which may otherwise have been unsaleable. Such usage is of considerable silvicultural benefit in many situations but unfortunately the availability of raw material for these purposes is far in excess of the capacity of the local market to absorb the finished product. The recent announcements of very large sales of eucalypt chipwood to Japanese pulping industries have therefore been of considerable interest.

Up to the end of 1970 four sales agreements have been signed with Japanese paper companies and have been granted export licences by the Australian Government. These agreements are as follows:-

Sale Area 1

Eden (NSW) - between Harris Holdings Ltd and Daishowa Paper Manufacturing Company.
(Australian Financial Review : 15.11.67)

Sale Area 2

Triabunna (Tasmania) - between Tasmanian Pulp and Forest Holdings Ltd and Mitsui and Co. (Aust.) Ltd.
(Australian Financial Review : 15.11.68)

Sale Area 3

Wesley Vale (Tasmania) - between Associated Pulp and Paper Mills Ltd and Mitsubishi Shoji Kaisha Ltd with Sumitomo Shoji Kaishi Ltd.
(Australian Financial Review : 5.10.70)

Sale Area 4

Bell Bay (Tasmania) - between Northern Woodchips and Yamamoto Sangyo Co. Ltd.
(Australian Financial Review : 30.11.70)

Table 5 gives details of the quantities involved in these sales.

TABLE 5

DETAILS OF AUSTRALIA - JAPAN WOODCHIP AGREEMENTS
(31.12.70)

Sale Agreement Number (see text)	1	2	3	4
Annual value ($million)	10.0	7.5	8.2	10.8
Annual quantity ('000 green tons)	750	600	660	700
Annual quantity (million c.ft round)	28.8	23.1	25.4	26.9

Table 5 indicates that the total expected chipwood sales to Japan, already agreed to, will be approximately 104.2 million cubic feet round measure per annum. The importance of this yield in the management of the broad-leaved sclerophyll forests can be gauged from a comparison with the total Australian broad-leaved sclerophyll sawlog production of 241 million cubic feet in 1965-66, as given in Table 4. The chipwood sales are expected to earn approximately $36.5 million per annum.

The raw material supply sources for these sales vary to some extent, although in every case there is an intention to make some use of current sawmill waste and logging residues associated with sawmilling operations. At Eden, in New South Wales, the pulpwood harvesting will be associated with a simultaneous sawlog operation on areas of State Forest and other Crown lands carrying an overmature stand of silverto ash (E. sieberi) degraded by previous selective logging and frequent fire. The Tasmanian Pulp and Forest Holdings Ltd operations in Eastern Tasmania will draw extensively on similarly degraded and unproductive State Forests, supplying only about 5 per cent of the raw material from sawmill waste. Northern Woodchips, on the other hand, will rely much more heavily upon logging waste and sawmill residues, with any remaining requirement to be drawn from private forest lands. Associated Pulp and Paper Manufacturers are a somewhat older Australian company and are already engaged in pulping operations in Tasmania. Some of their present supply is drawn from Crown lands, some from their own holdings and some from sawmill residue. For some years they have also been engaged in reforestation with planted Pinus radiata. Doubtless, their recently announced sales to Japan will principally involve a general expansion of their current operations, together with the utilisation of wastage in their present plantation clearing.

Clearly, the sale of pulpwood has already become a major factor in the utilisation and management of Australian broad-leaved forests. With the possibility of further large sales in Western Australia, Northern Territory, Queensland and New South Wales, pulpwood operations may dictate sweeping changes in management policy in the broad-leaved forests, particularly in regard to selective logging.

1.3 Commercial production of other quantities than wood

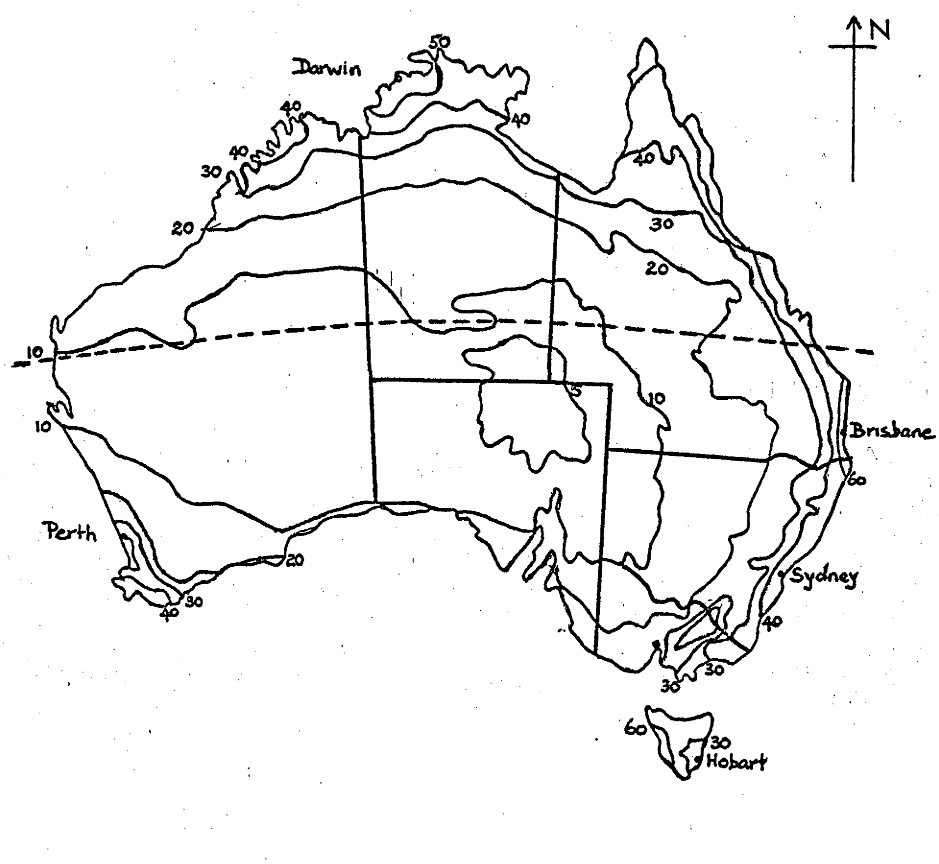
It has been shown in the previous section that wood production is a prime usage of the native broad-leaved forests of Australia and most of the inventory problems discussed in this thesis are associated with management for wood production. The forests are put to many other uses, however, and it is important to examine them to consider their effects on the determination of management objectives and inventory requirements. Broadly, forest uses fall into two categories, those which are associated with commercial material production and those which are not.

1.3.1 Water production

Ranking at least with wood production in the first group is water production. Australia is a continent of generally low average annual rainfall, as illustrated in Figure 2, and it is imperative that high soil productivity be maintained on well-watered areas and that, at the same time, there is wise conservation of surface water for irrigation and the generation of electricity for industry. The mean annual total discharge from Australian rivers has been estimated at 280 million acre feet, which is about one tenth the total flow of the Amazon and less than one third the total annual flow of the ten major rivers of the United States of America. Of the total area of Australia of about 3 million square miles only 1.9 million square miles contribute significantly to stream flow. Table 6 shows the storage capacity of major Australian reservoirs.

Figure 2

AUSTRALIA



MEAN ANNUAL RAINFALL

inches

TABLE 6

STORAGE CAPACITY OF MAJOR AUSTRALIAN RESERVOIRS

30.6.68

(thousands of acre feet)

Storage purpose	Capacity
Irrigation	9,490
Generation of electricity	4,024
Combined irrigation and electricity	8,528
City water supply	3,274

(Information collated from The Official Year Book of the Commonwealth of Australia, 1969).

A high proportion of the area of the catchments supplying the reservoirs listed in Table 6 would be tree-covered, particularly in the extensive catchments of the Tasmanian hydro-electric schemes. Studies of the effect of forests on the quantity of water produced in a catchment are rare and it is therefore difficult to place a value on the water production of forests. A good general review of forest effects is given by Boughton (1970) and some relevant remarks are also offered by Thistlethwaite (1966). It is quite clear, however, that the quality of the water produced can be greatly affected by some forest activities, and further research may indicate ways of manipulating forest cover to have a strong influence on total water yield. McArthur and Cheney (1965) illustrate some of the effects of various forest management practices in water catchments.

At present timber harvesting and other activities are permitted on most Australian catchments, the most notable exception in the past being the water supply catchments for Melbourne. The State Development Committee (Victoria) (1960), however, in its final report on the utilisation of timber resources in the watersheds of that State accepted that some multiple use of the catchments was reasonable. Chandler (1959) in his evidence to that Committee had demonstrated that such multiple use had been practised effectively for many years in many other of the town supply catchments of the State. However, these recommendations were largely rejected by the Metropolitan Board of Works who have in fact gained an increase in the area of forest reserved for single-use water production. Recently there has been some easing of the restriction of public access to the Lower Cotter Catchment of the Australian Capital Territory, although plantation establishment procedure still takes catchment values into account. In summary, whilst financial values have not been calculated for the water yield of the forests, they are undoubtedly of considerable importance and future forest management may need to take them more and more into account.

1.3.2 Grazing

Very few published figures are available to give a quantitative statement of the importance of grazing in Australian forest management. It is clear that forest pasturage forms only a small fraction of the very extensive total Australian grazing resource, with fully cleared and savannah lands being much more important. At present there is very little active management to improve grazing values in coastal forests, although it may be possible to derive some benefit from keeping forest stockings low enough to promote grass growth or from using grazing as a means of reducing fire hazards. The most extensive grazing areas at present are in the drier western forests of the eastern states, particularly in the native cypress pine country, and in the riverain forests of the Murray River valley. In the year ending 30 June 1969, rents and grazing dues in Queensland earned $67,500 compared to $4,001,000 from timber and other products. In Tasmania, in the same year, lease rentals, agistment fees and other miscellaneous income amounted to $6,600 compared to $1,496,000 from timber and other products. No figures were readily available for Victoria. In New South Wales the total area rented under occupation permit for pasturage was approximately 1.5 million acres, yielding annual rental of $100,648 compared to $6,076,000 for timber and other products. Approximately 500,000 acres of the area under grazing permits was in the coastal Districts, and these permits earned $31,000, approximately 31 per cent of the total grazing revenue. These figures represent only the payments to State Forest Services and do not represent the ultimate value of the grazing production, for which no figures are readily available.

Lucas and Sinden (1970) discuss some aspects of the economics of grazing in cypress pine forests in New South Wales. But despite isolated instances where grazing can already be shown to be profitable, it seems unlikely that this form of forest use will assume any pre-eminence in the management of the coastal broad-leaved forests. More likely is it that timber production, environmental preservation and recreation values will prevail in these areas, particularly as even the most profitable sectors of pastoral industries in Australia are currently facing financial crises.

1.3.3 Bee-farming

Like grazing, bee-farming brings in little revenue to the management of public forests in Australia, but the total value of production is not entirely insignificant. In 1967-68 the total value of honey and bees wax production was $4.627 million, equivalent to 3.8 per cent of the value of Australian wood production in the same year. Very little forest management is directed towards honey production but a substantial part of the yield is obtained from eucalypts, largely on forest country. For social and, to some extent, economic reasons, management practices which would drastically reduce the honey flow must be considered undesirable.

1.4 Forest usage not involving direct commercial production

Although the uses discussed in this section may ultimately be of immense value to the community, they do not involve the production of readily measurable quantities. In an attempt to achieve an objective rationalisation of management priorities some recent attempts have been made to determine objective value indices for these uses but, as yet, most of these remain at an experimental stage. Leslie (1967) attempts to show how such indices may operate in economic appraisals of management alternatives.

1.4.1 Soil Protection

Section 1.3.1, earlier in this chapter, made brief reference to the role of forests in the regulation of the quantity and quality of the water yield of catchments. Clearly, control of soil erosion in catchments is a factor in regulating water quality through reduction of turbidity. Soil protection, however, has probably even greater importance because of the effects of sediment deposition in rivers and flood plains. Boughton (1970) cites a report by Brown (1948) listing cost estimates for various aspects of damage by soil deposition in the United States of America. Amongst the aspects listed were damage to agricultural resources, damage to storage reservoirs, the cost of maintenance or progressive impairment of drainage works, maintenance to irrigation enterprises and harbour facilities and several others. Brown suggests that, at that time in the U.S.A., the total annual damage from sediment deposition was $174 million compared to $100 million from flood damages.

Most European countries, and many others, have at one time or another recognised the need for formal acknowledgement that forests are vitally important for their soil protection role in hilly or mountainous country. Many of these have done so only after disastrous floods and siltation. Francois (1950), in the F.A.O. publication setting out guidelines for national forest policies states the following as a policy priority:

'First, this policy will aim at ensuring an adequate area of forests to protect the climate, the soil and the water resources of the country; then, at satisfying as far as possible the national wood requirements....'

Australia, with its limited area of well-watered country and its heavy reliance upon primary production, could well follow these guidelines. In fact, many important catchments are protected by native forest. In recent years, government policy for the alienation of Crown forested lands for private agriculture has paid some attention to the problem, although in the earlier years of settlement extensive clearing resulted in massive siltation of the coastal river systems. Moreover, soil conservation organisations in every State undertake works to rectify soil erosion problems in cleared country. But despite these efforts very little recognition is given at this time to the effects of management activities within forested areas. Only minimal restrictions are imposed on clearing activities along water courses in private property and few management plans for State forests make detailed provision for the control of soil losses, except in some major town supply catchments.

1.4.2 Environmental preservation

The general acceptance of the concept of conserving natural resources for one purpose or another is comparatively recent. Early clearing and burning of the forests after the settlement of white man in Australia wrought massive changes on a flora and fauna that had remained largely undisturbed for hundreds of thousands of years. Exploitation of the forests for their timber values also took its toll. From the turn of the century some enlightened people began to see the time when the whole countryside would be ruined if this rampage of settlement and development went on unchecked. Gradually, State Forest Services and other conservation authorities came into being. State Forests and other lands came under their control and some National Parks and other reserves were established. But, with the rapid increase in population and the even more spectacular increase in man's ability to destroy his environment, it has become apparent to many that the present conservation effort is inadequate. And as they put together the statistics of the losses and the potential losses their movement gathers support. Turner, J.S. (1966) stated that 'when Cook, Banks and Solander landed at Botany Bay in 1770, they opened the door to a remote continent, with 12,000 species of plants mostly new to science'. In the same book, Turner goes on to quote Mr J.H. Willis, Government Botanist of Victoria, referring to plant species facing extinction in that State:

> These include 12 which are presumed extinct through destruction of their known habitats. There are another 36 which have not been seen for many years and, if still existing, must be extremely rare. A third list comprises 201 species which are by now restricted to a very few colonies or even to individual specimens. The total represents a considerable proportion of the native plants of Victoria and includes a large number, such as some of the *Acacias*, *Boronias*, Orchids, *Grevilleas* and even *Eucalyptus*, which are of considerable scientific interest.

By all accounts, the situation is similar in all the other States of Australia. As losses of this kind become apparent the need for active environmental conservation becomes more urgent. Table 7 sets out some details of Australian National Parks and Reserves at 30 June 1968. The Australian Academy of Science (1968) stresses the scientific value of parks and reserves in addition to other aesthetic and cultural values. This publication points out the 'urgent need to speed up the (park) surveys throughout Australia' and remarks that 'this task is never completed because new reasons for protecting special features or threatened features will continue to arise'. It cites the example of the N.S.W. National Parks and Wildlife Service which, in 1968, had 'some two million acres under examination for inclusion in parks and reserves - more than the total area of parks and reserves covered by the 1967 legislation', under which the organisation was established.

Whilst by no means all of the areas of scientific interest include the native sclerophyll forests, many of them do fall in the climatic zone of occurrence of sclerophyll forest and it is often in these areas that there is greatest pressure for alternative uses and the greatest clamour for preservation. It follows, then, that one important role of the broad-leaved sclerophyll forests at present is to act as a reservoir of suitable habitats for the maintenance of communities of both plants and animals. The extent to which

TABLE 7

AUSTRALIAN NATIONAL PARKS AND RESERVES - 1968

State	Number of Parks and Reserves	Area of Parks and Reserves ('000 acres)	Percentage of State Area	Area per Capita ('000 acre
NSW	89	2,144	1.1	0.5
VIC	48	497	0.9	0.2
QLD	258	2,364	0.6	1.4
SA	110	2,889	1.2	2.6
WA	380	3,042	0.5	3.6
TAS	113	712	4.2	1.9
NT	34	11,638	3.5	315.0
ACT	1	12	1.9	0.1
TOTAL	1,033	23,295	1.2	2.0

from 'National Parks and Reserves in Australia', Australian Academy of Science, 1968.

society will be able to afford to set aside some of these areas solely for this purpose, by reserving them in some way, remains to be seen. In the meanwhile forest management should attempt, as far as possible, to avoid complete destruction of these values, since it may well prove that society will eventually place a far greater premium on some facets of environmental preservation than it does at present on the timber, grazing and recreational value of forests. In view of these increasing demands for preservation of the environment, the Forestry Commission of N.S.W. has recently increased the area of flora reserves it is empowered to set aside under the Forestry Act of 1916. The Forests Commission of Victoria has also set aside a variety of reserves, some of which are administered by joint committees of management involving members of the public outside the Commission.

1.4.3 Recreational use of native forests

The need for recreation is generally accepted by the community, and outdoor recreation has always been a part of the Australian way of life. But as the population of Australia has increased and the availability of recreational areas has decreased under clearing, housing estates and other development, the ratio of population to suitable recreational outlets has rapidly increased. Baur (1968) lists five factors markedly affecting the increased recreational demand, namely, increased mobility of the population, increasing leisure, increasing urbanisation, increasing population and increased education. He recognises that some activities demand '<u>mass recreation use</u> involving intensive occupancy of limited areas of land for what is frequently a rather sedentary recreationist (picnics, camping)', and others demand '<u>dispersed recreation use</u>, involving the low density use of extensive areas by a rather mobile recreationist, (e.g., pleasure motorist, bushwalker, hunter)'.

To some extent, various aspects of both types of use can be catered for with very little disturbance to other activities in the forest. Other recreational pastimes may require multiple use with special management constraints or, in the extreme, single-use recreation areas. To some extent the latter case is provided for in the National Parks system but, as these are extended and the demand for other reserves increases, foresters can expect that the area available at present for multiple use will be restricted by the reserving of single-use recreation areas. Although coniferous plantations do provide some degree of recreational amenity it is probably correct to say, in general, that many more recreational pursuits are better suited to the more variable nature of irregular native forests than to the comparative monotone of plantations. In this respect, plantations of native species probably differ little from exotic conifers. Moreover, if the high cost of initial establishment of these plantations has been justified largely by their potential timber value, it will be difficult later to justify any activity which excludes them from this function. Thus, the recreational use of the irregular, broad-leaved forests of Australia, particularly in the coastal band, is of considerable present importance and is likely to have important effects in future management. Recent papers by Ferguson and Greig (1971) and Ranken and Sinden (1971) have sought to develop means of predicting these effects and of quantifying their values. As yet the studies are restricted in scope and their criteria of assessment are arguable but ultimately this type of work is bound to lead to a considerable reappraisal of forest values.

CHAPTER 2

PRESENT MANAGEMENT OBJECTIVES FOR THE FUTURE

2.1 Introduction

It is an underlying tenet of this thesis that, if inventory is to be any more than 'just adequate' and, rather, the true servant of management in supplying the necessary information for efficient decision making, the design of the inventory - the information to be sought, the reliability to be attempted and the expenditure involved - must be conditioned by the objectives of the management itself. This chapter examines probable management objectives for the irregular broad-leaved forests of Australia. At the outset it is assumed, and later demonstrated, that wood production will be a primary concern in the determination of a management objective and that most of the inventory data will be used in this aspect of management. Several other forest uses likely to be strong influences in future decision making are also discussed, for two reasons. Firstly, the rapid increase in demand for the forest for these other purposes indicates the increasing pressure for efficiency in wood production. Secondly, there is no basic reason that inventory should not be designed to serve these other aspects of management, although at this stage it is difficult to state their information requirements.

The following three types of basic considerations will affect the determination of management objectives:-

(a) The basic silvicultural characteristics of the forests.

(b) The effects of past management leading to the present condition of the forests.

(c) Present and foreseeable economic and social considerations.

These three are discussed below.

2.2 Basic silvicultural characteristics of the broad-leaved forests

2.2.1 Ecological characteristics

This thesis is concerned primarily with the large areas of broad-leaved sclerophyll forest rather than with the smaller areas of rainforest. In a previous work the author summarized many of the silvicultural implications of the ecology of the sclerophyll forests, (Phillis, 1965). The most important feature to realise is that these forests are part of a dynamic vegetation pattern, in which one vegetation type replaces another, proceeding in succession to some form of climax. The undisturbed 'natural' succession is termed primary succession but the catastrophic interference of fire, wind or the activities of man may bring on a secondary succession. Most Australian coastal forests are now in a state of secondary succession. The vegetation sequence may proceed towards either of the two types of climax:

(a) Climatic climax

'This is the most advanced type of vegetation capable of development under the climatic conditions which characterize a climatic region.'

(b) Physiographic climax

'This is the most advanced type of vegetation capable of development in any physiographically uniform area. In physiographically favourable areas the physiographic climax corresponds with the climatic climax.'

Throughout much of the east coast of Australia, where-ever average annual rainfall exceeds forty inches, rainforest must be regarded as the climatic climax, although its current distribution is extremely discontinuous. It is interesting to conjecture how much the intervening sclerophyll forest and other vegetation types represent sub-climax phases in active progression and how much in fact, represent physiographic climax.

The description by Williams (1955) may give an indication for the types with which this thesis is most interested:-

(a) Wet Sclerophyll forest

'This is a closed community dominated by sclerophyllous tall trees with densely interlacing flat crowns, below which a discontinuous stratum of small shade-tolerant trees may sometimes develop along with well developed continuous or discontinuous strata of mesomorphic shrubs and a dense or sparse herbaceous stratum. This sub-form is quite evergreen with a small proportion of annual herbs.'

(b) Dry sclerophyll forest

'This comprises closed communities dominated by sclerophyllous trees forming a continuous to interlacing canopy. There is generally a well developed, discontinuous layer of xeromorphic shrubs and a usually discontinuous herbaceous stratum.'

The distribution of these types in eastern Australia is shown in Figure 1. Whilst there may be some differences in the species composition of the dominant tree layer of the wet and dry sclerophyll, the principal distinction drawn in the above definitions is the strong development of the shade-tolerant understorey in the wet sclerophyll form. In many cases it is probably correct to say that this represents the early development of rainforest and that, in general, wet sclerophyll is a sub-climax form proceeding towards the rainforest climatic climax. An example of this kind of succession is given by Fraser and Vickery (1938). At the other extreme, some of the more westerly occurrences of dry sclerophyll probably represent a climatic climax.

In between the 'driest' of the dry sclerophyll and the 'wettest' of the wet sclerophyll there is room for considerable argument over the successional status of the sclerophyll forests. For the Florentine Valley of Tasmania the situation has been well summarized by Gilbert (1959), who recognises a wet sclerophyll 'fire-climax' between rainforest and dry sclerophyll. In the absence of fire the area now occupied by wet sclerophyll would probably carry rainforest and the ecotone between this type and dry sclerophyl would probably be very abrupt along the boundaries of poor soil. At the other end of the geographic range, Swain (1928) describes the situation for blackbutt, the most important of the eucalypts in the sclerophyll forests of Queensland:-

'In the moist hollows blackbutt is beaten by the jungle invasions, becomes faulty and gradually falls out. On the slopes it has an advantage over the tenderer jungle trees in its greater hardihood, and this advantage is made binding by the incidence of bush-fires.'

It can be seen that a variety of sclerophyll stands are considered to be maintained at a sub-climax condition through fire or some other influence.

On the other hand, Florence (1964), in discussing differences in species composition of sclerophyll forest in northern New South Wales, devised a diagram illustrating something of the physiographic influence on succession. This diagram is reproduced here as Figure 3. Florence draws attention to two factors, soil fertility and soil depth and permeability, which may singly, or in combination, be the limitations determining a physiographic climax.

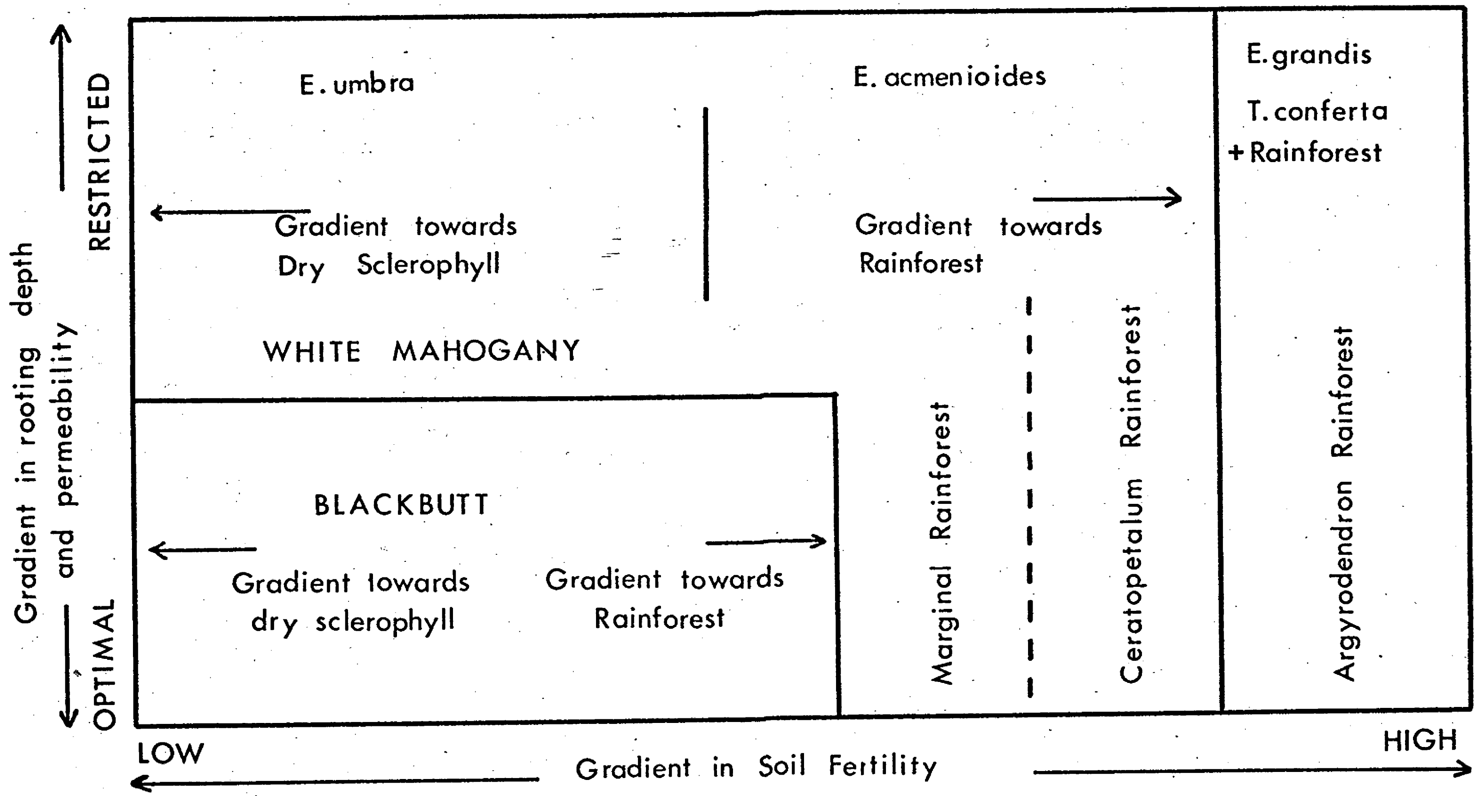
The dynamic status of sclerophyll forests may thus vary considerably from those in a state of active succession, those in a state of unstable equilibrium, perhaps maintained by fire, and those in a state of stable equilibrium, having already reached some type of climax condition.

A second ecological aspect of the sclerophyll forests is their species composition, and of principal concern in this thesis is the dominant tree layer. In almost every situation these forests are dominated by trees of the genus Eucalyptus. Research into the true membership of the genus

Figure 3

Ecological Relationships Between Blackbutt, White Mahogany & Rainforest

— Florence (1968)



is still being carried out, but about 500-600 species are generally accepted. Fewer than 100 of these are important commercial species. A large number of eucalypt associations have been classified by Baur (1965). The underlying reasons for these associations and their distribution are still matters for argument, and it is probably true that various factors are predominantly active in different situations. Barber and Jackson (1957), for example, postulate that slight changes in environment can be reflected in very sensitive selection in eucalypts. Florence (1964) also argues a theory on the distribution of *Eucalyptus pilularis* and *Eucalyptus acmenioides*, using variations in edaphic factors. Other workers are inclined to believe that such factors as wild-fire frost and disease may often be more important. In these latter situations management to alter the natural species composition of the forest would be considerably easier than if soil factors were all important, since the effects of fire, frost and disease would usually be more easily controlled than soil properties. This is an important consideration when management is trying to increase the representation of fast-growing species with desirable qualities.

2.2.2 Growth habits of the eucalypts

The most important reference on this subject is the book by Jacobs (1955) bearing the above title. At first thought, the inclusion of such a topic may appear to have little relevance in a treatise on inventory. In justification it must first be stressed that the characteristics of the species composing a forest have an important bearing on the management practices that are feasible in the forest. Secondly, and perhaps more importantly, is the fact that certain features of the eucalypts pose peculiar mensurational and inventory problems which sometimes even negate the application of techniques developed for other species, particularly conifers overseas.

The genus *Eucalyptus* varies considerably through all 500-600 species, some appearing as small, shrub-like mallees in inland and alpine areas, others, notably the mountain ash of Victoria and Tasmania, being amongst the tallest trees in the world. Even amongst the fifty, or so, species that predominate in the taller sclerophyll forests there is considerable variability in appearance, shade tolerance, regenerative capability, vigour and wood quality. To achieve any brevity in this section, a certain degree of generality must be accepted.

In general, eucalypts can be said to be shade intoleran compared, for example, to the trees of the rainforest or even to many of the hardwoods of North America. This means that they do not regenerate nor develop very vigorously in the shade of an overtopping canopy. If they do survive for some time in a state of suppression, they frequently degenerate to a physiological condition which renders them incapable of vigorous response to subsequent release. In this respect they vary from the extreme intolerance of blackbutt, flooded gum and mountain ash, to the reasonable tolerance of tallowwood, white mahogany and the non-eucalypts, with which they are often associated, turpentine and brushbox.

The second important characteristic of the eucalypts is their variety of regenerative powers. Jacobs (1951) summarizes these features. All regenerate from seed, although, as indicated above, they have a fairly strong light requirement for this purpose, and some especially so. As a consequence, eucalypts regenerate most strongly from seed in large openings with a fairly clean seed-bed, since this situation offers maximum sunlight. Many of the stands of eucalypts first seen by man would have been largely even-aged, often resulting from the action of some particularly catastrophic wildfire in destroying the overwood and baring a clear seed-bed.

However, eucalypts also possess a second, very powerful regenerative feature in their capacity to produce and preserve dormant buds. This capacity has undoubtedly been a primary force in the highly successful evolution and spread of the genus in an environment where frequent fire would have been the norm. Jacobs (1955) has observed in considerable detail the formation and behaviour of these dormant buds and describes them as follows:

> When a parent leaf falls, a small shaft of tissue with bud-producing properties grows radially outwards from the old leaf axil at a rate that corresponds almost exactly with the diameter growth of the mother stem. The termini of the shafts are at the wood surface or in the live bark. Dormant bud strands are persistent and are rarely killed unless fire, or other damage kills the wood cambium.

With these buds eucalypts have the potential to regenerate their crowns, even after insect attack or fire has removed virtually all the primary leaves. Thus, only the severest fire is likely to kill a eucalypt outright. Of course, as Jacobs points out, such temporary losses of crown will inhibit the realisation of maximum growth potential. The principal factor in many of the spectacular eucalypt growth rates observed overseas is probably the absence of such problems of crown loss.

In addition to the dormant buds of stem and branches, some eucalypts also develop, at the base of the stem, woody structures with the same dormant bud potential. These structures, called lignotubers, develop early in the life of the seedling. Whilst the stem and leaves above maintain a normal hormone balance, these buds remain dormant. Should the action of a fire disturb the balance, the buds shoot rapidly from the lignotuber which is probably partly embedded in the soil. Since the lignotuber is attached to an established root system, species of the lignotuberous habit often regenerate more extensively by this method after a fire than from seed. It is interesting to note that three of the fastest growing species, blackbutt, flooded gum and mountain ash, are intolerant species and are amongst those which do not form lignotubers.

A third feature, of particular mensurational interest, is the branching habit of the eucalypts. In general, the eucalypts which eventually dominate in the sclerophyll forest, usually start life with a fairly strong apical dominance. The upward development of the main stem is not always straightforward, and may involve accessory buds or even dormant buds, but at least in the young stages, in a forest situation, a central stem predominates with lateral branches being restricted in size. Jacobs (1955) recognises first a juvenile stage and then a sapling stage in which there may be several branches competing to form the principal stem in the top of the crown but from which older branches at the base of the crown will ultimately be shed. In this way the tree grows to a pole stage, in which there is a long clean bole, but with the lower branches of the crown, although subordinate, being retained for a longer time. Finally there is a mature stage with what is sometimes called 'crown break'. The tree largely loses its apical dominance and develops several large persistent branches which virtually prevent the further extension of the principal single bole.

As a fourth and final feature some mention must be made of wood properties and stem characteristics. The eucalypts, being angiosperms, are termed hardwoods as distinct from coniferous softwoods. Unlike many rainforest hardwoods, the eucalypts do, in general, have fairly hard to very hard woods. Some possess exceptional durability. Many of the wood properties are described with quantitative data by Pearson, Kloot and Boyd (1958). Rudman (1964) discusses some aspects of durability in the eucalypts. Nelson and Heather (1971), working with flooded gum (E. grandis), observed a change from immature, decay susceptible heartwood near the pith to more mature, somewhat decay resistant wood at the sapwood-heartwood boundary. Radial variation in decay resistance seemed to be associated with position relative to the pith and with in situ ageing. The former was postulated to be controlled mainly by deposition of polyphenols, while the loss of decay resistance with ageing was considered to be due to polyphenolic polymerization. Although detailed studies of decay resistance in the living tree are few, it is possible that the above pattern of decay resistance occurs in most eucalypt species, since the great majority of eucalypts reveal some central column of internal defect. This matter is discussed at greater length in a later chapter, but it is important to stress here that the internal decay does not necessarily reveal itself in any external symptom.

The situation is often considerably complicated by the destructive activities of a number of termite species. An anonymous worker in 1968 gives a general summary of the activities of these insects in the publication 'Rural Research in CSIRO'. Greaves (1964) offers technical information on some aspects of termite colonies. Greaves et al (1965) discuss timber losses caused by termites, decay and fire in an alpine ash forest in New South Wales. Greaves and Florence (1966), discussing the incidence of termites in blackbutt regrowth, propose the hypothesis that, whilst the extent of attack is not necessarily unrelated to the invasion potential provided by surrounding colonies, it is possible that soil properties affecting the formation of termite galleries together with the physiological condition of the regrowth may be more important. This last suggestion is of considerable importance to management since it implies that proper silvicultural practice may help to minimise the very costly losses due to termite activity.

The properties of sound eucalypt woods are also of considerable interest, particularly in regard to their effects on paper making. The most important characteristic is the short fibre-length relative to the coniferous timbers which have been the traditional source of paper pulp throughout the world. The first use of eucalypts for newsprint began in 1941 with Australian Newsprint Mills Ltd producing paper from high quality mountain ash in Tasmania. A suitable mechanical pulping technique was developed for mature and overmature trees. Later research by CSIRO in Australia has led to the development of a pretreatment technique, using pressure impregnation with caustic soda, to enable regrowth trees also to be processed. More recent research, however, has shown that chemically produced eucalypt pulps are eminently suited for the production of fine printings and writings, which are in rapidly increasing world demand. The relatively low price of the necessary chemicals in Japan and the shortage of other economically available raw materials have recently created a very strong demand for australian eucalypt woodchips in the Japanese paper-making industries. At present the chemical pulping technique used in Japan is best applied to the lower density and paler colour eucalypts, principally mountain ash, silvertop ash and flooded gum, since fibres of these species are more easily beaten to give the necessary conformity in the paper-making process. The current export agreements, referred to in section 1.2, will make use of even-aged stands of these species, and they will probably predominate in most sales in the near future. It appears, however, that the use of denser woods is not beyond the realm of possibility. More research and changing economic conditions may soon create avenues for the sale of pulpwood from many of the more mixed eucalypt forests which have been previously exploited and managed for the production of sawlogs all along the east coast of Australia

2.3 The contribution of past management to present forest conditions

2.3.1 Early exploitation

Aitchison (1969) has gathered together some interesting features of the first cutting of Australian forests, from the time of the first British settlement in 1788. By 1800, one quarter of the convicts of the colony were employed in timber-getting or brick-making to establish buildings for the growing community. Aitchison also notes that, only seven years after settlement, red cedar (*Cedrela australis*) was being obtained from the Hawkesbury Valley, some 40 miles to the north-west of Sydney. In 1803, a General Order was issued, restricting the misuse of timber likely to be useful for ship-building.

After the initial period of establishment, the major expansion of the colony was westward, over the Great Divide, and there was rapid growth of an immense pastoral industry in the natural grasslands and savannah country. The discovery of gold in the mid-nineteenth century also brought a great influx of population to these areas. The demand for building, mining and fencing timbers would have been satisfied mostly from local sclerophyll forest and woodland. On the coast, the steady expansion of the principal settlements always required the clearing of forest and woodland, and at first, this provided sufficient timber for development.

The earliest exploitation of the more distant coastal forests was therefore left in the hands of an intrepid group of pioneers who became known as the cedar-getters. Webb (1966) describes their ruthless exploitation of this species, almost to its extinction. The native Australian cedar requires very favourable conditions of soil moisture and fertility, and was mainly to be found through the valleys of the coastal plain and on parts of the eastern escarpment of the Tablelands in New South Wales and southern Queensland. Cedar-cutting was often the first development of these areas.

2.3.2 Forestry on private lands

The supply lines of the cedar trade and the trails of the cutters themselves were later developed by the agriculturalists. From the middle of the nineteenth century, well into the twentieth century, State governments proceeded to alienate a very large part of the Crown Lands of the coast for private settlement. The holdings were generally small compared to the vast grazing properties established to the west, and many of the earliest settlers were those returning from the goldfields. The predominant form of land use was dairying. Except for those farms established in the rich flood-plains of the largest rivers, most of these small dairy holdings were made up partly of limited areas of alluvial flats, well suited to agriculture, and partly of more extensive areas of prime sclerophyll forest ranging from hilly to steep away from the river flats. The normal practice was to clear these wooded areas, fence them and graze cattle. Some of the timber would have been used in fencing and farm buildings, the better quality and more accessible logs sold to the sawmillers, and much of the remainder felled or ring-barked regardless of quality.

Except in areas with an outlet to a major city, the profitability of dairying has declined in recent years. The lure of more profitable employment in the cities has often left only the less ambitious workers on the more remote farms and management standards have declined. Frequent burning of paddocks has led merely to the development of useless bladey grass (<u>Imperata cyclindrica</u>) and bracken fern (<u>Pteridium</u> sp). Over the years many such areas have been abandoned and re-invaded by the forest. Even some of the better farmers have suffered the same fate as low prices in situations of over-supply have prevented the pasture improvement necessary to keep back the forest.

The privately owned forest lands of the eastern coast of Australia therefore fall into three main categories. Firstly, there are young even-aged stands on failed agricultural land, as just described. Most of these are not yet of sawlog size but would be ideally suited to pulpwood cutting. Secondly, there are stands which have been very heavily logged for all but the poorest remnants of the original stands. Some of these areas, because of the heavy cutting, do now contain regrowth suitable for pulping, together with scattered larger trees of poor quality which are sometimes useable as sawlogs under modern utilisation standards. Thirdly, there are still a few stands, in less accessible areas, which are untouched or only lightly selectively logged. With improvements in logging machinery and extension of logging to adjacent state forests, many of these are now being cut for sawlogs.

In the Tablelands the situation is a little different. In Victoria and Tasmania fine quality even-aged stands of mountain ash have usually regenerated in like manner after logging. Further north in New South Wales and Queensland, the Tableland forests are of generally lower quality than the nearby coastal forests. Clearing for sheep grazing has usually been effective and fairly profitable, and any logging of uncleared stands has necessarily been fairly selective because of the poorer quality. These private forests therefore remain fairly much even-aged.

Whilst individual land owners have not been unaware of the value of occasional timber sales, there are few of the small owners who have deliberately managed their land for the purpose. Nevertheless, many of their activities have led to the regrowth of fairly vigorous even-aged stands. Few private companies engage in forest management in Australia and some of these are concerned only with softwood afforestation. A small number of companies do manage poorer quality stands for hard fibreboard production and one large Australian company has recently entered the field of hardwood afforestation for production of paper pulp.

Although the techniques developed in this thesis are aimed principally at large holdings of irregular forest which are mostly under public ownership, many of the principle and methods are nevertheless applicable to smaller, privately-owned stands, whether even-aged or irregular.

2.3.3 Development of an irregular condition through past management

Table 2 gives the areas of 'forest lands permanently dedicated for the production of logs, pulpwood, pit-props, poles, posts and fuelwood, for commercial purposes'. Only the figures for areas considered 'productive' have been given. The most interesting feature of this table is that, of the 26 million acres of State-owned forest, 21.5 million acres are of sclerophyllous eucalypts, and about 80 per cent of this area lies in the eastern states. In Section 2.2.2

it was stated that the eucalypts tend to occur in <u>even-age stands</u>. It is therefore important to consider how the previous management of State forests brought them to an <u>irregular</u>, or uneven-aged condition, particularly in the coastal areas of New South Wales and Queensland.

Basically this pattern of development has evolved from up to a century of selective logging. Selective logging began, partly because of the economic difficulties of primitive logging equipment and partly because a more intensive utilisation seemed unnecessary in a situation of apparently limitless forest. Power saws are only recent and the slowness of earlier felling with axe and cross-cut saw meant little time could be spared for trying trees suspected of being defective. Moreover, the difficulties of logging with bullock teams, together with the problems of early sawmills, made for little interest in the utilisation of small or defective trees. Trees of less than 32 in. dbhob were considered small.

The value of eucalypts for pulping has only recently emerged with the development of new processing techniques. The principal sales have therefore been in the larger round timbers and, more importantly, in sawlogs, mostly to supply the house construction market. Although most other countries have drawn largely on coniferous softwoods, the eucalypts have been able to substitute for them in most places in Australia. Uses were found for almost all of the forest species, provided the log quality was good. If anything, in earlier times there was perhaps a prejudice against the less durable, and incidentally less tolerant, species such as blackbutt and flooded gum.

The net result of the first 50 years of exploitation was that by the turn of the century, most of the readily accessible areas, from gully bottom to ridge top, had experienced at least one selective logging, with the selection preference being more for log size and quality than for any particular species. It was about this time that the State

Forest Services were set up. They inherited some virgin stands in the tablelands and less accessible coastal areas together with the cut-over remnants of the very fine accessible coastal sclerophyll forests. Moreover, much of the best of the forest resource had already passed from the control of the Crown during settlement, and was soon cleared for agriculture.

Management by the Forest Services generally began with restrictions to reduce the intensity of selective cutting in some areas. The demand for housing and other timbers still had to be met, however, and in time more and more areas were opened up and others logged for a second time. Most important is the fact that it was selective logging that continued to predominate. This situation was brought about partly by the continuation of the circumstances that led to the beginning of the practice, as discussed earlier, and partly by the observation that every area of the forest logged earlier contained small trees referred to as 'advance growth'. Any conversion to a more manageable even-age system by clear-felling would have resulted in the sacrifice of this advance growth.

The formation of the State Forest Services also saw the initiation of extensive attempts to rehabilitate and improve the forests after logging. Such silvicultural treatment has had to work within the bounds imposed by selective logging and has generally been concentrated more on post-logging regeneration treatment than on the thinning and improving of existing stands. Henry (1960) however, does discuss the effects of some thinning treatments.

For the most part logging and treatment have been conservative, in that any tree of apparent commercial potential, even if slight potential, was retained in the hope of supplying some future sawlog market. Regeneration treatment is often termed 'Timber Stand Improvement', or more commonly, T.S.I. The basis of this form of treatment has been the extension of logging openings to permit the entry of sufficient light onto the seed-bed. In some cases further treatment has included seed-bed preparation by burning or dozer clearing and the provision for additional stocking by artificial sowing or even planting. This combination of selective logging and extension of regeneration openings was described by Jolly (1920) and again, formally, by Jacobs (1955) as 'The Australian Group Selection System' of silviculture. In large part the success of the system in producing vigorous seedling regeneration has depended upon the ecological status of the original forest and upon the size of the openings created.

The drier ridge sites, frequently stocked with the less tolerant species, such as blackbutt, have usually regenerated fairly well after treatment. Before logging, these stands were reasonably open, with little understorey, probably due in part to the incidence of recurring fire. With ridge-top roading being common, access was good and logging was fairly intensive, leading to large openings which were easily extended by the felling of smaller useless trees and the ringbarking of large, overmature veterans. The best of these areas, if well treated in the past, are probably now in satisfactory production.

In situations where there was a greater mixing of intolerant species and the more tolerant, lignotuberous species, Group Selection has been less effective. Such mixtures were found on the intermediate slopes between gully bottoms and ridge tops. Before logging, these stands carried a substantial understorey of pole size trees in suppression under the main canopy and of smaller, suppressed, lignotuberous advance growth. Unless logging and treatment were particularly intensive, the openings were taken up, not by vigorous, new seedling regrowth, but by the gradual expansion of the lignotuberous stock and by the encroachment of tolerant weed species favoured by the shade from the taller suppressed remnants of the former stands. Florence et al (1970) described the degeneration of a lignotuberous spotted gum stand in Queensland through conservative silvicultural practice of cutting down to a minimum tree girth and the retention of all stems of even the smallest potential. Florence (1970) describes similar situations in mixed species forests in New South Wales and Queensland. Wherever treatment has favoured the regrowth of seedling blackbutt in these forests, individual tree increments of this species have been good. But wherever old advance growth of tolerant species, such as turpentine, tallowwood, white mahogany and grey ironbark, has been retained, increments have been poor.

In the true wet sclerophyll situations, particularly in the gully bottoms, only virtual clear felling with subsequent burning and sowing has been successful, thus leading to the continuation of even-aged stands. Any treatment much less intensive than this has usually resulted only in a reduction of the useful overstorey and an increase in the useless tolerant understorey of rainforest species.

2.3.4 Productivity in the irregular forests

From the foregoing discussion it could well be expected that productivity in the irregular forests would be poor wherever it has not been possible to follow selective logging with intensive silvicultural treatment. But the actual yields commonly quoted are alarmingly low, particularly in comparison to the widely claimed figures of at least 250 cu.ft per acre per annum for average quality plantations of Pinus radiata in Australia. The problem is given a thorough coverage by Curtin (1970). Table 8, reproduced from that paper, illustrates the low yields for several managed eucalypt forests in New South Wales.

There are two important aspects of these quoted yields. Firstly, actual forest production is restricted by the accumulation of useless and non-vigorous material, as discussed in 2.3.3. This accumulation is largely due to the high standards applied in previous selection for utilisation as sawlogs. Subsequent silvicultural treatment has failed to eliminate the non-vigorous trees, partly because of the cost involved, partly because of a failure to recognise the inability of suppressed stems to respond to treatment, and partly because of the desire of the State Forest Services to conserve forest capital of any apparent potential against the time when coniferous plantations could help support the sawnwood demand. Moreover, Curtin (op.cit.) also emphasises that not all vigorous regrowth is useful and treatments have not always eliminated vigorous but useless trees occupying vital growing space.

The second aspect of the depressed yields is bound up in the terms in which the yields themselves are defined. Although Curtin does not give such a definition, in accordance with New South Wales Forestry Commission practice they would refer to the gross volume under bark, for merchantable stems only, from a standard stump height to the top of the merchantable bole. The trees considered merchantable, the stump height and the merchantable height depend to a large extent on the product intended. Curtin's figures undoubtedly refer principally to sawlogs and, perhaps to some poles and piles, but not to pulpwood. Since the quality requirements for sawlogs are fairly high, not only is the actual productivity of the forest depressed, but the expected yields are even more greatly reduced by the inability to utilise all of the actual production. Moreover, these yields would be reduced even further if conversion were made from gross volume to nett volume by making allowance for losses due to fire, disease, termite attack and other defects. Heather (1962) refers to Australian Forestry and Timber Bureau estimates that in the period 1956-60 the total annual losses due to fire, disease, termites and similar agencies in broad-leaved forests were 90,000,000 cubic feet, equivalent to approximately 20 per cent of the estimated annual increment

TABLE 8

PAST YIELDS, PRESENT YIELDS AND PRESENT GROWING STOCK OF VARIOUS FORESTS AND SPECIES ASSOCIATIONS

Forest	Major Species	Average net yield since 1920 c.ft/acre/ann.	Calculated sustained yield in 1969 c.ft/acre/ann.	Present growing stock c.ft/acre
Coopernook	Blackbutt	33.6	38.6	1482
Kendall	Blackbutt	11.3	23.2	1139
Lansdowne	Blackbutt	12.6	14.6	692
Wyong	Various	7.2	12.9	697
Kiwarrak	Grey gum - Ironbark	5.5	8.2	607
Yarratt	Grey gum - Ironbark	3.0	5.3	560
Styx River	Tableland Hardwoods	3.3	-	-
Bago	Alpine Ash	13.8	12.9	807
* Pine Creek	Blackbutt	18.0	22.0	2197

From : Curtin, R.A. (1970) Increasing the productivity of Eucalypt forests in NSW. Australian Forestry 34:97-106

* Not given by Curtin but supplied by author of this thesis.

of these forests. Heather stresses that these are mortality losses and do not include the effects of fire and disease in depressing increments.

The limitations of sawlog operations are further illustrated by Mann (1958), using the example of a mixed-species forest in eastern Victoria. The area had been heavily logged in the past and was in need of regeneration treatment. It was considered that a further sawlog harvest alone would be uneconomic. But in a combined sawlog-pulpwood operation the yields per acre were 200 c.ft of pulpwood logs and 500 cu.ft of pulpwood billets. More recently, similar increases in yield have been observed in combined sawlog-pulpwood operations in cut-over State Forest at Eden in New South Wales. The combined operation on a block of about 1200 acres yielded approximately 1400 cu.ft per acre in pulpwood and 200 cu.ft per acre in sawlogs, even though the area had recently been considered logged out for sawmilling purposes.

Whilst there is certainly room for improving the productivity of the irregular eucalypt forests through silviculture, there is even further scope for improvements in utilisation to harness a greater proportion of current production.

2.4 Present and foreseeable economic and social considerations

2.4.1 Multiple use management

In the determination of objectives for the management of publicly-owned forests an attempt must be made to satisfy the many different demands of the public to the greatest common good in the long term. Although some of these demands may be conflicting, many people in recent times have emphasized the desirability of attempting to satisfy more than one of them simultaneously on the one area in order to make best use of a limited resource. The term, 'Multiple Use Management', has become common. Two of the earliest exponents of the formulation of a considered policy for the multiple use of Australian forests were Crane (1958) and Harris (1960). McGrath (1962) stressed the growing urgency for the recognition of the need to plan for the satisfaction of different needs for forest and some of his sentiments were re-echoed by Ovington (1968).

McGrath (1962) offers the following reasons for attaching greater importance to a rationalised national policy on land use:

1. The great rise in population and its concentration in a very few high density centres - a condition requiring maximum multiple service from the local gathering grounds for an ever increasing water demand.

2. The rise of secondary industry and its requirement for water in unprecedented quantities.

3. The great rise in consumption of goods of all types and of forest products in particular.

4. The exceptional cost of transport which now consumes an unparalleled one-third of the national income in Australia, and which demands reassessment of the geographical relationship of crops to centres of consumption, in accordance with the freight content of their cost.

5. The uncertain external marketability of surplus agricultural production, plus the mounting cost and uncertain future of imported forest products obtained from countries of lesser forest productivity than our own.

6. The failure of coastal shipping and consequent reduction of river dredging, which has accentuated the necessity of erosion control for the protection of agricultural bottom lands from floods.

7. The great rise in irrigation and the general capacity for scientific agriculture to meet a given demand from a constantly decreasing land area.

8. The great capacity for destruction by the modern machine when misapplied, a condition that requires thought and planning as never before.

With the current rapid development of Australia it is not difficult to envisage the eight factors listed above acting together to require the efficient use of the native forests for several purposes including the following:-

(a) Production of wood.

(b) Regulation of catchments.

(c) Provision for grazing.

(d) Erosion protection.

(e) Outlet for recreation.

(f) Preservation of the environment.

The best collective interest may be served in some situations by multiple use and in others by single use, if the conflict of uses would produce an unsatisfactory management compromise. The present usage of the forests was discussed in Chapter 1 using the above categories, and in respect of the latter five, some indications of future trends were given, although specific requirements were not stated. In general, pressure for all uses, with the possible exception of grazing, is increasing. The Forestry Acts under which the State Forest Services conduct most of their operations vary from one State to another. A brief resume of this legislation is given by Slinn (1964). Only in Queensland has the Forestry Department had direct responsibility for the administration of National Parks. In other States greatest emphasis in the legislation has been upon commercial timber production although some provision has been made for other activities. Moreover the State Forest Services have had power to act under legislation other than the Forestry Acts. Under these provisions it has bee possible to entertain and, at times, encourage uses of the forest other than timber production. With increasing pressure for <u>planned</u> multiple use foresters will probably find in the future that they are not only permitted to consider forest uses other than timber production but that legislation will require them to maintain a balanced use of the land they control. For example, in addition to the regulation of timber yields, the Forests Act of Victoria (1958) makes the following stipulation in Clauses f and g of Section 20:

> Subject to this Act, the Forests Commission shall out of such moneys as are legally available make provision for the following:
>
> ...The provision of facilities for public recreation and for the protection of native flora and fauna in State forests.

...The promotion of good relations between the Commission and the public.

It was suggested in Chapter 1 that uses such as recreation, soil protection and environmental preservation are more readily compatible with an irregular forest condition than with even-aged plantations. It is therefore necessary to assess the importance of the timber production requirement and to consider how well this requirement may be met from irregular forests. This is a particularly important consideration since timber production may well be necessary to provide the cash for the services required to sustain forest uses which do not involve direct commercial production. It will be the task of inventory to facilitate the timber production management.

2.4.2 Wood production requirement

Although a small amount of timber formed the earliest export from the colony established at Sydney Cove in 1788, the pattern of development of the country has led to a reversal of the situation. Table 9 shows the relative importance of local and imported supplies of forest products consumed in Australia in 1966-67, indicating that 27.4 per cent of consumption was imported. Imports were valued at 192 million dollars, equivalent to 25.7 per cent of the cost of all products consumed. In the same year, Australian exports of forest products were valued at only 22 million dollars.

Such a high import requirement and consequent drain on overseas funds have understandably led to a desire to increase Australian production, a desire accentuated by the following three predictions for the future in Australia:-

1. Decreasing overseas supplies.
2. Increasing import costs, particularly relative to the values of major primary produce exports.

3. Increasing demand for forest products, not only through increasing population but also through expected increases in per capita consumption.

There have been several attempts to forecast likely future demands and a fairly extensive treatment of the subject was given by Hanson (1962). It is not surprising that this was the first problem to receive attention from the Australian Forestry Council, established in 1964, (Jacobs, 1965). McGrath (1965) reports that the Council appeared to accept the following figures for the year A.D. 2000:-

Australian population	22,400,000
Per caput roundwood consumption (cu.ft)	58
Total industrial roundwood requirement	1,293,000,000
Expected availability from 25,000,000 acres of native forest	375,000,000
Expected deficit	918,000,000

Because it was readily apparent that the 650,000 acres of exotic conifer plantation in Australia in 1965 would do little to meet the expected deficit, the Council recommended an increase in the annual national planting programme to 75,000 acres. Under the 'Softwood Forestry Agreements Act, 1967' the Commonwealth Government gives loan assistance to the States for 65,000 acres of plantation establishment per year. It was expected that private enterprise would plant a further 10,000 acres annually.

There is no doubt that some such programme will be worthwhile. Many workers can testify to yields well in excess of 200 cu.ft per acre per annum from Pinus radiata. But such a planting programme obviously involves a very high capital outlay. Moreover, the severe ecological disturbance involved in the introduction of monocultures of exotic species on a large scale is the justifiable cause for concern amongst many people. The role of the native forests in fulfilling the wood requirement is therefore of increased importance.

TABLE 9

PRODUCTION, IMPORTS, EXPORTS and CONSUMPTION of FOREST PRODUCTS
AUSTRALIA - 1966/67

(Thousands of cubic feet round measure true volume)

	Production	Imports	Exports	Consumption
Broadleaved				
Sawnwood	231541	10296	2360	239477
Plywood & veneer	4354	4141	150	8345
Sleepers	27042	-	4338	22704
Pulpwood	35206	-	6751	28455
Other products	24141	-	685	23456
Coniferous				
Sawnwood	58156	42026	262	99920
Plywood & veneer	1983	1509	-	3492
Sleepers	5	-	-	5
Pulpwood	16599	87181	87	103693
Other products	980	-	-	980
Total	400007	145153	14633	530527

From: "Compendium of Australian Forest Product Statistics"
Australian Forestry and Timber Bureau (1969)

The figures quoted above indicate an expected annual production of 275,000,000 cu.ft from 25,000,000 acres, representing a Mean Annual Increment of 15 cu.ft per acre per annum, which is only 6 per cent of the expectation for fair quality *Pinus radiata*. Yet this figure is in excess of all but three of the predicted yields for native forest given in Table 8, and these stands represent those considered some of the more productive of native forests. Only the simplest of arithmetical calculations is needed to show that almost any reasonable attempt to increase the productivity of the native forest on a broad scale is likely to be well justified. Every increase of one cubic foot in the expected mean annual increment on the 25,000,000 acres of native forest is equivalent to the planting of 125,000 acres of conifers, if an M.A.I. of 200 cu.ft is accepted for these plantations. At an average establishment cost of $50 per acre, this would make available the sum of $6,750,000 for the less ecologically drastic treatment of native forests. If maximum multiple benefit is the broad goal of management, the problem is to determine means of achieving the necessary production within the context of an irregular forest.

2.5 Increasing the productivity of the broad-leaved forests

There are four principal factors influencing the low commercial productivity of irregular eucalypt forests in Australia. These are :-

(a) Understocking

(b) Stocking with trees physiologically incapable of rapid growth.

(c) Excessive damage in relogging regenerating areas.

(d) Poor utilisation.

Through past management all four problems occur simultaneously to varying degrees over almost all the coastal sclerophyll forest of eastern Australia.

In an attempt to overcome the first three of these factors the forest manager could resort to a conversion of existing stands to even-aged plantations, including plantations of native species. Whilst eucalypt plantations have been shown to be highly productive in some circumstances, it is not easy to give a realistic assessment of their probable productivity if supplying only the type of market presently supported by the irregular mixed-species forests. Very little plantation area has been grown to trees predominantly of sawlog size. F.A.O. (1955) report production of 150-200 cu.ft per acre per annum from E. globulus grown on short rotation in Spain. Average production of 330-430 cu.ft per acre per annum is also reported for eight-year rotations in Brazil. Whilst eucalypts undoubtedly do well as exotics, in the absence of natural pests, much of these high yields could be attributed to high levels of utilisation associated with pulping operations. In Australia, Curtin (1969) reports probable increments of 159 cu.ft at age 40, or 125 cu.ft at age 70 for even-aged plantations of blackbutt intensively managed for pulp and sawlog. The establishment of such plantations will necessarily involve a heavy cash outlay, with the possibility of only low returns. Holmes (1968), for example, demonstrates earning rates for clear-felling and planting with blackbutt of only 3.02 per cent on a 70-year rotation or 3.85 per cent on a 40-year rotation. These figures make no allowance for increases due to monetary inflation but they do depend on the ability to market intermediate pulpwood thinnings, even though present pulpwood operations in Australia are based almost entirely on clear-felling. Moreover, the conversion to even-aged stands does involve the loss of some of the benefits associated with uses other than wood production, as discussed earlier.

Accordingly, Florence and Phillis (1971),* examine

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* Note: The author's part in the collection of data and the formulation of this paper were performed as part of his studies towards this thesis.

methods of increasing commercial productivity within the framework of an irregular forest structure. This paper re-emphasizes the fact that previous conservative treatments have left behind large numbers of useless and substandard trees, mainly of the more tolerant species. It is stated that:-

> In the light of present market expectations, the most appropriate silvicultural approach is one aiming at a substantial improvement of long-term production whilst providing a continuing output of quality sawlog.

The following four treatment schedules are put forward:-

1. Conservative schedule

The principal objectives of this schedule are the maintenance of a large growing stock to ensure the continuing short-term supply of sawlogs, poles, piles and girders to established markets concurrently with some improvement in commercial productivity.

2. Radical schedule - with natural regeneration

This treatment recognises that forest productivity may be raised appreciably only by a rigorous elimination of all stems with poor bole quality and those of insufficient vigour to make a satisfactory contribution to stand increment. At the same time, the need is recognised to maintain the output of high quality sawlogs over a number of cutting cycles.

3. Radical schedule - with enrichment planting

In logging and treatment prescription this schedule is identical with the previous one, except that gaps are planted with seedling blackbutt where it is expected that natural regrowth would be mostly of the more tolerant eucalypts originating from lignotubers, coppice and small advance growth. Where necessary, the gaps are extended by tractor clearing.

4. Complete logging schedule - with advance growth salvage

Under this treatment there is a complete logging of all trees of saleable size, except for the retention of a few of the smaller merchantable stems with outstanding potential. Only higher quality advance growth is retained in treatment and all gaps are enriched with seedling blackbutt.

For both the radical and the conservative schedules the paper gives a detailed qualitative description of the trees to be removed in logging and treatment, expressed in terms of tree size, crown quality, apparent bole quality and probable effect on subsequent regeneration. One of the most striking features of the study is the very large volume of wood felled to waste in treatment. In discussing the four schedules the authors recognise that one end of a spectrum of possible silvicultural approaches is represented by selective logging, more or less to a cutting-girth-limit, without investment in post-logging treatment, or alternatively the application of the conservative schedule, which resembles current silvicultural practice. Since past application of these types of approach have led to low commercial yields under existing utilisation standards they can only be justified if it is expected that there is an imminent possibility of selling the substandard material to a wood-chip or pulpwood industry. Immediate improvement of productivity is delayed in the expectation of greater gains from commercially profitable treatment at a later date.

In the absence of a market for small substandard trees Florence and Phillis (op.cit.) lean toward the radical schedule in preference to a more complete logging, or even clear-felling approach. The radical schedule maintains a greater short-term flexibility of product supply, involves a lower initial treatment investment than plantation establishment and continues to provide the recreation, environmental preservation and water regulation benefits of the irregular forest. At the same time it aims to increase long-term commercial productivity. Moreover, areas are brought into increased productivity more quickly as the required annual yields are obtained from a larger area than they would be under clear-felling.

CHAPTER 3

ERROR CONCEPTS

3.1 Introduction

Since forest inventory aims to provide the forest manager with information necessary for efficient decision-making, one of the most important aspects of inventory is forest mensuration, the process of determining the characteristics of individual trees, of the stands they comprise and of the sites they occupy. Carron (1968) provides an outline of forest mensuration, making particular reference to Australian conditions. In the course of their treatment of the whole subject of forest inventory Loetsch and Haller (1964) and Spurr (1952) deal with several aspects of mensuration at some depth.

In his introductory chapter, Carron (op.cit.) discusses the question of error, with the following statement:

> If measurement is thought of as an exact determination of the size of some property in terms of a unit which relates to a standard, then the 'measurement' of forest mensuration is most often rather an estimate - an inexact determination. The difference between a true value and an inexact determination is an error.

Decisions based on estimates are often affected by the confidence the manager is able to place in the estimate and it is therefore necessary to find ways of determining the likely errors involved. Estimates of error can be made only by understanding sources of error. These sources are of two main kinds.

Firstly, there are errors associated with processes of measurement. For example, it is a commonly accepted practice to measure the diameter of a tree with a girth tape. Diameter is then often converted by arithmetic transformation to give sectional area. This process assumes that the tree section is exactly circular but if, as is usual, the section is not truly circular the method gives only an estimate of the true sectional area. Forest mensuration is replete with such examples.

Secondly there are errors associated with sampling. Forest management in Australia is extensive, compared to the intensive methods of some European countries, and the use of complete enumerations, as practised in Europe, is not possible in most circumstances. Sampling techniques are essential. The use of sampling is common in other sciences such as psychology, demography and agriculture and there are numerous general texts on the subject. Three such texts of considerable use are Yates (1949), Cochran (1963) and Sampford (1962). Freese (1962) gives a particularly simple and clear exposition of some sampling methods for forestry.

Examples of errors in measurement and sampling will be discussed in later chapters, but it is first necessary to discuss certain concepts associated with inventory errors.

3.2 Precision

Precision is an aspect of error associated with sampling and is described by Finney (1947) as 'the reproducibility of an estimate in repeated sampling conceiving an infinite repetition of the sampling procedure'. This definition is best explained by example. Consider a forest of 100 acres for which a forest manager wants to know the average number of trees per acre. If the forest were of very uniform stocking, as plantations occasionally may be, it would be possible to obtain a fairly good estimate of the stocking by counting the trees on one single-acre plot. Repeating this procedure by counting several like plots would be expected to give similar results in each case. The estimate is therefore easily reproducible and of high precision. If, as is more common, the forest stocking were more variable, there is a much lower probability that the stocking on any single plot would approximate the stocking of other like plots, or that it would represent the average of the population as a whole. All other things being equal, an estimate obtained as the mean of ten such plots could reasonably be expected to be closer to estimates obtained from other samples of ten plots, and also to have a greater probability of being close to the actual population average. The plots are termed sampling units. Using the simple examples above as an illustration of a general working rule, the precision of an estimate can be expected to be strongly related to the population variability and the number of sampling units used to provide the estimate of the population mean. As it will be discussed in later chapters, much statistical theory devolves around providing mathematical estimates of precision in given sampling situations.

3.3 Bias

Bias involves a consistent tendency for estimates to differ in a particular direction from the true value sought. Both measurement and sampling may involve elements of bias. The example given above involved counting of numbers and involved no real problem of measurement estimates. Suppose, however, that it was necessary to determine the average height of the trees in the stand. If the height determination were made on standing trees, using an instrument such as an Abney Level, and if the instrument were wrongly graduated, there would be a consistent error, or measurement bias. If the height determination were made by measuring the length of trees felled in a thinning from below, there would be a sampling bias, since only the smallest trees would be included in the sample.

Several standard sampling procedures which avoid bias will be discussed in later chapters. Measurement bias may be less easily avoided and it is often prudent to institute checks which will lead to the detection of such bias. All too often, forest inventory results are credited with a false air of 'respectability' because they are of acceptable precision, even though there may be considerable uncontrolled measurement bias.

3.4 Accuracy

Accuracy involves errors of measurement associated with the limitations of operators and instruments, but not including such things as incorrect calibration of instruments or operator preferences leading to bias. In using an Abney Level, for example, there will be slight random variations in readings due to the operator's inability to hold the instrument steady or level it exactly. Carron (1968) calls these accidental errors. Usually they are unavoidable, but do not greatly affect overall accuracy since they tend to be compensating.

On the other hand if an instrument scale is difficult to read, the operator may frequently make mistakes. Inaccuracy caused in this way may be considerable and should be avoided where possible. Whilst such errors may ultimately be compensating between themselves, they need not necessarily be so. Moreover, if the individual estimate in error is being used in conjunction with estimates of other characteristics, as in the combination of diameter and height in a volume regression, the errors in combination are unlikely to be compensating.

3.5 Reliability and efficiency

The three preceding sections have discussed errors in terms of precision, bias and accuracy and it has been indicated that some of these errors arise in both sampling and measurement. The reliability of an estimate is the nett effect of all errors of measurement and sampling in combination. Statistical methods supply mathematical expressions of sampling precision in the absence of sampling bias, but other elements of reliability are often overlooked, even though they may frequently be greatly in excess of errors of sampling precision, and may therefore render efforts to attain precision of little value. Although convenient mathematical expressions of bias and accuracy are not always available, it is still possible to institute various checking operations to minimise their occurrence. For example, estimates made on a large number of standing trees may be checked for bias by felling a sample of the trees and making accurate measurements on the ground. With temporary sampling units the checks must usually be instituted at the time of measurement, but with permanent sampling units checks may be built in to the remeasurement procedure or incorporated at times of plot maintenance.

In general, increasing levels of reliability will only be obtained at a cost and the forest manager should be concerned with selecting inventory procedures which are efficient. The most efficient sampling procedure is one that gives maximum reliability at a given cost or incurs minimum cost for a given level of reliability. Sampling texts often describe techniques for 'optimal allocation', to give maximum sampling efficiency but most of these consider only sampling precision and ignore bias and accuracy.

3.6 Utility

The preceding discussion has centred on errors associated with the estimate of a mean value for a single population, and this is the situation commonly considered in inventory and sampling texts. However, the problem is usually more complex in a forest inventory, which involves the simultaneous estimation of a number of population means. Population, here, is meant in a statistical context. A forest may be thought of as a population of trees, but if it is desired to obtain an estimate of the mean diameter of the trees, the sample is taken from a population of diameters. There is another population of heights. Although there is only one population of trees, the pattern of distribution of the population of diameters may be quite different from the pattern of distribution of the population of heights. From a sampling viewpoint, the forest may be made up of a large number of specific populations, for each of which an estimate of the mean is required. For example, one such population may be the heights of blackbutt trees in the 24-28 inch dbhob class, merchantability class 1, dominance class 1, on the ridge type stratum. If there were in this forest ten principal species, ten diameter classes, three merchantability classes, three dominance classes and two sampling strata, there would be 1800 specific populations of heights, and there could well be a similar 1800 populations of volume. This example perhaps represents an extreme (although not unheard of) case. But even when interested in a much smaller number of specific populations it would be economically impossible to design a new sample to give maximum efficiency for each.

The real problem, therefore, is to design an inventory procedure which gives greatest efficiency for the items of most importance. This introduces the concept of the utility of the results, a concept that is scarcely mentioned in general texts, perhaps because it depends so much on specific circumstances. In some circumstances management decisions may be based on the values of individual means. A common use of inventory information, however, is as a basis for yield control and, here, several estimates may be used in combination. The yield calculation method then becomes a means of integrating various types of information. The importance of reliability in a particular item of information may be adjudged from its effect on the final yield result. Mathematical simulation models, recently developed for use on computers, have been used in this way. The sensitivity of the model to particular items of data is tested by systematic variation of the input data in successive runs. Greatest reliability is required in the input items that most affect the calculated results.

The next five chapters will discuss reliability and efficiency in various aspects of sampling and measurement. A later chapter will deal with the utility of results in yield calculation.

CHAPTER 4

SAMPLING FOR THE PRESENT STATE OF THE SYSTEM

4.1 Introduction

Ultimately, the forest manager is always concerned with the dynamics of the forest resource as he attempts to manipulate growth and drain to maximum advantage. In a variety of ways he assesses past performance in order to make predictions of probable future performance. Recent advances in computing science have made it much easier to combine mathematical expressions of the factors affecting performance and so to simulate long term changes in the forest in a very short period of real time. Mathematical simulation, however, is too difficult or too costly in many circumstances and the forester must still rely on the ability of his mind to integrate all his knowledge of forest behaviour to enable him to predict future performance with sufficient confidence to allow him to make management decisions.

One of the best bases for short-term decisions is a sound knowledge of the current state of the system. As a matter of standard procedure, public companies in Australia are required to present such information formally in the annual balance sheet. The preparation of the balance sheet serves two main purposes. Firstly it allows the directors to review the strength of the company's assets and, by comparison with other balance sheets, to review the company's current performance. Secondly, it provides the investing public with similar opportunities of review so that they can not only consider the security of their investment, but also assess the past performance of the directors. In other words, the balance sheet fulfills an audit requirement. Inventory which provides data on the current timber capital of the forest resource is used in the same way by forest managers. It is rather strange, however, that public administration in Australia usually demands very little audit of the timber capital although it places very strict audit requirements on the financial investment in public forests.

A statement of the current distribution of wood capital in the forest is of principal use in the making of short-term decisions. Over a longer period of time, elements of change inside and outside the forest are likely to be more and more important in determining future forest performance and would need to be taken into account in making longer-term predictions. Two short-term applications of inventory data are particularly important. The first is the quantitative specification of various components of the prescribed yield. The second is the derivation of a suitable, systematic cutting-plan or order-of-working.

From the immediate viewpoint of the forest manager, the quantitative specification of various components of the yield need only be in sufficient detail for him to ensure that his current operations are compatible with his long-term management objectives. He must know which trees to cut and the quantities to be cut. But the utilising industry may have a requirement for considerably more detailed information. Modern businessmen generally find it pays to advertise and good promotion is often achieved by giving the customer as much reliable information about the product as possible so that he knows what to expect and can make efficient use of it. The following types of information are commonly supplied in advertising:-

(a) Type of product.

(b) Quantity, availability.

(c) Composition.

(d) Quality.

(e) Dimensions.

(f) Price.

Since forest managers selling timber are engaged in business, it would be reasonable to expect them to be faced with the same advertising requirement. Very often, however, the State Forest Services do not operate in an intensely competitive market, since for most of the existing sawmills there is no alternative source of supply of raw materials. The sawmillers themselves may be operating in a competitive market against imported supplies and alternative products, such as steel, aluminium and concrete. Although, in these circumstances, the forester may not see an urgent need to provide detailed yield specifications, the achievement of a high level of utilisation may depend upon his ability to do so, since such information is necessary for the utilising industry to plan conversion plants and devise market strategies. This matter will be taken up again later in discussing the utility of the inventory overall, but is introduced here to help illustrate the role of inventory of the present state of the system.

Information on the spatial distribution of the forest yield is a prerequisite to the formulation of a cutting plan. Inventory of irregular native forest in Australia has usually neglected this kind of information, probably because apparently useful levels of sampling precision for localised information seem to be well beyond the bounds of economic feasibility. The problem is illustrated later in this thesis.

4.2 Fundamental approaches to sample selection

Much has been written by numerous authors on the subject of sampling theory and sampling methods. A few of the more important texts are mentioned in section 3.1. Brief descriptions of several applications to forestry are given by Finney (1947) and Carron (1968). Although many detailed procedures have been devised to employ various characteristics of the populations to be sampled, or to achieve some particular goal, ultimately all methods resolve into a small number of fundamental approaches to the selection of the sample.

4.2.1 Subjective, or purposive, selection

Most texts use the terms subjective selection and purposive selection interchangeably to describe occasions where an operator deliberately selects particular sampling units which he considers will represent the average or the range of the population he wishes to sample. This sort of approach can be helpful in obtaining quick preliminary estimates, or when budget restrictions prevent the use of a more extensive objective sample. Extreme care is necessary to keep personal bias to a minimum. Lack of familiarity with a population may cause an operator to select quite unrepresentative units. Undue familiarity, on the other hand, may cause an operator to ignore certain aspects of the population which he personally considers unimportant. In any event, it is not possible to calculate an unbiased estimate of the sampling error associated with this type of selection.

Purposive selection of plots is also of use when it is intended to assess some feature of a particular subpopulation of special interest. For example, if it was desired to know the average tree height at a range of stand basal areas, rather than the average height of the whole population, it would probably be more efficient to choose plots for their basal area to cover a range, rather than to attempt some form of objective sample of the whole population. McIntyre (1952) describes a method of selection from subjectively ranked sets in order to obtain unbiased estimates from the entire population range.

4.2.2 Haphazard selection

In an attempt to remove personal bias from the sample selection an operator may try to approximate true random selection by such methods as pinning plot locations on a map whilst blindfold or 'thinking of map co-ordinates at random'. Selections made in this way are still open to considerable personal bias and are not suitable for statistical determinations of sampling precision. Haphazard selection has virtually no place in forest inventory.

4.2.3 Random sampling with equal probability

In a process of true random sampling every unit of the population has an equal chance of being selected in the sample. All units must be present at the start of selection to have an equal probability of being chosen. Yates (1949) emphasizes that this latter condition is obtained by defining a frame. The frame specifies the extent of the population in terms of the units to be selected in the sample. The frame would be a list of compartments if a sample of compartments were to be chosen. A frame for a forest inventory is often in terms of a map on which any plot may be defined in terms of co-ordinates and the extent of the population, the forest, is defined in like co-ordinates.

Random samples may be drawn with or without replacement If the sampling unit is replaced in the population after each draw, and given equal probability of selection at the next draw, the process is known as sampling with replacement and is equivalent to selecting from an infinite population. More usually, however, there is little interest in including any one sampling unit more than once in the sample and units are not considered again after being once drawn. This is sampling without replacement, selection from a finite population. In practice, if the ratio of units selected without replacement to the total number of population units is small, there is little difference between the methods. (The terms used here should not be confused with 'sampling with partial replacement', which is a technique for sampling on successive occasions and which will be discussed in a later chapter.)

Simple random sampling has two important features. Firstly the method of sample selection does not bias the estimate of the population mean, though clearly it does not control measurement bias. Secondly, it permits an unbiased estimate of the variance of the sample mean, from which an unbiased estimate of the variance of the population can be obtained. This can be used as an estimate of precision. The following two formulae are used for calculating variances:-

Population variance

$$\sigma^2 = \frac{S.\ (Y_i - \bar{Y})^2}{(N - 1)} \qquad (A)$$

where:

Y_i = value for the i'th unit of the population

$\bar{Y}$ = population mean

N = number of units in the population

S. denotes summation of all terms from 1 to N

Sample variance

$$s^2 = \frac{S.\ (y_i - \bar{y})^2}{(n - 1)} \qquad (B)$$

where:

y_i = value for i'th unit of the sample

$\bar{y}$ = sample mean

n = number of units in the sample

S. denotes summation of all terms from 1 to n

The two formulae are effectively of the same form if we think of the sample as a small subpopulation. For computation formula B is more easily used as:-

$$s^2 = \frac{S(y_i^2) - \frac{(S\ y_i)^2}{n}}{(n - 1)} \qquad (C)$$

If the population were reasonably homogeneous it could be expected that most samples would give an estimate of the population mean very close to the actual population mean. Estimates from similar samples of the one population would show little variability. Any one sample estimate could be considered precise, or easily reproducible. If a number of similar samples were taken the individual sample means would be expected to be distributed symmetrically around their combined mean according to the 'normal distribution'. It would also be possible to calculate a variance associated with the mean of the sample means. In practice, it is not necessary to take several samples, since the variance that would be so obtained can be predicted from the variance of a single sample. The following formula applies:-

Variance of the estimate

$$s_{\bar{y}}^2 = \frac{s^2}{n} \qquad \text{(D)}$$

where:

s^2 = sample variance (Formula B or C)

n = number of units in the sample

In the case of sampling without replacement from a finite population, the variance of the estimate may be reduced by multiplying by the finite population correction factor, as follows:-

$$s_{\bar{y}}^2 = \frac{s^2}{n}\left(1 - \frac{n}{N}\right) \qquad \text{(E)}$$

where N is the number of units in the whole population.

The square root of the variance of the estimate is the standard error of the estimate.

Because the normal distribution has certain standard properties, the variance of the estimate and its derivative, the standard error, can be used to fix confidence limits for the estimate of the population mean. The confidence limits are a useful means of expressing the precision of the estimate.

The following formulae are used to calculate confidence limits using the terms of the formulae given earlier:-

At the 67 per cent confidence level

Estimated population mean = $\bar{y} \pm$ S.E. (F)

At the 95 per cent confidence level

Estimated population mean = $\bar{y} \pm 1.96 \times$ S.E. (G)

These formulae will be slightly different for small samples.

To illustrate the method of random sampling and to facilitate later comparison with other methods, a random sample of 29 plots has been drawn in a completely enumerated area. The area used is the Australian National University silvicultural treatment demonstration block in Compartment 26 of Pine Creek State Forest on the north coast of New South Wales. The composition and condition of this block is fully described by Florence and Phillis (1971). The present enumeration was made in preparation for the establishment of four demonstration treatments. Prior to this the area had had a long history of selective logging and had been conservatively treated, bringing it to a general condition comparable with large areas of intensively managed, irregular sclerophyll forest on the north coast. Steel pegs are used to mark out about 100 acres with a permanent two-chain square grid. On the enumerated section of 27.2 acres, the position of each tree larger than 12 in. dbhob was recorded by means of co-ordinates along the grid axes. This information, together with tree diameter, species code and other details, was punched on computer cards. A computer program was written to select plot centres at random and to calculate basal area for half-acre circular plots.

The mean basal area for the 29 plots selected was 36.32 square feet, equivalent to 72.64 square feet per acre. The standard error and the confidence limits can be calculated using the formulae C, D and F given earlier. Full details of the individual plot basal areas are given in Appendix II and only the necessary summarised information is given below.

<u>29 circular 0.5 acre plots</u>

$S.y_i = 1053.27$

$(S\ y_i)^2 = 1109377.69$

$s(y_i^2) = 42844.84$

$n = 29$

From formula C

$s^2 = 163.94$

$s = 12.80$

From formula D

$s^2_{\bar{y}} = 5.653$

$s_{\bar{y}} = 2.38$

$\bar{y} = 36.32$

The sample gives a basal area estimate of 36.32 ± 2.38, or 36.32 ± 4.66 at the 95 per cent confidence level. To convert to basal area per acre, both the mean and the standard error must be multiplied by 2.

Since this particular area had been completely enumerated for other purposes, it was possible to calculate the actual population mean which was 74.21 square feet per acre, only 1.57 square feet greater than the estimate from the random sample. The statistical evidence of the sample alone cannot indicate the size of this actual error but can only estimate the probability of the estimate lying within a given range of the true mean.

If it is critical that the estimate of the mean be fairly close to the true mean, it may be necessary to select a sample with a smaller standard error and a higher level of precision. The variance of a single sample can be used to predict the size of sample that would be necessary to give a required level of precision. The sample variance is assumed to be an estimate of the population variance. From formula D:-

$$n = (s/s_{\bar{y}})^2$$

Suppose a precision of ± 10 per cent at the 95 per cent level of probability were required. In the example given this is a range of ± 3.63, or a standard error of 1.85. Therefore:-

$$n = (12.80/1.85)^2$$

$$= 47.87$$

Thus, it is expected that at least 48 units would have to be included in the sample to obtain the required level of precision.

4.2.4 Ratio estimation and objective sampling with unequal probabilities

At the beginning of Section 4.2.3 it was stated as a condition of simple random sampling that every unit in the population should have an equal chance of selection. In subjective sampling the probabilities of selection for different units are not equal because of personal bias. In the methods to be described in this section the probability of selection is not the same for each unit but is, nevertheless, objectively determined.

Consider the situation in which it is intended to use some form of inventory to determine the volume on a sample of ten compartments in the list of twenty given as Table 10. The aim is to determine the mean volume per acre in the forest. The actual volume on every compartment is shown for the purposes of this theoretical demonstration.

If the compartments to be assessed are selected at random from the list of compartment numbers, each compartment has an equal probability (0.05) of selection at the first draw. If the sampling is made without replacement, the probability of selection at the second draw increases to 0.053 for each of the nineteen compartments remaining, and so on. Because the compartments, the units of the population, are of unequal size, the estimate of the population mean obtained by either form of random sampling is not necessarily unbiased, particularly if there is a correlation between the variable of interest and the size of the unit. Equal probability samples may give undue weight to small units not representative of the general population. A sample of ten plots was randomly drawn without replacement to illustrate the point. Another was drawn with replacement.

The results were as follows.

Sample drawn without replacement

Compartments drawn : 2, 5, 7, 9, 10, 15, 17, 18, 19, 20
Mean volume per acre: 1114.6
Standard error : 8.1 (using finite population correction)

Sample drawn with replacement

Compartments drawn : 1, 3, 7, 10, 10, 10, 12, 12, 17, 19
Mean volume per acre: 1122.3
Standard error : 37.4

The actual mean volume for the population was 1154.5 cubic feet per acre, which is outside the expected error range

TABLE 10

DEMONSTRATION FOREST FOR PPS SAMPLING

Cpt.No.	Area (x) acres	Volume (y) cu.ft	r y/x	Cum. Area acres
1	40	45680	1142	40
2	30	31590	1053	70
3	75	86400	1152	145
4	50	57900	1158	195
5	25	25200	1008	220
6	120	139800	1165	340
7	20	16160	808	360
8	60	75360	1256	420
9	40	48040	1201	460
10	40	44520	1113	500
11	30	34920	1164	530
12	55	67430	1226	585
13	45	43110	958	630
14	70	82810	1183	700
15	100	119000	1190	800
16	50	59250	1185	850
17	60	70560	1176	910
18	20	25600	1280	930
19	30	34620	1154	960
20	40	46520	1163	1000

at the 67 per cent level of probability in the sample drawn without replacement. The actual volume is just in the wider error range of the sample drawn with replacement. These statistics indicate that such errors are by no means unlikely. However, a further examination of the data of table 10 indicates the following relationship.

Volume per acre = 1067 + 1.395. Compartment Area

r = 0.3328

This relationship expresses a positive correlation, albeit a weak correlation, between volume stocking and compartment area. Under these conditions the underestimate observed in the random sample taken could be expected to constitute a negative bias in repeated sampling because the smaller compartments are given the same probability of selection as the larger ones.

It is possible to reduce the level of bias expected by working with weighted mean ratios, using the compartment areas as weights. The weighted mean ratio of volume : area (volume per acre) is obtained by dividing the sum of the volumes on the selected compartments by the sum of the areas of the selected compartments. The sample variance is then found using formula B given in Section 4.2.3, substituting the individual volume : area ratios of the selected compartments for y_i, and using the weighted mean volume : area ratio for $\bar{y}$. This technique is known as <u>ratio estimation</u>. When applied to the samples used in the above illustration, it leads to the following results:-

Sample drawn without replacement

Compartments drawn	:	2, 5, 7, 9, 10, 15, 17, 18, 19, 2
Weighted mean volume per acre	:	1140.3
Standard error	:	30.18

Sample drawn with replacement

Compartments drawn : 1, 3, 7, 10, 10, 10, 12, 12, 17, 1

Weighted mean volume per acre : 1148.9

Standard error : 38.4

In this example the use of the ratio technique has reduced the actual difference between the estimate and the true value from nearly 40 to 14 in the case of sampling without replacement, but there is some loss of precision. A similar reduction of bias is observed in the sample drawn with replacement.

The technique of sampling with unequal probabilities aims to improve the sampling efficiency by weighting the selection process in favour of those units in which the variability of values in the dependent variable, volume, is likely to be greatest. In the example of Table 10 these are the units with highest values of the independent variable, area. The probability of selection is therefore made proportional to the area of the compartment, and the sample becomes self-weighting. The procedure used for selecting units is taken from Sampford (1962). Table 10 shows a column headed 'Cumulative Area'. Each compartment is allotted the numbers from 1 greater than the previous cumulative acreage up to the cumulative acreage for that compartment. Numbers from 1 to 1000 are drawn from a table of random numbers, and a compartment is selected if its number is drawn. For the probability of selection to remain constant, selection must be with replacement. The value for r, the volume : area ratio, is calculated for each compartment, and the variance and standard error are calculated as for a simple random sample with replacement, using the formulae C and D given in Section 4.2.3. No further weighting procedure is necessary since the sample selection is itself weighted. In a demonstration of the method, using the data of Table 10, the following results were obtained.

PPS Sample with replacement

Compartments drawn : 1, 1, 3, 3, 4, 6, 11, 15, 15, 17
Mean volume per acre: 1163.1
Standard error : 5.6

Sampling with probability proportional to size gives an unbiased estimate of the mean in every case. It will usually give an estimate with higher standard error than equal probability sampling without replacement unless, as in this case, there is a strong correlation between the parameter of interest and the size of the unit in the units of greatest size. More commonly, the larger units will show the weaker correlation. Sampling with probability proportional to size can be performed without replacement but the theory becomes quite complex and Sampford (1962) refers his readers to Yates and Grundy (1953) for its explanation.

There are many variations of the method of sampling with unequal probabilities. The principle underlies the very important technique of point sampling using an optical wedge, (Section 4.3.6). Another important application is in the use of dot-grid counts for determining areas on maps, (Section 6.4.3). Probabilities need not only be made proportional to size of unit. In general, the method finds its greatest application in some form of ratio estimation. Greatest efficiency is achieved when the probability of selection is made proportional to some attribute, x, which is strongly correlated with the variable of interest, y. Grosenbaugh (1965) has developed the theory for '3P' sampling, where probability is made proportional to an x value which is a prediction of the true y value, (Section 4.3.7).

4.3 Elaborations of sample selection procedure

4.3.1 Stratified sampling

It is often possible to make considerable gains in efficiency by structuring the sample design to take advantage of some prior knowledge of the population distribution.

Stratification involves the recognition of several broad types or groups within the main population, each stratum being more homogeneous than the whole population in at least one attribute. In a forest situation the strata may be geographically continuous or they may be made up of a number of similar separate groups, provided that each group can be accurately defined in order to determine its contribution to the total population. Map types, forming discontinuous strata across the forest, are often used as a basis for forest inventory.

The choice of an attribute on which to stratify will depend upon the type of gain which it is hoped to achieve. If the attribute to be estimated in the sample is the one for which the individual strata are more homogeneous than the population as a whole, it can be expected that the variance of the estimate of the population mean for that attribute will be less for a stratified sample than for a sample of the same size without stratification. The precision of the estimate is increased by stratification. In other situations the individual stratum means may themselves be of interest with the result that stratification may be justified even when no gain in precision is expected. For example, if a forest were to be managed in two working circles, stratification into working circles for volume assessment would facilitate yield regulation.

The statistical gains to be made from stratification may be illustrated by the formula for calculating the variance of the estimate of the combined population mean. The calculation of the variance within strata, i.e. the variance of the estimate of the stratum mean, depends upon the method of sample selection within strata. The formulae for random sampling were given in Section 4.2.3. Consider a forest of j strata, in which the ratio of the area of stratum i to the whole forest area is k_i. The estimate of the mean of the attribute of interest is $\bar{y}_i$ in stratum $\underline{i}$. The estimate of the population mean is:-

$$\bar{y} = S.k_i.\bar{y}_i \tag{H}$$

where:

$\bar{y}$ is the total population mean

S is used to denote summation over all strata from 1 to j.

The variance of the estimate of the population mean will be the variance of a sum. Since the stratum means are obtained by independent samples, the variance of the sum is the sum of the individual variances weighted by the square of the weights of the individual means in the combined mean.

$$s_{\bar{y}}^2 = S.k_i^2.s_{\bar{y}_i}^2 \tag{I}$$

where:

$s_{\bar{y}}^2$ = variance of the estimate of population mean

$s_{\bar{y}_i}^2$ = variance of the estimate of the mean in stratum i

k_i = ratio of the area of stratum i to the whole area

S denotes summation over all j strata.

If each of the strata is reasonably homogeneous, the variance of the mean within each stratum will be low, and the total variance correspondingly low. The more different the strata are one from another, yet still homogeneous within themselves, the greater will be the gains from stratification. Moreover, since the variances are weighted by the square of the proportion of area that the stratum represents, the gains in precision are best if the larger strata are homogeneous.

When it is possible to recognise several large blocks, or subpopulations, which are not homogeneous within themselves, but similar to each other in their heterogeneity, stratification may be inefficient and the situation is better suited to multi-stage sampling, which will be discussed in Section 4.3.3. As a population approaches a truly random distribution in respect of the attribute of interest stratification will give less gain in precision over simple random sampling but, in theory, it will never give a worse estimate of the mean. Some preliminary knowledge of the population variability is necessary to be able to predict that the gain in precision through stratification will offset the additional administrative difficulties that may be involved. As indicated previously, the individual stratum means may provide some utility other than that to be gained from increased precision.

After stratifying the population there is the problem of how best to apportion the sampling units among the strata. If an estimate of the population variance is required, there must be at least two sampling units in each stratum, in order that the stratum variance may be estimated. After this general stipulation there are several bases for selection. Equal numbers of units in each stratum may give unnecessary weight to unimportant strata, particularly if the strata vary considerably in size. This may be overcome by proportional allocation, in which the fraction of the total number of plots allocated to a particular stratum is the fraction the stratum area is of the total area. This is an efficient allocation if the individual stratum variances are equal or nearly equal, and it serves as a useful basis if little is known of stratum variability. The more strata differ in their internal variability, the less efficient this method of allocation becomes. Greater gains in precision may then be obtained by allocating the plots in proportion to the product of the expected variance of each stratum and the area of the stratum. This technique is known as optimal allocation for a fixed sample size. If there is a cost differential in the sampling of different strata it may be more desirable to select more sampling units in the strata where costs are lowest. The optimal allocation for a fixed sample cost will depend on differences between fixed and variable costs for different strata, and the variances of the different strata.

Whilst all these considerations of optimal allocation appear theoretically sound, they do not always lead to results which are practically feasible. To begin with, the estimation of the relevant costs and variances may require a disproportionate effort and time. Secondly, what is optimal allocation for one population is not necessarily optimal for another population with the same stratum boundaries. This presents a problem in forest inventory where the one set of plots is used for a simultaneous sample of several populations such as diameters of merchantable trees, diameter of unmerchantable trees, heights of merchantable trees and so on. These problems do not preclude the use of stratified sampling, but they do complicate the consideration of optimal allocation.

The use of stratification is illustrated by the following example drawn from the Periodic Management Inventory of Pine Creek State Forest in New South Wales. Prior to establishment of the permanent inventory plots it had been decided that management would employ two working circles designated 'ridge type' and 'gully type'. The ridge type was to be converted to even-aged stands of flooded gum. The inventory sample was therefore stratified to provide information for each working circle separately, with improvements in precision being a secondary consideration. The strata were defined on a species type map, combining 'blackbutt' and 'mixed hardwood' types to form the 'ridge' stratum and 'flooded gum' and 'brushbox' types to form the 'gully' stratum. The total number of plots was fixed by the expected availability of manpower. Proportional allocation was used to divide this number between strata and random selection was used to locate the units within strata. The results were as follows:-

Ridge stratum

Stratum area (acres)	5000
Number of plots	69
Mean volume per acre (s.ft Hoppus)	13064
Sample variance	12406045
Variance of estimate of stratum mean (per plot)	179798
Variance of estimate of stratum mean (per acre)	719192
Standard error (per plot)	424
Standard error (per acre)	848

Gully stratum

Stratum area (acres)	2500
Number of plots	35
Mean volume per acre (s. ft Hoppus)	14162
Sample variance	13343302
Variance of estimate of stratum mean (per plot)	381237
Variance of estimate of stratum mean (per acre)	1524948
Standard error (per plot)	617
Standard error (per acre)	1234

Total forest

Note: the forest mean and the variance of the estimate of the forest mean are calculated using formulae H and I, given earlier in this section.

Total area (acres)	7500
Proportion of ridge stratum	2/3
Proportion of gully stratum	1/3
Mean volume per acre (s. ft Hoppus)	13430
Variance of estimate of mean	489080
Standard error	699
Expected error range (95 per cent)	10.2

These standard errors represent 95 per cent confidence limits of ± 12.7 per cent in the estimate of the mean for the ridge stratum and ± 17.1 per cent in the gully stratum. The confidence limits for the overall mean are ± 10.2 per cent.

The various benefits to be derived from stratification are well illustrated in the calculation of the stocking for the principal species, blackbutt, occurring mainly in the ridge stratum, and flooded gum, occurring mainly in the gully stratum. The relevant figures are given below:-

Ridge stratum - blackbutt

Stratum area (acres)	5000
Number of plots	69
Mean volume per acre	6174
Variance of estimate of stratum mean (per acre)	482451
Standard error	695
Expected error range (95 per cent confidence)	±22.1%

Gully stratum - blackbutt

Stratum area	2500
Number of plots	35
Mean volume per acre	502
Variance of estimate of stratum mean (per acre)	89309
Standard error	299
Expected error range (95 per cent confidence)	±117%

Total forest - blackbutt

Total area	7500
Proportion of ridge stratum	2/3
Proportion of gully stratum	1/3
Mean volume per acre	4284
Variance of estimate of mean	224346
Standard error	474
Expected error range (95 per cent confidence)	±22%

Since proportional allocation was used to allocate the total number of plots between ridge and gully strata, a fair approximation of a probable result by using simple random sampling without stratification can be obtained by simply ignoring the stratum boundaries. The mean volume per acre, calculated for the 104 plots as if they formed a simple random sample, was 4265 super feet with an expected error range of $\pm$ 37 per cent at the 95 per cent confidence level. Stratification has therefore given some increase in precision in the estimate of the total forest mean. More importantly, it has provided useful means within the strata. The stocking of blackbutt within the ridge stratum is estimated at 6174 super feet per acre with an expected error range of 22.1 per cent at the 95 per cent level of confidence. In the gully stratum the standard error expressed as a percentage is considerably higher, although considerably smaller as an absolute value. Of more importance to management is the indication that the stratification has fairly successfully isolated many of the areas not carrying blackbutt, since only two of the plots established in the gully stratum carried more than 1000 super feet of blackbutt. These results facilitate the prediction of the proportion of blackbutt to be encountered in selective logging of the ridge type, and give weight to the expectation that very little blackbutt will be obtained from clear-felling the gully stratum. The pattern for blackbutt in the ridge stratum is repeated for flooded gum in the gully stratum.

Because the stratification was based on management units, the individual stratum means are themselves of value. But because the management units were based on a species type map there was a greater degree of homogeneity within strata in respect to the stocking of the principal species than there was in the population as a whole. This in turn led to decrease in cost for a given level of precision in the estimate of the stocking of the principal species.

In summary, stratification can be regarded as a two-stage process in which all the primary units, the strata, are sampled, either because the individual stratum means are of interest or because it is known in advance that the strata differ one from another. Decreased cost for a given precision can be achieved by a reduction in the number of second-stage sampling units required, if the homogeneity within strata is recognised in advance

4.3.2 Multi-stage sampling

Stratification was considered in the previous section for a population made up of large first-stage units, or strata, each one different from the other but fairly homogeneous within itself. Multi-stage sampling on the other hand, is designed for a population made up of large first-stage units, each one heterogeneous within itself but similar to other first-stage units in its heterogeneity. Decreased cost for a given precision can be achieved by a reduction in the number of first-stage, or primary, units sampled. Unlike stratification, where all strata are sampled, two-stage sampling makes use of sampling at both stages. Moreover, there is no theoretical objection to more than two stages in the sample structure. The sampling is independent at each stage, and different selection methods may be used at each stage.

As usual, the argument for structuring a sample into more than one stage reduces to a balance between statistical precision and cost. One of the principal claims for the use of multistage sampling arises in the situation where much of the permissible inventory budget would be spent in travelling between primary units if each were to be sampled. By selecting only some of the primary units for sampling, parts of the population will be ignored but the money saved in travelling cost will be available for selecting a greater number of secondary units to estimate the means within the primary units. The primary units are in fact subpopulations made up of secondary units. If there is little difference between primary units, but some variation between the secondary units that comprise them, multi-stage sampling will produce considerable gains in precision. The more different are the primary units the greater will be the loss in precision through taking only a sample at the first stage, and the more important will it be that the cost savings at the first stage be sufficient to permit sufficiently intensive sampling to gain precision at the second stage.

Most text-book examples of multi-stage sampling are for census surveys where a natural population structure is apparent. A typical example is a county with villages forming the first-stage units and houses within the villages forming the second-stage units. The county may even be considered as one of a subpopulation of counties. So great may be the importance of reducing the cost of a widespread coverage of the population, it may be desirable to establish a population structure quite artifically. This is a common problem for the resource inventory of inaccessible forest where there would be a high cost of travelling between sampling units. Since the primary units in an artificially devised population structure are unlikely to have convenient names, they are often referred to as clusters. The term, cluster sampling, appears to be synonymous with multi-stage sampling. Each primary unit is considered to be a cluster of secondary units.

The methods of calculating means for multi-stage sampling are illustrated by the formulae below. Since each cluster, or primary unit, is itself a population of secondary units, the calculation of each cluster mean is as it would be for an unstructured population. The calculation of the variance of the estimate of a cluster mean depends upon the method of sample selection at the second stage. The cluster mean is as follows:-

$$\bar{y}_i = S.y_{ij}/m \qquad (J)$$

where:

$\bar{y}_{ij}$ is second stage unit j in cluster i

m is the number of second stage units selected in the cluster

S denotes summation of all selected second-stage units from 1 to m.

If there are n primary units of equal size in the sample, the overall population mean is given by:

$$\bar{y} = S.\bar{y}_i/n \qquad \text{(K)}$$

where:

S denotes summation over all n clusters selected.

This formula simplifies to:

$$\bar{y} = y/n.m \qquad \text{(L)}$$

where:

y is the sample total of all second-stage unit values over all n clusters.

If the primary units are unequal in size, each cluster mean must be weighted by the proportion of the total cluster area sampled occupied by that cluster. Thus:

$$\bar{y} = S.k_i\bar{y}_i \qquad \text{(M)}$$

where:

k_i is the proportion of the total sampled cluster area occupied by cluster i

S denotes summation over all clusters from 1 to n.

When the primary units are of equal size, and they are selected at random, the formula for calculating the variance of the estimate of the population mean is:-

$$s_{\bar{y}}^2 = (1/m.n)(s_B^2(1-n/N)+n.s_W^2/N(1-m/M)) \qquad \text{(N)}$$

where:

- n is the number of primary units sampled
- N is the total number of primary units in the population
- m is the number of secondary units sampled in each of the primary units selected
- M is the total number of secondary units in each primary unit
- s_B^2 is the sample variance between primary units
- s_W^2 is the sample variance among secondary units within primary units.

Complete formulae for the calculation of the last two quantities are given clearly by Freese (1962).

If the sampling fraction at the first stage is small, i.e. if n/N is less than 0.01, formula N reduces to:

$$s_{\bar{y}}^2 = s_B^2/m.n \qquad (O)$$

In general, precision will increase with the number of primary units selected in the sample but, as there will usually be a greater travelling cost between primary units and a greater difficulty in locating primary units in the field, increasing the sample of primary units will also usually increase cost. The most efficient allocation of sampling resources between primary and secondary units will depend upon the cost differential between stages and the difference between the variances of the units of each stage population. An allocation formula is offered by Freese (1962).

An illustration of a simple two-stage sampling design is given in Figure 4. Random selection of units was made at each stage and volume was estimated on each 1-acre second stage unit. The aim of the sample was to determine

Figure 4

EXAMPLE OF TWO-STAGE SAMPLING

		1	2	3	4	5	6	7			
		17	16	15	14	13	12	11	10	9	8
	18	19	20	21	22	23	24	25	26	27	28
	39	38	37	36	35	34	33	32	31	30	29
40	41	42	43	44	45	46	47	48	49	50	51
61	60	59	58	57	56	55	54	53	52		
62	63	64	65	66	67	68	69	70	71		
75	74	73	72								
		76	77								

Forest tract of 1232 acres divided into 77 clusters of equal size.

Arrangement of secondary units in 16-acre cluster

1	2	3	4
8	7	6	5
9	10	11	12
16	15	14	13

Cluster selected	Secondary units selected					
12	Unit No.	3	8	14	15	16
	Volume	600	540	570	590	540
20	Unit No.	4	5	10	13	14
	Volume	560	620	530	580	570
57	Unit No.	1	4	10	12	16
	Volume	580	560	530	540	540
74	Unit No.	2	9	11	14	15
	Volume	550	590	600	570	590

the population mean volume per acre. The details of calculation of means and variance for this example are as follows:-

$n = 4$

$N = 77$

$m = 5$

$M = 16$

$s_B^2 = 792$

$s_W^2 = 663$

From formula (N):

$s_{\bar{y}}^2 = 36.23$

$s_{\bar{y}} = 6.02$

From formula K:

$\bar{y} = 567.5$

In the above theoretical example the estimated population mean volume per acre is 567.5 $\pm$ 6.0 cubic feet.

An excellent illustration of a highly sophisticated application of multi-stage sampling in forest inventory is given by Langley (1969). Each stage in the sampling is covered by a different scale of photography, beginning with very low resolution photography from space-craft and working up to 1:2000 70mm colour aerial photography at the final stage before ground assessment. The sampling at each stage involved the selection of areas to be photographed at increasing scale. At each stage the selection was made with probability proportional to prediction. This kind of approach depends upon the ready availability of high quality aerial photography facilities. It proved well suited to the very large job of assessing the forest resources of 6 million acres in the States of Lousiana, Mississippi and Arkansas in North America. With elimination of some of the earlier stages the techniques used could be well applied to much smaller, detailed management inventories.

4.3.3 Systematic sampling

In the example illustrated in Figure 4 it was possible to calculate a variance for the means within clusters and also for the mean between clusters, because random sampling was used at both stages. If it had been decided at the second stage to estimate the volume in every third unit of every cluster, the situation would have been rather different. The selection of the first unit to be estimated in each cluster would have fixed the probability of selection for all other units in the cluster. Every third unit from the first unit selected would have 100 per cent probability of selection. All other units would have zero probability of selection. This method of selection is known as <u>systematic sampling</u>. Because the probability of selection is fixed, the method is quite different from random sampling where every unit of the population has an equal probability of selection at each draw. It is also different from objective sampling with unequal probability, where different units have different probabilities of selection, but the probability is proportional to some attribute of the population units. It would still be possible to calculate an estimate of the mean within clusters, but it would no longer be possible to calculate an unbiased estimate of the variance for this mean. A variance could still be calculated for the estimate of the mean between clusters. Formula O, given in the previous section, shows how the estimate of the variance of the population mean in a two-stage sample is virtually independent of the variance within clusters when n/N is very small.

Viewed in the context of the simple example in Figure 4, systematic sampling does not present great difficulties in understanding the problem of not being able to calculate a variance for the estimates of the means within clusters.

Very often, however, systematic sampling is applied to the population as a whole rather than the subpopulations within clusters. Yet it is still possible to apply the same reasoning in these circumstances, if it is argued that the size of the cluster has been extended to cover the whole population. By taking a systematic sample within such a cluster, it is possible to obtain an estimate of the population mean, which is the estimate of the mean within the cluster, but it is not possible to obtain a variance for the estimate. To obtain a variance for the estimate of the population mean, that estimate would have to be derived as the mean of at least two such cluster means.

If it were decided to take a systematic sample of a population by selecting every twentieth unit, there would be twenty possible samples depending upon which of the first twenty units were chosen as the starting point for the system. In terms of the foregoing discussion each of the twenty possible samples would be a cluster, but in conventional terminology two such samples would be termed interpenetrating samples. If the starting points for interpenetrating samples are selected at random it is possible to calculate the estimated population mean as the mean of the interpenetrating sample means, and also to calculate a variance for the estimate as if the interpenetrating samples were primary units in a two-stage sample.

Numerous arguments have been advanced both for and against systematic sampling. In fact, foresters have very often made use of the method. Freese (1962) advances two reasons for this widespread use in forestry:-

1. The location of sample units in the field is often cheaper and easier.

2. There is a feeling that a sample deliberately spread over the entire population will be more representative than a random sample.

The first of these arguments is open to some question but it may be true in some circumstances. The second argument involves some risky assumptions. If the distribution of the elements of the population were truly random, the systematic sample would be equivalent to a random sample. Whilst most forest populations are often fairly irregular, particularly in selection forestry, they could not be considered random and the argument does not apply. If, on the other hand, a population exhibited a regular periodicity, a systematic sample could be very efficient if it were designed so that sample units were selected at the mean of the period. Again, this is a theoretical situation which would rarely be encountered in a forest population. The bias in the estimate of variance from a single systematic sample therefore remains unknown. Calculation of the variance as if the sample were randomly selected is not legitimate.

To overcome the problem of estimating precision interpenetrating systematic samples may be taken using random starting points. This procedure reduces one of the claimed advantages of systematic sampling by complicating the location of plots in the field. Despite this possibility, Shiue and John (1962) claim that interpenetrating systematic samples in an extensive resources inventory still gave easier field location than would have been possible with simple random sampling. They also point out the flexibility of the method in allowing them to vary sampling intensity through the addition or deletion of samples without disrupting the basic sampling design. Yates (1949) also claims that the agreement between two such independent estimates is 'often more convincing to the layman than any statement of the sampling error'. Some benefit may also be derived from the division of time and labour in taking separate samples. Results from the first sample may be put to some preliminary use before the second sample is completed.

As a demonstration of the method, four interpenetrating systematic samples were drawn in the silvicultural demonstration area described in Section 4.2.3. The plots were 0.25 acres and circular in shape, spaced on a 5 chain (330 ft) square grid. A computer program was used to select the plot centres from random starts and calculate the basal areas. There were nine plots in each sample. The results were as follows:-

	Sample 1	Sample 2	Sample 3	Sample 4
Mean basal area	18.92	15.28	14.30	17.68

Mean basal area per plot (sq.ft)	16.55
Mean basal area per acre (sq.ft)	66.19
From formula C, Section 4.2.3	
Sample variance	4.52
Variance of estimate of population mean (plot basis)	1.13
Standard error of estimate of mean (plot basis)	1.06
Standard error of mean per acre	4.24

Because there are only four units in the sample, the standard error must be multiplied by the appropriate value of 'Student's t' rather than the normal deviate, to obtain the 95 per cent confidence limits. With four units there are three degrees of freedom and the t value is 3.182. The estimate of the population mean basal area is therefore 66.19 square feet ± 13.49 square feet at the 95 per cent confidence level. The values of 'Student's t' are always higher than the corresponding values of the normal deviate, particularly for very small samples. For this reason there must be a very close agreement between the means of interpenetrating systematic samples, if only three or four are taken, since high variation will lead to a high standard error and very wide confidence limits. The more samples taken the smaller will be the value of 'Student's t' and the more likely will the standard error be low. But increasing the number of interpenetrating samples beyond three or four is likely to incur high cost in the assessment of a large number of secondary units and also to eliminate any administrative gains to made from systematic sampling.

Freese (1962) sums up systematic sampling as follows:-

> Despite the known hazards, foresters are not likely to give up systematic sampling. In most cases sampling errors will be computed by formulae appropriate to random sampling. Experience suggests that a few of these surveys will be very misleading, but that most of them will give estimates having precision as good as, or slightly better than, that shown by the random sampling formulae.

4.3.4 Two phase (double) sampling

Section 4.2.4 illustrated sampling with unequal probabilities with an example that involved ratio estimation. Areas were known for the twenty compartments of a forest and volumes were estimated on a sample of ten of these to determine the ratio of volume to compartment area. The average ratio of volume to area in the sample was used to predict the total volume on the whole forest area. If the compartment volume is called y and the compartment area is called x, the assumption is:

$$y/x = b$$

or

$$y = bx$$

where b is a constant. This is but a particular case of the more general linear regression form:

$$y = a + bx$$

Freese (1962) demonstrates the use of regression estimators when 'a' is not equal to zero and an example will be given in Section 5.4.

In the example given in Section 4.2.4 it was assumed that the twenty compartments constituted the entire forest and, therefore, that the population distribution of <u>x</u> was known. When the distribution of <u>x</u> is estimated only by a sample, the method is known as <u>two-phase sampling</u>, or <u>double sampling</u>. The concept is quite different from two-stage sampling in which the population is structured into units of decreasing size. At the first stage a selection of the larger primary units is made, each primary unit being a population of secondary units. At the second stage a number of secondary units is selected from each primary unit. The determination of the attribute of interest is only made in the final stage units. In two-phase sampling only one type of population unit is considered. A large sample of these is drawn for the determination of the independent variable, x. The estimation of y, the dependent variable, is then made on a subsample of the same units as originally selected. The population value of y is estimated from the relationship of y to x, determined at the second phase, and the distribution of x, determined at the first phase.

Greatest precision is achieved in the method when the distribution of x can be determined with a high level of precision and when y is strongly correlated with x. When compared to the direct determination of y, without the intermediary x, the method can often achieve great improvement in efficiency if there is a considerable differential between the cost of estimating x and y values. If x is easy to measure, it may be relatively cheap to determine the distribution of x with a high level of precision. If y is strongly correlated with x, y need only be measured on a small number of individuals to determine the nature of the correlation.

An ideal use of the method in the management inventory of eucalypt forests is given by Paine (1968). The ultimate test of an assessment of the merchantable volume standing on a plot is to fell the trees and measure them as they would be measured for sale. Not only is the procedure possibly wasteful, it is also extremely costly. Paine observed that the assessment of standing trees was twelve times as fast as felling the plots and that there was a strong correlation between the felled measurements and the standing estimates, even though the latter were prone to some bias. Following the procedure of Choate (1961), Paine considered that the ratio of felled plots to standing plots should be 1:70 for alpine ash where standing volumes could be estimated with a high degree of accuracy. In forests with greater defect, where standing assessment would be less accurate, the proportion of felled plots should be increased for the same efficiency.

A further common use of the double sampling is in the determination of the distribution of x using aerial photographs at the first stage, following with a second phase determination of the y/x relationship with ground plots. Shiue and John (1962) and Langley (1969) both illustrate this approach to the determination of forest volumes.

4.3.5 Sampling with concentric plots

Figure 5 illustrates the typical stand structure of an irregular Eucalypt forest revealed by the averaging of the stockings of a number of inventory plots. It is often referred to as a 'reverse-J' distribution. Discussion of the usefulness of such an arbitrary averaging process as an aid to silvicultural prescription will be left to a later chapter. But it is useful to consider here the implications of such a curve for sampling design. Clearly, the forest comprises a relatively small proportion of large trees. Under the present standards of utilisation, tree-marking prescriptions usually only require the sale of trees for sawmilling at sizes larger than 24 inches dbhob, and these are represented by less than 4 stems per acre in stand table of Figure 5. Moreover, if inventory for the present state of the system is primarily concerned with supplying information for short-term yield regulation, it is the larger trees which are of greatest interest.

The stand table represented by Figure 5 refers only to the average stocking of the forest and gives no indication of the way in which the sizes are distributed. If the larger trees tend to be grouped, it would be

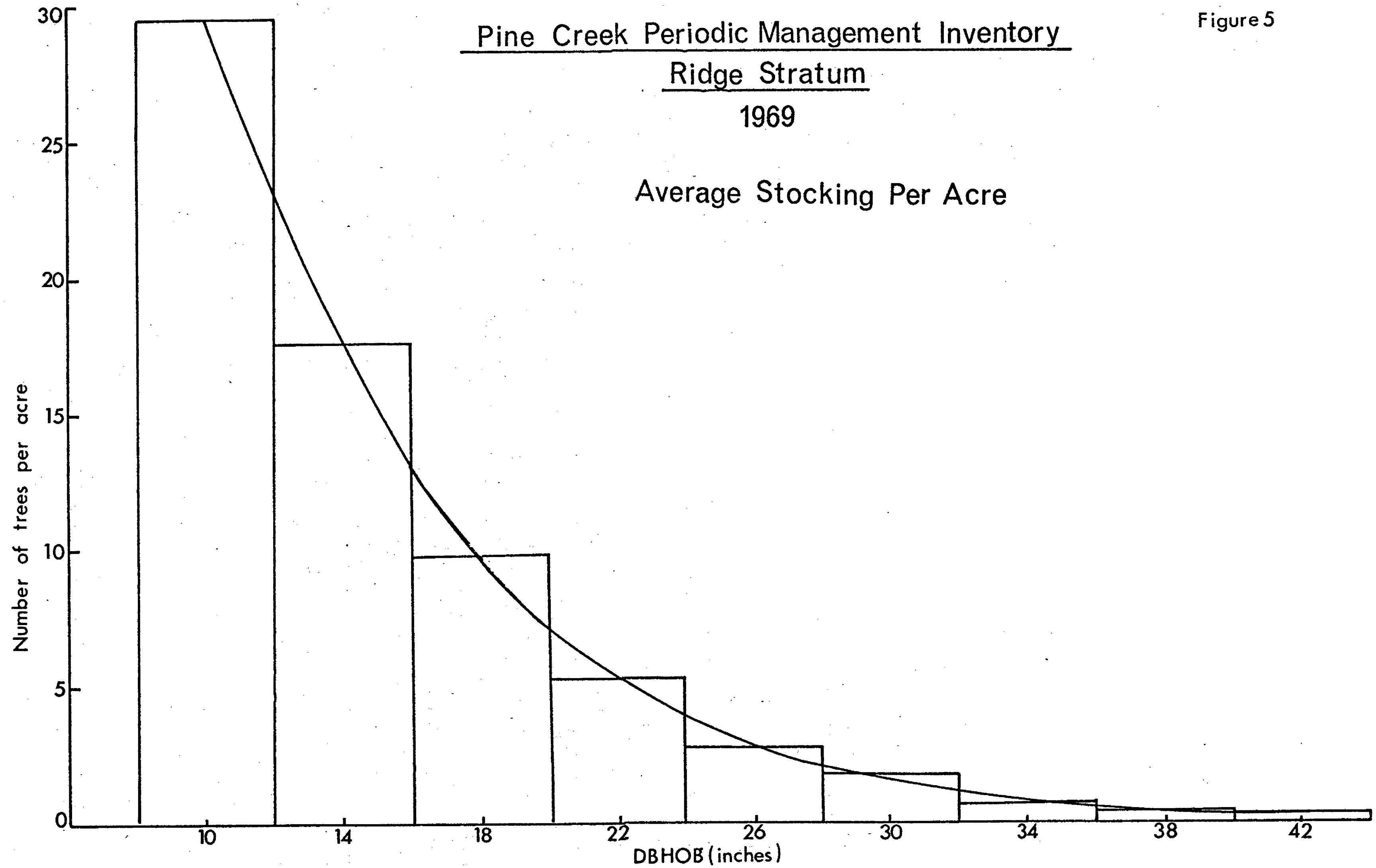
Figure 5

Pine Creek Periodic Management Inventory

Ridge Stratum

1969

Average Stocking Per Acre



expected that most small sample plots in a random sample would contain very few or no large trees, with the small remainder being reasonably well stocked with larger trees. The most effective way of increasing the precision of the estimate of the stocking of larger trees would be to increase the number of sample plots, in the expectation that more groups of larger trees would be sampled.

If the larger trees were fairly uniformly distributed, a greater number of them would be included in the sample simply by increasing the size of the sampling units. In general, this would be expected to be a cheaper procedure than establishing more plots, since much of the cost of a forest inventory is in travelling time and in the field location of units.

In the past there has been considerable discussion over the optimum size of sampling units. Spurr (1952) recommended that a plot should include 20-30 of the trees of interest and in the Northern Hemisphere forests this is often achieved with 0.2-acre plots. By contrast, Sandrasegaran (1965), uses one-acre plots for the sampling of rainforest in which the merchantable trees are well scattered. Turner (1968) quotes a study by Boon (1963) indicating that there should be a theoretical relationship:

$$\log C.V. = k - 0.5 \log P$$

where:

C.V. is the coefficient of variation for volume

P is the plot size in area units

k is a constant.

In computer-sampling forest data O'Regan and Palley (1965) confirmed this finding.

Turner (op.cit.) argued that, since the number of trees per plot should be roughly proportional to plot area a similar relationship should hold between co-efficient of variation and number of trees per plot. Using the data from 19 inventories of coastal eucalypt forests in New South Wales he developed the model:-

$$\log C.V. = 2.250 - 0.329 \log N$$

where:

C.V. is the co-efficient of variation for volume
N is the number of trees per plot.

From the stand table illustrated in Figure 5, it could be expected that a plot of fixed area would contain different numbers of trees in each diameter class. The above model predicts that in this situation there will be a different co-efficient of variation for each size class. Because of the form of the stand table, the co-efficient of variation for volume estimates will be greatest for the largest diameters, i.e. there will be least precision in the region of greatest interest. This problem is well illustrated by McGrath and Carron (1966) using data from earlier measurements of the permanent plots used to derive Figure 5.

To achieve adequate precision in the estimate of the standing volume in larger trees, relatively large plots are needed to give sufficient number of trees per plot. If all sizes of tree are measured on these larger plots, considerable cost is incurred in measurement of numerous small trees and the precision achieved in the estimates for smaller sizes will usually be greatly in excess of that required. Because of the distribution of diameters illustrated in Figure 5, the model proposed by Turner (op.cit.) suggests that a plot of different size for each diameter class would be necessary to achieve a uniform precision over all diameters. The plot area would need to increase with increasing diameter.

Turner (1968) considered that a wide range of plot sizes would be impractical for field implementation. He therefore proposed a sampling design with two sizes of concentric plots. On the inner plot, of 0.5 acres, all trees were measured. On a further acre surrounding the inner plot only trees considered merchantable and larger than 20 inches dbhob were measured. Because general experience in inventories of eucalypt forest in NSW had suggested that circular plots larger than 0.5 acres were impractical to establish and measure, Turner (op.cit.) recommended the use of rectangular plots 15 chains long by 1 chain wide. All trees were to be measured on the central section of 5 chains by 1 chain. The Forestry Commission of New South Wales has since used the method with some success, particularly in temporary inventories of extensively managed forests. In passing, however, it is suggested here that for permanent plots for growth observation a more satisfactory arrangement would be a plot 5 chains by 3 chains. Growth could be observed on the inner chain plot, with the outer plots serving to estimate the surrounding competition.

Turner proposed the name 'Variable Radius Plots' for this approach but the term 'Concentric Plots' is preferred here to avoid confusion with a rather different approach advocated by Grosenbaugh (1952) and sometimes termed the 'variable plot radius' method of sampling.

4.3.6 <u>Angle count sampling</u>

The use of this method in forest inventories was pioneered by the Austrian forester, Bitterlich, who called the method 'die Winkelzahlprobe', (Bitterlich, 1948). This name translates literally as 'the angle count sample'. The method involves an ingenious use of sampling with probability proportional to size and, in its first conception, was intended as a quick method of determining stand basal area at a sample point. Bitterlich's original exposition of the subject was not easily understood and over the next ten years forest mensuration literature contained numerous attempts to explain the method. A bibliography of the subject is given by Thomson and Deitschmann (1959). Cromer (1952) provides a good example of the way in which an Australian was able to clarify the

Bitterlich explanation. Grosenbaugh (1952), who has since pursued the whole realm of variable probability sampling considerably further, approached the development of the theory rather differently.

To perform an angle count an observer simply stands at a selected sampling point and counts the number of trees whose dbhob subtends at that point an angle greater than an agreed critical angle. The probability of inclusion in the count is proportional to the tree basal area. The actual relationship of tree basal area to ground area is obtained by multiplying the number of trees counted by a factor known as the 'basal area factor'. The value of the basal area factor is, in turn, determined by the critical angle. Grosenbaugh (1952) lists basal area factors for numerous critical angles, when the basal area is to be expressed in square feet per acre. For example, a critical angle of 104.18 minutes gives a basal area factor of 10; an angle of 147.34 minutes gives a factor of 20. A count of 8 trees would give a basal area of 80 square feet per acre in the former case and 160 square feet in the latter.

The smaller the critical angle chosen, the greater the distance at which a tree of a given diameter will subtend at the sampling point an angle greater than the critical angle. For any given critical angle there is a factor by which any diameter may be multiplied to give the maximum distance at which a tree of that diameter would be included in an angle count sample. Grosenbaugh (1952) terms this factor the 'plot radius factor'. He gives plot radius factor values corresponding to various critical angles. For example, for a critical angle of 104.18 minutes the plot radius factor is 2.750 and for a critical angle of 147.34 minutes the plot radius factor is 1.944. In the former case the maximum distance from the sample point for a tree of 30 inches dbhob to be included in the sample is 82.5 feet; in the latter case the maximum distance is 58.3 feet. Clearly, the smaller the critical angle used, the more trees will be included in the sample, but the greater will be the need for clear visibility to be able to determine which trees subtend an angle greater than the critical angle.

A simple instrument for gauging the critical angle can be made from a wooden rod with a peephole mounted at one end and a cross arm fixed at the other. The ratio of the crossarm length to the distance from the eye at the peephole determines the critical angle. Another commonly used technique is to make use of the refractive properties of wedges, or prisms, of optical glass. Such wedges have been included in various mensurational instruments but they may also be used simply hand held. Methods are available for calibrating the basal area factor of a wedge, but it is also possible to have them cut to given factor. The basal area factor is related to the optical property known as the diopter strength of the prism. When dbhob is expressed in inches and the 'plot radius' in feet, the following relationship applies:-

Plot radius factor = 100/(12 x diopter strength)

Thus, for a wedge of diopter strength 3, the plot radius factor is 2.778.

The probability of including a tree of a particular size in the angle count depends upon the extent of the area around the sampling point within which it could be included. Consider the case of a wedge of 3 diopters and plot radius factor of 2.778. Any tree of 10 inches dbhob will be included if it is in the area of a circle centred on the sampling point and of radius 27.78 feet. For a tree of 30 inches dbhob the radius is 83.3 feet. The areas of these two circles, 0.05566 acres and 0.50092 acres, are in the ratio 1 : 9, which is the same as the ratio of the two tree basal areas. The probability of inclusion in the sample is therefore indeed proportional to the tree basal area.

The stand basal areas obtained by point sampling in this way may be treated as any other population attribute. The method of calculating the variance for the estimate from the mean of a number of point samples depends upon the method of selecting the sampling points.

The use of the angle count principle and the optical wedge technique need not be confined to the determination of basal areas. It can also be used to select trees for the estimation of other quantities when the probability of selection is to be proportional to the basal area of the tree. Consider the problem of determining stand volumes by tree diameter classes in a forest in which the frequency within diameter classes is in inverse proportion to the mean basal area of the class. In such a forest there will be a large number of small trees and a small number of large trees, a fairly common situation for an irregular Eucalypt forest. As discussed in Section 4.3.5, Turner (1968) proposed the model:-

$$\log C.V. = 2.250 - 0.329 \log N$$

where C.V. is the co-efficient of variation in the volume estimate for a sample containing N trees. From this relationship it is possible to calculate the number of trees which should be included in a sample plot in order to give an acceptable level of precision as measured by the co-efficient of variation. In the present example, a plot of fixed area, designed to include the desired minimum number of trees in the largest size class, would include a far greater number of trees from the smaller size classes, thus giving a greater precision for these sizes. If the same minimum acceptable level of precision were set for all sizes, the smaller sizes would have been oversampled, possibly at considerable extra cost. If, however, the probability of selection were made proportional to basal area in a stand where the frequency distribution was inversely proportional to basal area, it would be expected that a constant number of trees would be selected from each diameter class. This would give a uniform precision throughout the range of diameters. The angle count principle could be used for this purpose and, provided the cost of implementing the technique in the field did not exceed the cost of oversampling with a fixed area plot, the method could be expected to give increased efficiency by decreasing cost for an acceptable level of precision.

Gwalter (1969) undertook this approach when faced with a similar problem in a forest whose structure approximated the theoretical structure just discussed. The problem was to determine basal area and frequency distribution by 1-inch diameter classes in 20,000 acres of mining timber forest in the Cessnock Management Area of the New South Wales Forestry Commission. It was a fairly open, dry sclerophyll forest, verging on a woodland condition.

The area was stratified into large blocks for administrative purposes and it was desired that a minimum precision be obtained for each of the stratum means. A large number of plots was therefore required. For immediate sales, principal interest centred on the 8 - 9 inch class, and it was considered that, with the large number of sampling units, a plot of 0.1 acres would give sufficient precision in this class. The wedge specification that would give such a sample was therefore calculated as follows:-

Plot area	=	0.1 acres
Plot radius	=	37.25 feet
Class mean diameter	=	8.5 inches
Plot radius factor	=	37.25/8.5
	=	4.382
Diopter strength	=	100/(12 x Plot radius factor)
	=	1.90

For convenience, a 2 diopter wedge was selected. The effective plot sizes for various diameter classes using such a wedge are indicated in Table 11, the plot radius factor for the wedge being 4.167. The basal area factor was 4.356.

TABLE 11

CESSNOCK MINING TIMBER INVENTORY

Dbhob Class (inches)	Mean Basal Area (sq.ft)	Dbhob Equiv. to Mean B.A. (inches)	Plot Radius (feet)	Plot Area (acres)	Number Counted (56 plots)	Number per Acre	Basal Area per acre (sq.ft)
2-3	0.0355	2.54	10.583	0.0081	38	83.8	2.956
3-4	0.0682	3.54	14.750	0.0157	59	67.1	4.589
4-5	0.1119	4.53	18.875	0.0257	74	51.4	5.756
5-6	0.1664	5.52	23.000	0.0382	75	35.1	5.834
6-7	0.2318	6.52	27.167	0.0532	65	21.8	5.056
7-8	0.3082	7.52	31.333	0.0708	63	15.9	4.900
8-9	0.3955	8.52	35.500	0.0901	40	7.9	3.111
9-10	0.4936	9.51	39.625	0.1132	40	6.3	3.111
10-11	0.6027	10.51	43.792	0.1383	33	4.3	2.567
11-12	0.7227	11.51	47.958	0.1659	26	2.8	2.022

Wedge specification : 2 diopters

Plot radius factor : 4.167

Basal area factor : 4.356

Adapted from Gwalter (1969)

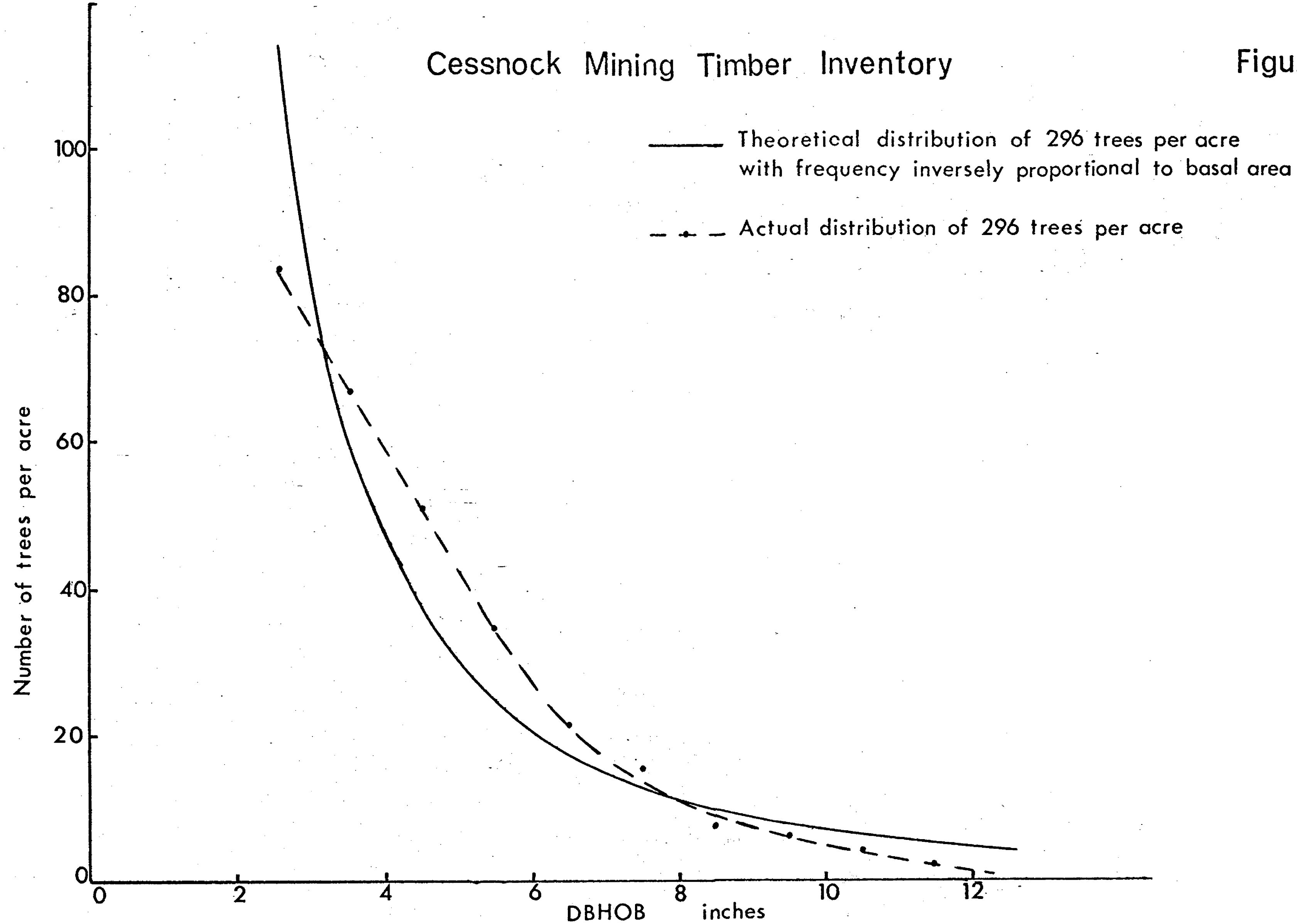
All trees included in the angle count at each sampling point were tallied in 1-inch dbhob classes. The basal area per acre in each class was obtained simply by multiplying the class tally by the basal area factor and dividing by the total number of sampling points. The number of trees per acre in each class could be obtained by dividing the tally for each class by the effective plot area for the diameter equivalent to the mean basal area of the class, and again dividing by the total number of sampling points. Although there is a wide range of frequencies in the forest stand table, from 83.8 trees per acre in the 2 - 3 inch class to 2.8 trees per acre in the 11 - 12 inch class, the distribution of frequencies in the sample is considerably more uniform, as shown in Table 11. From the relationship defined by Turner (1968) between co-efficient of variation for volume estimates and the number of trees per sampling unit, it could be expected that the levelling of sampling frequencies, indicated in Table 11, would lead to a more uniform level of precision for volume estimates by diameter classes. Moreover, the use of the optical wedge to select a sample with probability proportional to basal area, should theoretically have reduced costs by avoiding unnecessary oversampling of the small size classes merely to obtain an adequate precision at larger sizes. The stated aim of the Cessnock inventory, however, was to obtain estimates of basal area stocking. The author has not investigated the relationship between co-efficient of variation for basal area estimates and the number of trees per plot but, since volume is usually strongly correlated with basal area, a relationship similar to that defined by Turner (op.cit.) for volume is considered likely to obtain. It could therefore be expected that the technique applied in the Cessnock inventory would have achieved a levelling in the precision of basal area estimates through the principal range of diameter classes.

The fact that the number of trees selected in each diameter class is not exactly equal infers that distribution of tree frequencies by diameter classes is not strictly according to the inverse of the mean basal area of the classes. The actual diameter distribution indicated by the sample is shown in Figure 6 and compared to a theoretical distribution of the same number of trees according to the inverse of diameter class mean basal areas.

The use of sampling with probability of selection proportional to tree basal area can also be extended to regression estimation. Consider the problem of sampling to determine the coefficients for a linear regression of volume on basal area. Suppose it is desired to estimate the regression with equal precision across a range of the independent variable, basal area. Sampling with probability proportional to basal area could be expected to achieve this result in two situations. Firstly, consider the case in which the actual correlation between volume and basal area in the total population is constant over the range of basal areas. If the frequency distribution of the population is inversely proportional to tree basal area, the same number of trees will be selected from each basal area class. This will give a uniform precision to the estimate of the regression throughout the range of basal areas, since the correlation is uniform throughout. Secondly consider the situation in which the strength of the correlation is inversely proportional to tree basal area in the total population. If the distribution of tree frequencies is uniform over the range of basal area, selection with probability proportional to basal area will give a greater sample of trees of higher basal area than lower. This weightingshould overcome the heteroscedasticity of the actual relationship. In irregular forests it is more likely that the distribution of tree frequencies is in inverse proportion to tree basal area <u>and</u> that the variability of any relationship between volume and basal area might be proportional to tree basal area. Selection with probability

Figure 6

Cessnock Mining Timber Inventory



proportional to basal area would then only give a partial levelling of precision across the range of basal area. A more appropriate weighting would be to select trees with probability proportional to the square of basal area. Moreover, if it were desirable that the fit of the relationship be better at high basal areas, even heavier weighting towards trees of high basal area would be required. In neither of the latter cases would the use of the angle-count principle be practical.

4.3.7 Sampling with probability proportional to prediction

One of the more recent advances in sampling techniques for management inventory is the development of sampling with probability proportional to prediction, termed 3P sampling by Grosenbaugh (1965, 1967). The technique is used in two-phase sampling, with the probability of selection for measurement at the second phase being proportional to a prediction of the value of the attribute of interest made at the first phase. The method will be illustrated by a forestry example similar to the original application envisaged by Grosenbaugh and later used by the Forests Commission of Victoria.

The problem is to estimate the merchantable volume of the fifteen trees illustrated in Figure 7. The only sure way to determine the volume would be to fell the trees and measure them as for sale but this procedure would be both expensive and destructive in a large scale inventory. It is therefore necessary to seek a parameter which will estimate merchantable volume. Such a parameter should have three desirable qualities:-

(a) Non-destruction in determination
(b) Ease of determination
(c) Close correlation with the quantity of primary interest.

Whilst the first quality is of interest in the present example, it is of no relevance in the development of 3P sampling theory, which is based on efficient use of the second and third qualities.

The aim of using the two-phase sample is to increase efficiency, either by increasing precision for a fixed cost or by decreasing cost for a fixed precision. Consider the case of a dependent variable, y, which is costly to assess in the field but which is correlated with an independent variable, x, which is much cheaper to evaluate. If the entire inventory budget were spent on a single-phase determination of y, only a small sample of y values could be taken. This would lead to a low precision in the estimate of the population mean for y if the distribution of y were rather variable. But, with a considerably lower cost for the determination of x, it would be possible to take quite a large sample for x using only a small proportion of the total budget. The optimal allocation between samples at the first and second phases would depend on the sampling cost differential, the correlation between x and y and the efficiency of the second-phase selection procedure. Moreover, as Grosenbaugh (1965) points out, if the cost of determining x is very low, it may be better not to sample at the first phase but to evaluate the whole population for x. For simplicity, this will be the approach adopted in the demonstration example, but the theory is still available when there is sampling at the first phase.

In the extreme case, if there were a constant correlation of 100 per cent between x and y, it would only be necessary to determine two y values to establish the correlation. As the correlation weakens, there is an increasing need for samples at the second phase to maintain precision. If the variability of the correlation were constant over the range of x values, random sampling, with equal probability of selection at all x values, would be a suitable procedure selecting second-phase units. If, however, there were a linear relationship between the value of x and the variability of the correlation, it would be more efficient to select the second phase units with probability proportional to x.

Returning to the demonstration example, there are several possible independent variables with which the dependent variable, merchantable volume, could be correlated. Most do not meet the requirements stipulated in earlier discussion. In some conifer forests volume can be well correlated with basal area and the angle count technique, described in Section 4.3.6, could be used to select second phase samples. Because of the variability of eucalypt form, as suggested by Figure 7, the correlation of merchantable volume with basal area is not always strong, particularly in overmature, selectively logged forests. Grosenbaugh emphasized that an operator in the field can usually perform a rapid mental integration of all the visible factors influencing merchantable volume and so give a fairly good prediction of merchantable volume. Such predictions may often be biased but they may show a fairly high degree of precision over a number of trees. Any bias, however, is eliminated when the correlation is established at the second phase. Grosenbaugh therefore recommended that the parameter estimated at the first phase be a prediction of the volume to be measured at the second phase. This prediction is not only relatively cheaply made, but is also likely to be strongly correlated with merchantable volume, although the strength of the correlation may decrease with increasing values of the prediction.

The fifteen trees illustrated in Figure 7 were subjectively rated for merchantable volume using an integer in the range 1 : 5. A rating of 5 was given to those of highest expected yield. This rating, which is fairly quickly determined, is designated x. For the sample population the following three values apply:-

Population size	M	= 15
Sum of ratings	$S.x$	= 44
Maximum rating	x_{max}	= 5

3P SAMPLING DEMONSTRATION

Figure 7

XMAX = 5
ESN = 6
KZ = 7
Z = 2
M = 15

X	4	3	1	4	2	5	1	2	4	3	3	2	1	3	5	$\sum^{M} X$	44
K	B	2	5	1	5	1	3	5	3	3	2	B	1	B	B		
Assess	0	1	0	1	0	1	0	0	1	1	1	0	1	0	0	N	7
Y		640		790		1105			825	570	610		350			$\sum^{N} Y$	4890
Y/X		213		197		221			206	190	203		350			$\sum^{N} \frac{Y}{X}$	1580

It is now necessary to construct a probability set on which to base the selection of the trees to be felled and measured, so that the probability of selection will be proportional to the previously determined prediction. Such a set must contain all the integers from 1 to at least one greater than the maximum possible x rating. Grosenbaugh (1965) terms the upper limit of the probability set, kz. Depending on the number of trees desired in the second phase sample, kz may be increased to some value (x_{max} + z) where z is an integer not less than one.

Suppose z is made equal to 2 and kz becomes 7 in the demonstration example. To see if a tree is to be selected for the second phase measurement a single random draw is made from the probability set. Let the number drawn be k. If k is greater than x for the tree in question, the tree is not included in the second phase sample. When x is 1 the probability of selection is 1 : 7. When x is 5 only two numbers in the probability set are greater than x and the probability of selection is therefore 5 : 7. From this example it can be seen that the probability of selection is indeed proportional to x, the prediction of volume. The process is repeated for each tree after it has been rated, and there is replacement in the probability set after each draw.

kz may be varied to give a desired expectation to the size of the second-phase sample, provided kz is always greater than x_{max}. The expected number of second-phase units in the sample is given by the following formula:

$$ESN = (1/kz) \cdot S(x)$$

where:

ESN is the expected sample number

S(x) is the sum of the x ratings.

For a desired expectation of 6 second phase units in the demonstration example the calculation would be as follows:-

$$6 = (1/kz) . 44$$
$$kz = 7$$
$$z = 2$$

Grosenbaugh (1964) provides a simple means of dispensing from the probability set for such a simple case as the demonstration example. All that is required is a deck of uniform cards numbered from 1 to x_{max} inclusive, together with $\underline{z}$ blank cards. The cards are reshuffled for each tree before drawing a value of $\underline{k}$. If the drawn value is greater than $\underline{x}$ for that tree, or if the drawn card is a blank, no further measurement is made on the tree. The k values obtained in such a test are shown in Figure 7, with the letter B signifying a blank. Of the 15 cards drawn, four were blank and on four the number exceeded the $\underline{x}$ value for the tree. Thus, only the remaining 7 were selected for second-phase determination. In practice these trees would have been felled and measured and the merchantable volumes would have been recorded in the y-row as indicated. The value of y/x would then be determined for each tree measured, with the sum of these values to be recorded as in the bottom right-hand corner of Figure 7.

Provided $\underline{x}$ is not strongly and negatively correlated with $\underline{y}$, the best 3P estimate of the total population Y value, when all the population is estimated for $\underline{x}$, is given by :-

$$Y = S_M(x)/N.S_N\ (y/x)$$

where:

M is the number of units in the total population

N is the number of units in the second-phase sample

S_M denotes summation over all units from 1 to M

S_N denotes summation over all units from 1 to N.

In the demonstration example:-

$$S_M(x) = 44$$

$$N = 7$$

$$S_N(y/x) = 1580$$

$$Y = 44/7 \times 1580$$

$$= \underline{9931} \text{ super feet.}$$

It is important to note that, whilst the determination of x is a subjective one, and therefore liable to bias, the population estimate from 3P sampling is virtually unbiased if x and y have a strong, positive correlation. This fact can be demonstrated statistically but even intuitively it would seem reasonable. Roughly speaking, the determination of the x parameter provides an estimate of the 'population spread' on some arbitrary scale, whilst the determination of the y parameter corrects the arbitrary scale to true values.

An unbiased estimate of the variance of the estimate from 3P sampling is only obtainable by taking interpenetrating samples of the same population. In practice this may not prove too laborious, at least for two samples, since once the tree has been rated for x, the selection process for extra second-phase samples only requires repeated drawing from the probability set with the results to be recorded separately. Many of the trees selected will be the same for both samples and little extra measurement may be required.

Several practical considerations arise in dealing with examples more complex than the simple illustration in Figure 7. Firstly it may not always be feasible to allot an x-value to every individual. Thus it would not be possible to determine $S_M(x)$ and it would be necessary to use a less efficient estimator:-

$$Y = kz.S_N\ (y/x)$$

Secondly, there is the question of selecting a suitable expectation for the size of the second-phase sample, ESN. The problem is the usual cost/precision compromise.

Precision is dealt with fully by Grosenbaugh (1965). If ESN is set too high, the second-phase sample may be too costly. Moreover, the determination of ESN requires a prior estimate of value of $S_M(x)$ preferably within 20 - 30 per cent of its true value. For large surveys a preliminary diagnostic survey may be necessary to provide a quick guide to the true value.

Thirdly there is a need to fix the highest possible prediction, x_{max}. This value should be set for the upper limit of the general population, yet the occurrence of occasional individuals much larger than this may upset the x/y correlation since their x-rating would be depressed by the x_{max} limitation. Grosenbaugh (1965) suggests the practical expedient of setting an upper limit for the size of individuals to be included in the sample. All trees larger than this would be measured for y.

Fourthly there is the problem of generating a probability set for a large population. Grosenbaugh (1965) has developed a computer program, THRP, for the task and Mesavage (1967) describes a suitable field dispenser for the information.

4.4 Plot size, shape and orientation

4.4.1 Plot size

The variance of the estimate obtained by sampling depends upon the variation between the values of the individual units comprising the sample. If there is considerable local variation in a population, the larger the plot used the greater its chance of being a true representation of the average condition of the local population, and the greater the chance of stability in plot means. If, however, the population is in a grouped condition, there is a fair chance that a small plot will be representative of the group into which it falls. In this circumstance it would be better to allocate the inventory budget to a large number of small plots in order to sample the range of groups. This concept is formally recognised in the method of stratification which can be employed when the population groups, or strata, can be recognised and defined.

The balance between number of plots and plot size should be influenced by the cost of establishing plot positions in the field and by the cost of travelling between plots. If these costs are high, it may be necessary to use a small number of large sample plots or to adopt some form of cluster sampling.

4.4.2 Plot shape and orientation

Sample plots established in forests are usually regular in shape, most commonly circular or rectangular. Theoretically, a circular plot is a more stable base for a permanent inventory since it can be re-established from a single datum point, the plot centre. Moreover, if the plot is to be permanent for the examination of tree growth in the light of surrounding competition, the circular plot can be divided into an inner and outer plot. The growth study is made on the inner plot, with the outer plot being measured principally to express the surrounding competition. The circular design is most efficient for this purpose since it involves the least boundary for a given area enclosed. Forrest (1961) does suggest, however, that there may be an economical limit to the size of circular plots in irregular eucalypt forest with heavy undergrowth.

Rectangular plots may be more useful if it is desired to obtain a wide sample from a population showing some clinal variation. Rectangular plots may be oriented with their long axes at right angles to the clinal gradient so as to take individuals towards both ends of the gradient. Such populations are common in forestry when the site quality or species distribution varies regularly at right angles to the prevailing contours.

As a comparison of circular and rectangular plots, a computer program was used to calculate basal area for rectangular 0.5 acre plots on the same centres as those used with circular plots to illustrate random sampling in Section 4.2.3. The plots were 330 ft long by 66 ft wide, oriented at right angles to the prevailing contours. The results were as follows:-

	Circular	Rectangular
Number of plots	29	29
Mean basal area per plot	36.32	36.59
Standard error	2.38	2.01
Standard error per cent	6.55	5.50

The means in each case were very similar and slightly higher precision was obtained using rectangular plots. Details for each plot are given in Appendix II. It is most interesting that, although the sample means were nearly identical, the individual plot values were widely different, despite the fact that nearly 50 per cent of their area was common to each shape of plot. The individual plot values had a correlation co-efficient of 0.3979 between the different shapes. This is only just a signficant correlation at the 95 per cent confidence level. Since the difference between the means is not statistically significant and there is a significant correlation between the observations, a statistician might remark that there is no statistical evidence from this sample for any difference between circular plots and rectangular plots on the same centres. The author, however, was particularly interested to observe the weakness of the correlation between plots with the same centre, despite the fact that nearly half their area was in common. This is a reflection of the extreme local variability of the irregular eucalypt forest.

CHAPTER 5

SAMPLING FOR CHANGES IN THE SYSTEM

5.1 Introduction

It was stated at the beginning of the previous chapter that the forest manager is ultimately concerned always with the dynamics of the forest resource. Growth and drain must be manipulated to some advantage. To appraise past performance and to be able to make predictions of future performance for various management purposes he needs the backing of inventory information. The prediction of growth and drain can be approached in three ways.

The first approach, discussed in the previous chapter, is to take an inventory which provides detailed information on the present state of the system, its volume distribution, species composition and similar information. With a general knowledge of other forest performance in similar conditions it is possible to make reasonably satisfactory decisions for future management in the short-term, provided that it will be possible to revise the decision on the basis of another inventory within ten years or so.

The second approach is to establish an inventory specifically to measure the current performance of the forest system. Current performance is used as a prediction of future performance and information on the present condition of the forest is of secondary importance. In this category is the general technique referred to as Continuous Forest Inventory (C.F.I.) or Periodic Management Inventory (P.M.I.) Information provided from inventory of this type is little more a basis for long-term predictions of future performance than inventory that deals only with the current state of the system, unless it is fairly certain that the management for the future will perpetuate the conditions which have led to current performance. For this reason the information obtained provides little opportunity to invoke changes to optimise for some future benefit.

The third approach is to make a more fundamental examination of the factors affecting growth with a view to devising a mathematical model which would simulate changes in the forest under a variety of management regimes. The idea of simulation is not new. Engineers have long used the technique of building physical models to simulate various mechanica problems. Mathematical models have been used in various fields, including forestry, to simulate dynamic processes but in the past such models have been restricted by difficulties of computation. The rapid expansion of electronic computer facilities in the last fifteen years has not introduce mathematical simulation concepts that are fundamentally new, but the enormous improvement in computation speed has led to widespread use of mathematical procedures in ways that would have been economically impossible twenty years ago. The attraction of the approach is the opportunity for quick examination of alternative strategies with a view to some optimisation. Some knowledge of the present state of the system is always required as a starting point for the simulation. But derivation of growth information for a variety of situations requires a rather more deliberate sampling design than the general samples usually used to determine the growth of the forest under current conditions.

Sampling design considerations for each of these three approaches will be discussed in this chapter.

5.2. Sampling for change using temporary units

Sampling for change using temporary plots is a simple extension of the techniques put forward in the previous chapter. The forest is sampled on two occasions and the growth or drain in some quantity is estimated by the difference between the population means for that quantity at each occasion. The variance of the estimate of growth is therefore the variance of difference of two estimates and, because the samples at each occasion are independent of each other, the variance of the growth estimate is obtained by the following formula:-

$$s_{\bar{d}}^2 = (s_{\bar{x}1}^2 + s_{\bar{x}2}^2)$$

where,

$s_{\bar{x}1}^2$ is the variance of the estimate of the population mean at the first sample.

$s_{\bar{x}2}^2$ is the variance of the estimate of the population mean at the second sample.

$s_{\bar{d}}^2$ is the variance of the estimate of the difference of the population means between sampling occasions.

The method of calculating the variance at each occasion depends upon the method of sampling at each occasion and there is no theoretical need to use the same sampling procedure both times. Formulae for calculating the variance for various sampling procedures are given in the previous chapter. The variance of the growth estimate obtained from independent samples may be very high; from the very nature of the formula by which it is calculated it must be greater than the variance of the estimate on each occasion. This is the principal argument usually advanced against sampling on successive occasions using temporary plots. Indeed, it may well be a very cogent argument if the estimate of current growth is of major importance. Moreover, it may be supported by certain positive arguments in favour of permanent plots (Section 5.3). On the other hand, there are several arguments in favour of temporary sample units.

First there is the question of cost. It is often argue that it is considerably cheaper to establish temporary plots on two occasions than it is to establish permanent plots, maintain them between measurements and then relocate and remeasure them at the second occasion. Unfortunately, detailed records of costs have seldom been kept for this purpose in Australia. Moreover, without a close familiarity with the forest conditions, the prevailing weather conditions, the information to be collected and with many other important factors, it is difficult to deduce useful results from the general costing records of the Forest Services. However the Forestry Commission of New South Wales has kept time studies on the last four management inventories it has conducted in sclerophyll forest. Unfortunately it is still very difficult to draw any conclusions from these because of the widely differing circumstances in which they were conducted. The available details are given in Appendix IV. A general model for comparing inventory time studies would be quite complex; it could take the following form:-

$$T = a + U + b.k.V + c.k.W + d.X + e.k.Y$$

where:

T = time required per plot

U = time required to drive to plot

V = distance to walk to the plot

W = area of plot

X = number of trees per plot

Y = distance to walk from the plot

k = a coefficient reflecting the difficulty of moving in undergrowth or steep conditions.

Such a model would be necessary for proper comparison of inventories in different forests. Other quantities such as the size of the assessment party and the number of variables to be assessed would also need to be included if they were not kept constant. The model could also be used to predict the time differential between temporary and permanent plots in the same forest. The coefficient b would depend on whether the plot was being located for the first time, as in the establishment of permanent or temporary plots, or whether existing plots were being relocated. The coefficients c and d would differ between permanent and temporary plots because of the need to establish permanent field marks and draw location diagrams in a permanent plot. Whilst the New South Wales figures are too few to derive such a relationship as yet, they are not difficult to record and, as more are recorded, some clear pattern may begin to emerge. In Appendix IV B the differential between the time needed to establish a temporary plot and the time needed to remeasure a permanent plot is not as great as in the Victorian figures below.

Cowley (1968) is able to propose the following figures for 0.3 acre plots in mixed-species Eucalypt forest in Victoria:-

a. Permanent plots

1st occasion, establishment - 2 plots/day/2-man party
2nd occasion, remeasurement -10 plots/day/2-man party

b. Temporary plots

1st occasion - 5 plots/day/2-man party
2nd occasion - 5 plots/day/2-man party.

For an inventory of 200 plots on two occasions the total labour requirement would be 120 man-days for permanent plots and 80 man-days for temporary plots. This time (cost) ratio of 2:3 in favour of temporary plots makes no allowance for any time necessary to service the permanent plots between measurements.

Secondly, it is probably much easier to use temporary samples in conjunction with assessments to be made from aerial photography. In eucalypt forest the degree of ground control needed to provide sufficient reliability in repeated photography of a permanent sample would probably be prohibitive. Of course, aerial photography would still have an important part to play in the field location of sample plots, whether permanent or temporary.

A third favourable aspect of temporary inventory is the freedom of bias during routine operations in the forest between successive samples. Permanent plots must usually be clearly marked in the field and it is often claimed that this results in their receiving preferential treatment in the course of routine operations. Clearly, there is little advantage in obtaining a highly precise estimate of average forest growth if the growth that is measured by the sample is heavily biased by treatment preference.

5.3. Sampling for change using permanent units

The idea of repeated sampling with permanent units was not new when it began to be widely incorporated in Continuous Forest Inventories, or Periodic Management Inventories, in post-war years. It did receive considerable impetus when rapid advances in computer technology greatly facilitated the expansion of this type of inventory in North America. The immediate advantage of permanent sampling units is the increase in the precision of the growth estimates when the estimates of the population mean on each occasion are dependent and closely correlated. Hall(1959) has strongly emphasized this aspect. The variance of the growth estimate for a permanent sample is obtained as follows:-

$$s_{\bar{d}}^2 = (s_{\bar{x}1}^2 + s_{\bar{x}2}^2 - 2s_{\bar{x}1\bar{x}2})$$

where,

- $s_{\bar{d}}^2$ is the variance of the estimate of the difference between the population means for the parameter of interest
- $s_{\bar{x}1}^2$ is the variance of the estimate of the population mean at the first measurement
- $s_{\bar{x}2}^2$ is the variance of the estimate of the population mean at the second measurement
- $s_{\bar{x}1\bar{x}2}$ is the covariance of the estimates

This formula may also be written:-

$$s_{\bar{d}}^2 = s_{\bar{x}1}^2 + s_{\bar{x}2}^2 - 2r.s_{\bar{x}1} . s_{\bar{x}2}$$

where r is the correlation coefficient between estimates

Clearly, the closer the correlation (larger r value) the smaller the variance of the difference. As Hall (1959) stresses, the variance of the difference may well be less than the variance of the estimate on either occasion. The point is well illustrated by information from the Pine Creek Periodic Management Inventory. Here there is a random distribution of 69 permanent plots within the 5000 acres of the ridge stratum. The area is comprised of mixed eucalypt irregular forest. The sample has been measured on several occasions and Table 12 sets out the progression of volume growth and relevant statistics for the period 1963-1969 For the three two-year intervals between measurements the average annual increments of merchantable volume per acre were 284, 401 and 354 s.ft Hoppus respectively (30, 43, 38 c.ft). The respective standard errors were 32, 40 and 32. Had the element of covariance been ignored and the variance calculated as though the samples were temporary, and therefore independent, the standard errors would have been 587, 590 and 605, respectively. These values are approximately double the actual increment and approximately 16 times the magnitude of the errors when the dependence of the successive estimates is acknowledged.

Some other advantages can be claimed for permanent sampling units. Firstly, they provide about the only means of studying the various components of growth. The computer program, written by the author, to process the basic data for Table 12 readily sorted out current volume, ingrowth volume and volume removed for each measurement period. It was therefore possible to exclude ingrowth and calculate volume increment for the growing stock present at the start of each period. The rate of mortality, the rate of ingrowth and the composition of ingrowth may also be of interest and these must be estimated with sampling units that are permanent. Berklund (1960), in discussing problems of processing inventory data, shows how it is possible to use permanent plots to detail a variety of possible changes in 'tree status' as trees are cut and used, cut and left, become culls etc.

A second advantage of objectively distributed permanent plots is that they can be used to monitor routine forest operations to some extent. Because of the variability of irregular eucalypt forest, the few plots logged or silviculturally treated each year may not be sufficient to give

TABLE 12

PINE CREEK PERIODIC MANAGEMENT INVENTORY - RIDGE STRATUM

Merchantability Classes 1 and 2

First Measure	1963	1965	1967
Mean volume per acre (s.ft Hoppus)	12208	12124	12442
Variance of sample mean (0.5-acre plots)	11610380	11500439	12177963
Variance of estimate of population mean (per plot)	168266	166673	176492
Variance of estimate of population mean (per acre)	673064	666692	705968
Standard error of estimate of population mean (per acre)	820	816	840
Second Measure	1965	1967	1969
Nett accumulated volume per acre (s.ft Hoppus)	12776	12926	13150
Variance of sample mean (0.5 acre plots)	12159397	12492438	13098312
Variance of estimate of population mean (per plot)	176223	181050	189831
Variance of estimate of population mean (per acre)	704892	724200	759324
Standard error of estimate of population mean (per acre)	840	851	871
Increment			
Nett annual volume increment per acre (s.ft Hoppus)	284	401	354
Covariance of plot volumes	172031	173520	182920
Variance of nett increment estimate	427	683	483
Standard error of increment estimate	21	26	22

Nett accumulated volume = Current volume - Ingrowth for period + Removals for period

TABLE 13

COMPARISON OF ASSESSED AND ACTUAL MERCHANTABILITY

Pine Creek Periodic Management Inventory

Trees Removed from Plots Over Ten Years

Ridge Type - 71 Plots

	Number	B.A. (sq.ft)	Volume (s.ft H)
Commercial Removals			
Assessed as merchantable	177	461	100952
Assessed as unmerchantable	9	27	3096
Uncommercial Removals			
Assessed as merchantable	247	272	43311
Assessed as unmerchantable	206	296	30353

Gully Type - 43 Plots

	Number	B.A. (sq.ft)	Volume (s.ft H)
Commercial Removals			
Assessed as merchantable	89	183	43839
Assessed as unmerchantable	6	42	4191
Uncommercial Removals			
Assessed as merchantable	154	168	28649
Assessed as unmerchantable	159	246	24195

very precise general estimates of basal areas removed in treatment or volumes removed in logging, but isolated plots may be able to indicate apparent trends worthy of further investigation. Moreover, the longer the plots are maintained the more likely are such trends to become apparent.

Records kept of trees removed from the Pine Creek Inventory plots over a ten-year period provide one example of the sort of checks that permanent plots can allow. This information is set out in Table 13. For trees assessed as merchantable the volumes given are gross volumes (s.ft Hoppus) assessed standing from a 4 ft stump to the top of the merchantable bole.

For trees assessed as unmerchantable an arbitrary bole height of 20 ft is used in the calculation of volume. The basal area figures are therefore more representative of the relative amounts of material removed in each case. Table 13 makes it clear that a very large proportion of the trees removed uncommercially had in fact been assessed as merchantabl The forest manager is therefore forced to consider whether the assessment of merchantability is incorrect, either through misjudgement or through changes in utilisation standards, or whether silvicultural treatment and other uncommercial fellings have been making drastic inroads into the useful growing stock. When the figures of Table 13 are extrapolated for 8500 acres of forest the uncommercial losses of trees assessed as merchantable amount to over 500,000 super feet per annum, which is roughly equivalent to 35 percent of the annual commercial cut.

A third favourable feature of permanent plots is the opportunity to study bias and accuracy, particularly in measurement. All too often in inventories of eucalypt forest in Australia there has been a preoccupation with errors of sampling precision with little regard to errors of measurement even though these frequently amount to very considerably more than any likely sampling error. This problem will be discussed in detail in succeeding chapters. With permanent plots the time of remeasurement can be an occasion to eliminate 'obvious' mistakes made by the assessment party at the previous measure. These include such things as incorrect recording of diameters or wrong statement of species. From experience with several inventories, and the Pine Creek inventory in particular, the author has no hesitation in stressing that no-one can afford to be complacent about the possibility of mistakes. Despite intensive checking on previous occasions it always seems possible to find yet another error or omission. It is essential that computer programs used to process the data should provide various screens to highlight apparent anomalies. But some mistakes will only be detected at time of remeasurement and, for this reason, Paine (1970) states the following procedure as policy for the Forests Commission of Victoria:-

> A check measurement of all trees is made in the first winter after establishment, to ensure complete accuracy of the initial data before the growth period begins. Location maps and other markers of the plots are checked also. All tree characteristics are checked, dbbob measured, and merchantable heights are checked against utilisation classes. A high degree of accuracy in all details of the initial measurement is justified in this inventory system which depends entirely on the comparison of two measurements, especially when a delay of 3-5 years is to ensue before the growth data are collected.

If it is not possible to entertain such a heavy additional cost, at least there should be an aim for as early a full remeasure as possible, with specific instruction to check for mistakes at that time.

A convenient opportunity for checking measurement bias occurs when routine logging or silvicultural treatment affects a plot. Clearly, if the plots are to remain as average representatives of the population, serious bias is introduced if sample trees are felled specifically for check-measuring. But such checks can be made without biasing the sample when trees are felled in the course of routine operations taking place in the forest surrounding a plot. Freese (1960) gives the following formula for a chi-square test to compare estimates against a reliable standard:-

$$\text{Chi-square}_{(n)df} = \frac{196^2}{p^2} S.(d_i/u_i)^2$$

where:

(n)df is the number of degrees of freedom and is equal to the number of observations in the comparison.

u_i is the standard value for the i'th unit (obtained by measuring the felled tree).

d_i is the difference between the estimated and the actual value for the i'th unit.

S denotes summation over all i values from 1 to n

p is a percentage acceptable random error (as explained below).

196 is 100 times the normal deviate corresponding to a confidence level of 95 per cent.

Freese (op.cit.) gives a clear derivation of this formula from the basic chi-square test. The formula is used in the following way:-

If p is set equal to 30 and the chi-square value obtained is less than the critical chi-square for the appropriate number of degrees of freedom, it means that, at the 95 per cent confidence level, the difference between the mean of the actual values and the mean of the estimates is not significant, allowing for an average random error of estimate of up to 30 percent of the true value. As p is made smaller, for increased precision, the factor $196^2/p^2$ will increase and the chi-square value will be more likely to exceed the critical value.

The chi-square test is applied to a hypothetical example in Table 14. Here, there is a considerable difference between

TABLE 14

PRECISION IN BIASED ESTIMATES

Hypothetical data for log length in 60 trees estimated in the course of inventory and later measured at time of harvest.

LOG LENGTH
(feet)

Actual	Estimate	Actual	Estimate	Actual	Estimate
91	80	62	50	79	70
43	30	70	60	70	60
64	55	49	40	51	40
80	70	37	30	31	20
83	75	55	45	50	40
90	80	37	25	43	30
84	75	31	20	69	60
66	55	28	20	40	30
30	20	64	55	57	50
40	44	60	50	88	80
58	55	57	45	39	30
39	30	60	50	88	80
67	55	56	45	50	40
43	30	60	55	42	30
30	20	66	60	41	30
50	40	60	55	87	80
41	30	61	60	92	75
40	30	32	25	69	60
33	25	71	60	87	75
59	50	90	80	47	40

Mean of actual log lengths	:	57.27	
Mean of estimated log lengths	:	47.90	
Bias	:	9.37	
Chi-square (allowing for bias)	:	11.33	± 30% Error
Chi-square (no bias allowance)	:	103.40	95% Probability
Degrees of freedom	:	60	

the mean of the actual log lengths and the mean of the estimates. When the chi-square is calculated for the raw data it is found to be 103, which is in excess of the critical value of 79.08. This means that the estimates are outside the probable error range at the 95 per cent confidence level when allowance for up to 30 per cent random error is made. But, when adjustment is made for a constant bias of 9.37 in the estimates, the chi-square improves to 11.33, which is well within the confidence range for 30 per cent random error. In fact the difference between actual mean and estimate mean only becomes significant for a precision of 11.3 per cent random error. Without checking the measurement at time of harvest this serious bias might well have gone undetected and the reliability of the estimate would have remained unknown. When the check is made, the bias can be allowed for and the results used with a fairly high level of confidence, giving due consideration to the fact that the trees marked for logging will probably be a biased subsample of the inventory sample. The same sort of study can be made by felling in temporary plots, but this will not detect bias arising with the efflux of time, as would be caused by a change in utilisation standards.

Five important advantages have been claimed for using permanent plots. In summary they are:

(a) High precision in estimates of current growth.

(b) Opportunity to examine components of growth.

(c) Possible use to monitor routine operations.

(d) Opportunity to study accuracy of measurement and recording

(e) Opportunity to study measurement bias.

The further opportunity of being able to study individual tree growth is discussed in section 7.4

One of the principal disadvantages claimed against the use of permanent sample plots is the possibility of the sample itself becoming biased through some form of preferential treatment. If the plot is to be maintained for successive remeasurements, it must be marked in such a way that it can be relocated in the field. Moreover, for the attainment of high precision and accuracy in growth estimates, it is essential that diameter measurements be made at the same point on the stem. For this reason it has been a common practice to mark the point of diameter measurement at breast height, usually with a conspicuous paint line. These diameter marks, along with other indicators, also serve to make the plot more conspicuous for ease of relocation. But by being made conspicuous the plots are also made more susceptible to biased treatment during routine operations. It is a natural reaction for the tree-marker for logging, or the foreman for silvicultural treatment, to reconsider his approach to standard prescriptions when he finds himself in a plot where his performance can be measured. For example, if he decides his treatment has been a little light, the plot may receive a heavier treatment than the area through which he has just come, thus leading to a lower than average stocking, but perhaps a higher than average growth on selected stems. The problem can be even greater if subprofessional staff, unaware of the role of the plots, avoid them altogether in routine operations. This practice is known to have occurred in some eucalypt forests in New South Wales.

The effect of this kind of bias can be very serious indeed and several counter-measures have been proposed and employed at various times. In an inventory of Benandarah State Forest, the Forestry Commission of New South Wales did not conspicuously mark the trees but used only small permanent pegs and very carefully marked positions on aerial photography. Through the combination of undergrowth, fire and logging disturbance only a fraction of the number was ever refound, and then only with considerable difficulty. Moreover the servicing of plots during logging and treatment was made virtually impossible. On the other hand the Forestry Commission of Tasmania does appear to be able to maintain this type of permanent plot by using well detailed ground references. If it is accepted that permanent plots must be conspicuous, a constructive approach is to train operators in the use and importance of them so that they will attempt to treat them in the proper manner. To make the plots themselves more routine and, in addition, to provide greater control of operation, it may well be worthwhile to require field staff to establish temporary plots of their own to check field operations. A third approach is to establish a second unmarked plot close to the regular marked plot and attempt to compare treatments. This procedure may give interesting results but it will be costly to administer and will be fraught with all the usual experimental design problems caused by lack of homogeneity in the base population. A fourth possible approach is to replace part of the sample at each remeasurement, and this is the subject of Section 5.4

5.4 Sampling with partial replacement of units

A background to the idea of sampling with partial replacement of units at successive occasions is given by Cunia (1964) and a full statistical explanation and derivation of formulae is given by Ware and Cunia (1962). A further detailed exposition of the use of the method in continuous forest inventory is given by Cunia (1965). Cunia and Chevrou (1969) make necessary extensions of the theory to cover sampling on three or more occasions. Cunia has been a principal exponent of the method and, as a preliminary explanation, it seems difficult to improve on the following quote from his address to the Society of American Foresters (Cunia, 1964):

> In general, over two measurement times there are three groups of plots.

1) Plots measured at both occasions. These are all permanent plots.

2) Plots measured at first occasion only. They are either temporary plots or permanent plots that are dropped at the second measurement time.

3) Newly established plots at second occasion. They could be either temporary plots or permanent plots for the next (third) measurement time.

From the first group of permanent plots, we can establish a relationship between plot volumes per acre at different occasions. Then this relationship is used to estimate, through regression, the volume of the third group at the first measurement time. Consequently, we end up by having the volumes per acre of all the plots in the sample, some of them by direct measurement, others from regression estimates. in this way, the estimates for the average volume and growth per acre are obtained from <u>all plots both permanent and temporary</u>.

The method can be illustrated by reference to an example, the data for which is set out in Appendix III. The Pine Creek Periodic Management Inventory comprises 69 fully permanent plots in the Ridge stratum. Details of volume and basal area have been recorded at remeasurements of all plots in 1963, 1965, 1967 and 1969. For this demonstration 39 of these plots were selected at random to be the permanent plots to estimate the following regression:

$$V1965 = a + b.V1963 + c.BA1963$$

where:

V1965	is the volume per plot in 1965 less ingrowth and plus removals for the period 1963-1965.
V1963	is the volume per plot in 1963
BA1963	is the basal area per plot in 1963.
a	is the regression constant.
b and c	are regression coefficients.

The regression obtained by a least squares fit was:

$$V1965 = 265.2 + 1.062V1963 - 9.583BA1963$$

where volumes were expressed in super feet Hoppus and basal area in square feet. For this regression,

$$R^2 = 0.9976$$

This regression was then used to predict the volume in 1965 on the remaining 30 plots not used to calculate the regression. Because they had actually been measured in 1965, the regression estimates could be checked against the true 1965 figures. The results are shown in Table 15. Using the regression the predicted mean volume of the 30 'temporary' plots in 1965 was 9040 super feet, equivalent to a growth of 355 super feet per plot over the two-year period. The actual mean volume of the same plots was 9037 super feet, equivalent to a growth of 352 super feet. When the 30 regression estimates in the 'temporary plots are combined with the 39 remeasured plots, the estimated volume per plot in 1965 is 8317 super feet, equivalent to a growth of 339 super feet. The actual stocking when all 69 plots are remeasured is 8316 super feet, equivalent to a growth of 338 super feet per plot during the two-year period.

Clearly, in this example, the use of the regression technique with some temporary plots has been almost as accurate as complete remeasurement with all permanent plots. This success is due to the high correlation coefficient of the regression and its reliability in the range of independent variables covered by the 'temporary plots'. The high correlation coefficient is partly attributable to two important factors. Firstly, the measurement interval and the prediction period of two years is very short, thus restricting to some extent possible variations in growth. Secondly, it is nett gross-volume growth that is predicted; the nett growth includes removals but excludes ingrowth. Two problems arise here. In terms of growth, this kind of estimate is useful, but in terms of current stocking, the actual stocking including ingrowths and excluding removals is of primary interest. Secondly, this type of growth estimate is readily projected forward to give a new volume, but it is difficult to work

TABLE 15

SAMPLING WITH PARTIAL REPLACEMENT EXAMPLE

	Mean	Variance of Estimate	Std.Error of Estimate
39 Plots Measured in 1963 and 1965			
Volume per plot 1963	7435	267377	517
Basal area per plot 1963	41.7	7.705	2.78
Volume 1965 (regression)	7761		
Volume growth (regr.)	326		
Volume 1965 (actual)	7761	275134	525
Volume growth (actual)	326	785	28
30 Plots Measured in 1963 Only			
Volume per plot 1963	8685	541279	735
Basal area per plot 1963	49.6	1.02	1.01
Volume 1965 (regression)	9040		
Volume growth (regr.)	355		
Volume 1965 (actual)	9037	561717	749
Volume growth (actual)	352	1247	35
39 Permanent and 30 Temporary Plots			
Volume per plot 1963	7978	190461	436
Volume per plot 1965	8317		
Volume growth 1963-1965	339		
69 Permanent Plots			
Volume per plot 1963	7978	190461	436
Basal area per plot 1963	45.2	2.847	1.69
Volume 1965 (actual)	8316	196943	443
Volume growth (actual)	338	482	22

from the current volume of new temporary plots, measured at the second inventory occasion, back to volumes at the first measurement occasion without knowing details of ingrowth and removals.

When using longer periods between measurement and when using gross growth, the regression estimates of growth would probably be less reliable. The matter then resolves into a compromise between cost and precision. In Section 5.2, the following figures were quoted from Cowley (1968):

a. Permanent Plots
   1st occasion (establishment) - 2 plots/day/2-man party
   2nd occasion (remeasurement) -10 plots/day/2-man party

b. Temporary Plots
   1st occasion - 5 plots/day/2-man party
   2nd occasion - 5 plots/day/2-man party

On this basis the time required to sample with 69 permanent plots would have been 82.8 man-days. Using Sampling with Partial Replacement, and only 39 permanent plots, the time required would have been reduced to 70.8 man-days. These times are in the ratio 1.17 : 1.00. Although S.P.R. brings a saving in cost, it also brings a loss of precision in the growth estimate. The method of calculating precision is set out in Appendix VI. The best allocation between temporary and permanent units depends upon the expected reliability of the growth regression, the cost differential between temporary and permanent units and the importance attached to precision in the growth estimate.

As additional benefits, Cunia (1964) points out that partial replacement of permanent units reduces some of the risk of treatment bias (Section 5.3). Moreover the plots removed from the inventory provide a ready source of material for experimental treatments, since they already have a measurement history.

5.5 Purposive sampling for dynamic relationships

When random or other objective distributions of permanent plots are employed in Continuous Forest Inventories they are intended to fulfill two principal tasks simultaneously. Firstly they are used to estimate the current stocking of various components of the forest in terms of numbers of trees, basal areas, volumes etc. Secondly they are used to estimate some aspects of the average growth and drain of the forest. Some such system is undoubtedly useful in performing the first task, although in Section 5.2 it was suggested that temporary plots may be cheaper and involve less risk of bias. The usefulness of objectively distributed permanent plots for the second purpose is somewhat more questionable.

Section 5.3 showed how such permanent inventory systems can be used to obtain a very precise estimate of the immediate past average growth of the forest. Section 5.4 showed how regression estimation in conjunction with partial replacement of sampling units at each remeasurement can improve sampling efficiency. The use of estimates of growth made without regression estimation is confined to the review of past performance and the short-term prediction of future performance since the past growth will only mirror future growth when management operations and stocking conditions are kept constant Regression estimation, however, suggests the possibility of predicting growth in more varied stand conditions, the difference being expressed by changes in the independent variables of the regression.

The reliability with which regressions will predict future growth partly depends on the extent to which growth, as the dependent variable of the regression, is correlated with the various stand or tree parameters which are used as the independent variables. Standard statistical procedures are available for fitting regressions to experimental data and these are described in various statistical texts. Techniques of particular interest in forest research are described by Freese (1964). The most commonly used procedures for fitting regressions are derived from the 'least squares principle'. Suppose a multiple linear regression of the following form is used:

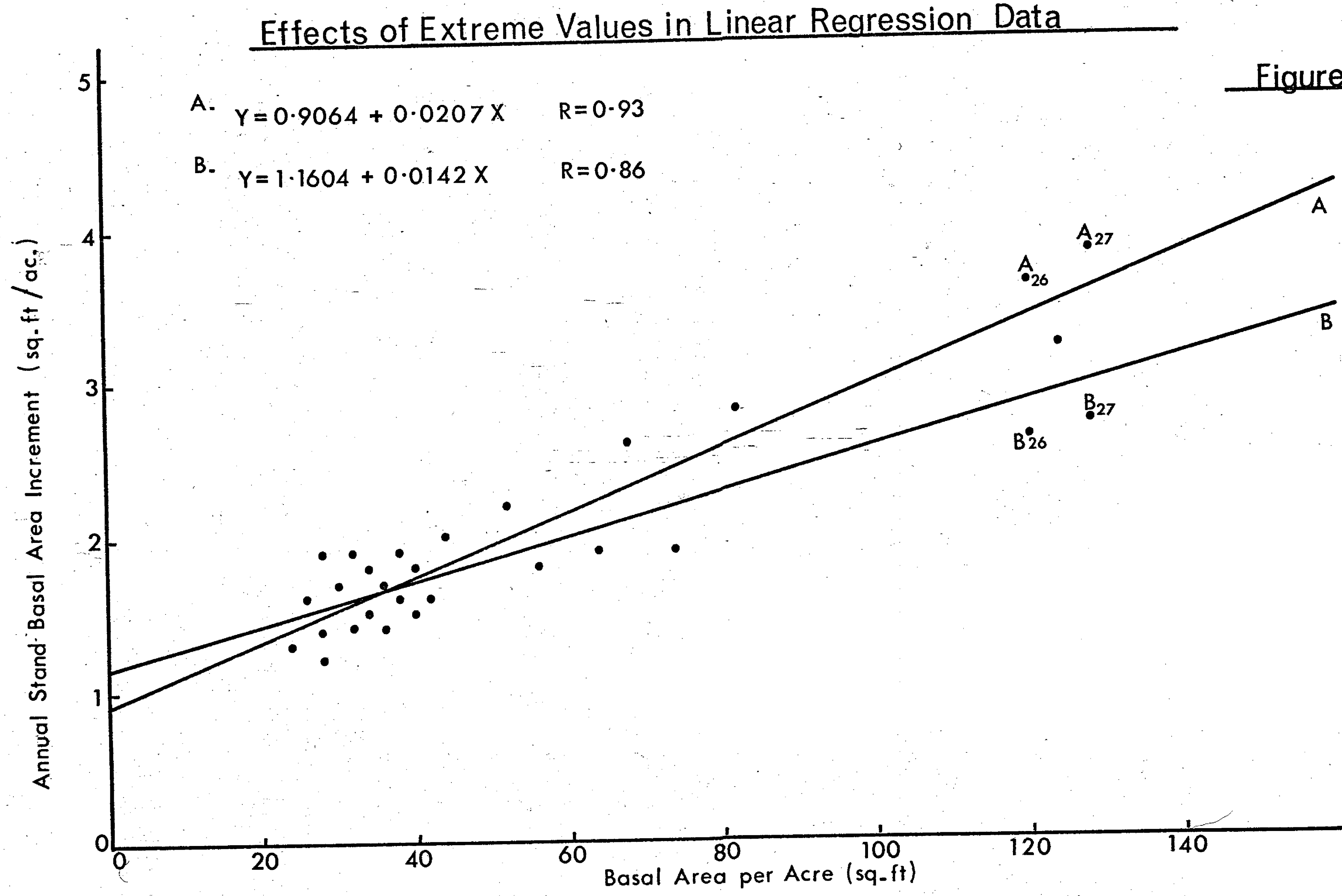
$$Y = a + bX_i + cX_2 + dX_3$$

the least squares principle assumes that the best estimates of the coefficients a, b, c and d are those that make the sum of the squared deviations a minimum when the actual Y values of the data used to compile the regression are compared with the Y values that would be calculated by the regression using the corresponding values of the independent variables X_1, X_2 and X_3.

Least squares methods can be used to fit a regression to any combination of variables in any block of data. But the mere existence of a mathematically calculated equation does not necessarily imply any true correlation between the dependent variable and the independent variables. Just as it was shown in Section 4.2.3 that there is a means of applying confidence limits to estimates obtained by random samples, so there are statistical methods for applying confidence levels to regression co-efficients calculated by the least squares method, and to the regression predictions. Freese (1964) also sets out the mathematical procedures for calculating these confidence limits for least squares fits of multiple linear regressions.

The least squares regression calculated for a block of data is strongly influenced by the distribution of the values of the independent variables. Consider the simple linear regression calculated for the data of Appendix V and illustrated in Figure 8. The slope of the regression line A is greatly altered by changes in the increment values obtained in the 26th and 27th observations. In the basal area range 20-40 sq.ft, where most of the observations are taken, the change of slope has only slight effect in the regression prediction of increment. But with increasing basal area, beyond the range at which most observations are made, the effect of the change in slope becomes more and more pronounced in the prediction of increment. The concentration of observations

Figure 8



Effects of Extreme Values in Linear Regression Data
A. Y=0·9064 + 0·0207 X R=0·93
B. Y=1·1604 + 0·0142 X R=0·86
Annual Stand Basal Area Increment (sq. ft / ac.)
Basal Area per Acre (sq. ft)
0
1
2
3
4
5
20
40
60
80
100
120
140
A
B
A27
A26
B27
B26

in a narrow range of the independent variable, basal area, has effectively produced a 'pivot' around which the regression may be fairly easily 'swung' by variations in increment at extreme values of basal area.

The great advances in computing technology in recent years have made it possible to form mathematical models, or simulators, of growing forests by combining several regressions expressing various components of forest growth. By varying the values of the independent variables, which describe various forest conditions, it is possible to use a computer model to search for the combination of conditions which produces optimum growth response. Whilst such models are theoretically feasible for hand calculation, all but the simplest of them would have been economically impractical without a computer because of the time required. Up till twenty years ago only fairly simple yield models ever found extensive use.

The ability to combine regressions and rapidly study the effects of data variations provides a powerful tool for the study of forest management regimes. But the speed of calculation and the neatness of results typed out from the computer can easily beguile the unwary user into forgetting that the results of the model are no better than the regression of which it is composed. The example illustrated in Figure 8, and mentioned previously, gives some clues to sound principles to be followed in the collection of data from which to derive regressions.

Firstly, it is desirable to take observations of the dependent variable at the extremes within which the independent variables are likely to be varied in using the model. Figure 8 illustrates this general principle, that it is safer to interpolate than to extrapolate. If there is no doubt that the relationship between the dependent variable and the independent variable is truly linear, the regression is conveniently 'fixed' by observing only at the extremes of values in the independent variables. If, as is more common, there is less certainty of the form of the relationship it is wiser to sample at intervals throughout the likely range of values in the independent variables. In general, it is perhaps better to recommend sampling over a range rather than sampling only the extremes but it is important to stress that either the reliability or the flexibility of a model can be easily impaired by failing to use a wide range of data in compiling the component regressions. One should not be bound too tightly by the ranges commonly encountered in current practice, since models may often suggest the examination of alternatives outside the range of current practice. Finally it is necessary to consider the variability associated with the relationship of y to x, of the dependent to the independent variable, over the range of x. If the 26th and 27th observations used in the B-set of data are considered as the 28th and 29th observations of the A-set, it can be seen that there is a much greater variability in the relationship of y to x, of increment to basal area, at high values of basal area. When the variability of the relationship is not constant over the range of x values, the relationship is said to be heteroscedastic. To increase general precision in such a case it is more sensible to concentrate the sample in the region of greatest variability and not, as in the example in Figure 8, in the region of least variability.

It is also a wise move not to include all the available data in the calculation of the regression. Although the more data included the greater the precision is likely to be, it is probably more important to use some data for checking, particularly for observing any prominent errors of bias.

It is important to consider how much conventional Continuous Forest Inventory is likely to fulfill these requirements for good design of samples to determine growth regressions. Unless the population is already fairly well distributed over all the likely range of values of interest in the independent variables, simple random or systematic sampling designs, used to estimate the current state of the forest system, are likely to be grossly inefficient for estimating regressions. This is a most important point for some purposes since it can offer a strong argument against extensive inventory systems of randomly distributed permanent plots.

The problem can be illustrated by reference to an example. Consider a forest which has been heavily logged and is generally understocked except in a few of the more inaccessible areas. A random sample of such a forest is very likely to give plots with basal areas distributed in the pattern illustrated in Figure 8. A large number of plots carry low basal area and only a few are well stocked. As discussed previously a growth regression derived from these data is likely to be increasingly unreliable with increasing values of basal area. The possible range of basal areas is not well covered and the sampling units that are observed are in the region of least variability. Moreover, if the stand is left to recover from heavy logging, the basal area range in which the sampling units were observed will be of decreasing interest as the general level of stocking recovers. The regression should produce good short-term predictions but would not serve as a good basis for longer-term simulation to search for optimum conditions. Irregular forests along the coastal region may not involve quite the same clearly defined problem. In Section 2.3.4, however, it was suggested that the pattern of previous management has led to a generally suppressed or stagnant forest condition. The use of Continuous Forest Inventory to determine the current growth with a high precision provides very little data for examining potential improvements. If conditions remain constant the estimates of past growth are useful short-term estimators of future growth, but the relative cost of temporary and permanent plots must be considered. It is possible that in these circumstances temporary sampling units would give adequate precision at lower cost. If conditions are to be greatly altered by silvicultural practices, the estimate of immediate past growth is likely to be an unreliable estimator of future growth unless it has been based on the sampling design principles just discussed.

The alternative is to divorce the task of growth estimation from the sampling used to take stock of the current condition of the forest. A step towards this approach is taken by sampling with partial replacement where only part of the sample is measured for growth. But the suggestion here is that the permanent plots used for regression estimation need not only be a random subsample of the original random inventory sample. The sample to establish growth regressions could also include special plots purposely selected so that the range of possible values in the independent variables is suitably covered. It may be that, because of the current condition of the forest, plots with these values would not be included with sufficient frequency in a random sample. It may be possible to select the supplementary growth plots by some objective means using variable probability sampling or it may be much more economically feasible to resort to subjective or purposive selection. If a thorough study of growth is being made, obtaining adequate information for management predictions may require the establishment of experimental treatments to study conditions not already represented in the general population. The idea of research plots to study growth is not new but in the past they appear to have been divorced from general management inventories. The contention here is that, if growth is of interest, special growth research plots should be an integrated part of management inventory. Their method of selection should not be too strongly governed by the selection needed to give adequate precision in information of current stocking.

CHAPTER 6

FOREST AREA DETERMINATION

6.1 Introduction

The previous two chapters have discussed various aspects of sampling. Sometimes the sample is intended to provide an estimate of the average value of some population characteristic. On other occasions the sample is established to determine the population total for a particular characteristic. In the former case it may not be essential to know the complete extent of the population. Very often, however, the sampling method requires a prior definition of the extent of the population, as in the requirement of a 'frame' for random sampling. But when population totals are required it is essential that the extent of the population be known.

Although the forest may be thought of as a population of trees, it is more usual for sampling purposes to think of the forest as a population of area units. The extent of the population can be delineated on a map, or sometimes on aerial photography.

In Section 4.3.1 the technique of stratified sampling was discussed. It is commonly overlooked, however, that most forest inventory samples involve elements of stratification and that it is essential to define the extent of the population specifically for each stratum. For example, most forests contain road networks and other unproductive areas. If no sampling units are to be assessed in these areas, they effectively form a non-productive stratum, the area of which must be deducted from the total forest area. Within the productive areas to be sampled several strata may also be recognised. If these are to be sampled independently, they must be mapped and their individual areas calculated.

The determination of forest areas, and stratum areas within forests, is by no means an easy process. Inexplicably, forest managers usually seem to overlook the possibility of errors in their map estimates, even though these may be very large and must inevitably flow on through all inventory results. There can be little value in spending large sums of money in achieving an estimated sample reliability of, say, ± 10 per cent, if the estimate so obtained has then to be inflated by a forest area factor which is only known to a reliability of ± 30 percent. This apparently simple consideration is all too frequently ignored and the reliability of the area estimate is not even estimated.

Because the ratio of area of the sample to area of the forest or stratum is usually very small, the absolute values of errors may be quite large. For example, a random sample of inventory plots estimates a mean volume of 13064 super feet per acre, with a standard error of 848. For a forest of 5000 acres, the estimate of total volume is expected to lie in the following ranges, since the standard error must also be multiplied by the forest area:

67 per cent probability
61,080,000- 69,560,000
(65,320,000 ± 4,240,000)

95 per cent probability
57,009,600 - 73,630,400
(65,320,000 ± 8,310,400)

At the rate of cutting in many irregular eucalypt forests the maximum error range at the 95 per cent confidence level could represent as much as the total harvest for 20 years.

If the forest area had been overestimated by 10 per cent, and was in fact 4500 acres, the estimates are changed to the following figures:

67 per cent probability

54,972,000 - 62,604,000

(58,788,000 ± 3,816,000)

95 per cent probability

51,308,640 - 66,267,360

(58,788,000 ± 7,479,360

The difference in the means due to the reduction in forest area is 6,532,000 super feet Hoppus, which could itself be approximately equal to the harvest for 9 years, at the current levels of utilisation.

There are three principal ways in which errors enter into estimates of forest areas:

(a) Errors in field survey and map compilation.

(b) Inexact definition of the true strata of interest.

(c) Incorrect calculation of the areas represented on the maps

These are discussed in the next three sections.

6.2 Errors of field survey and map compilation.

Unfortunately the literature appears to be almost bereft of any studies on the accuracy of compilation of forest maps and most maps themselves carry very little information on their reliability. With the use of modern machinery for plotting from aerial photography the transfer of information to map form is probably very accurate. Provided adequate accurate ground control has been established the reliability of the representation of clearly distinguishable permanent features should be good. No precision of instrumentation, however, can resolve the difficult question of subjective determination of type boundaries. It is difficult to place a figure on the magnitude of errors from this source since even between two experienced operators there can be considerable differences of opinion in the field as to the proper location of a type boundary. The map-maker's problem is clearly a difficult one. But without a solution to it the forest manager is left with just as difficult a one in trying to assess a figure for the reliability of an inventory, since errors in map compilation must flow on to estimates of the growing stock when data from the sample plots are extrapolated to the total forest area. This problem appears to merit considerable research.

6.3 Definition of Map Strata

The two broad types of gain to be expected from stratification have already been discussed at some length in Section 4.3.1. They are as follows:-

a) Increased sampling efficiency when the stratification achieves an increase in the homogeneity of the variance of the parameter of principal interest, say nett merchantable volume, within all or most of the strata recognised.

b) estimates of stratum means which are themselves of particular management significance, any gain in statistical efficiency in the estimate of an overall population mean being largely incidental.

The parameters of interest in management inventories of irregular eucalypt forest are discussed at some length in Chapter 7, but it is fairly obvious that current nett merchantable volume must always be a parameter of considerable interest. Stratification based on a volume type-map could be expected to lead to a more efficient estimation of a mean nett volume than would be obtained by simple random sampling without stratification. In New South Wales volume type-maps have been successfully prepared for native forests, but always for virgin or lightly logged stands and using gross volume of sawlogs as the basis for typing. In the 1972 assessment of such forest country in the Spirabo Management Area of the northern tablelands of New South Wales the volume of typing was used to improve sampling efficiency, first by excluding country not capable of economic logging and, secondly, by stratifying the loggable country into three strata for sampling purposes.

The volume typing is done by interpretation of aerial photography flown under strictly controlled conditions at a scale of approximately 1:15000. Such photography is itself an expensive item although part of the cost may be reasonably offset by its usefulness in a variety of aspects of management in the field. In an inventory context it is also a most useful means for a good operator to locate sample plots accurately in the field. The cost of typing is even greater, however, since it will take many hours of skilled labour to delineate types on the photographs, and many more man-hours to transfer these markings accurately to a base map. The formal preparation of a final volume type-map may be able to be avoided for sampling purposes if it is considered possible to estimate type areas with sufficient reliability directly from the marked photographs.

The real problem for irregular forests, however, is the delineation of merchantable volumes. In virgin or lightly logged forests the photo-interpretation of volume types is made possible by the natural patterns that are associated with the interactions of species types, site heights, topography etc. Once he can recognise with some certainty the patterns of different tonal variations on the photographs the experienced operator will reinforce his interpretations of these patterns into volume classes by making extensive field inspections. The conversion from total gross volume to merchantable volume is obviously a much more difficult matter in forests as prone to defect as eucalypt forests. Again, the success of this type of interpretation will depend upon the interpreter's knowledge of utilisation levels in the various species types, coupled with information gathered in field inspections and whatever he may be able to deduce from apparent fire history and any previous logging. In irregular eucalypt forest, whose very structure has been derived by many years of intensive selective logging, patterns of volume distribution will have been considerably disturbed and differences in volume in different parts of the forest will be much less consistently related to such things as species types and topography which will be identifiable on the photographs.

Moreover, the interpretation of merchantable volume will be made even more difficult by the variable combinations of effects of selective logging and silvicultural treatment. Considering the high costs involved and the reliability problems I have just discussed, I think it unlikely that much use will be made of volume typing as a basis for sampling stratification in irregular eucalypt forest, that stratification being intended primarily to increase sampling efficiency by delineating areas of increased homogeneity of variance in the parameter of most interest.

In some situations, however, it may be desirable to stratify for management purposes rather than with a view to specific gains in statistical efficiency. One frequently used basis for stratification with this intention has been the recognition of species types as illustrated in Section 4.3.1. It may be important to obtain management information separately for different species types when these types are likely to require widely differing silvicultural procedures. Other factors which may be of considerable management interest and which are capable of type-mapping from aerial photos are slope and the incidence of apparent surface rock. It may even be desirable to recognise strata defined by the interaction of more than one of these factors. For example, it may be impractical to consider logging on slopes in excess of 25 degrees where there was a high incidence of apparent surface rock. Steep rocky country could therefore constitute a stratum which need not be sampled, on the grounds that any volume standing on these sites would be economically inaccessible. Again, on the basis of 1972 amendments to the Forestry Act in New South Wales it may be wiser to consider country of slope greater than 18 degrees as a doubtful proposition for logging on the grounds of erosion risk, and it may therefore merit definition as a specific management stratum.

In recognising management strata, however, it should be remembered that each extra stratum recognised will increase the cost and complexity of mapping and if too fine a separation is made individual units of each stratum will be so small and form so complex a mosaic that they will be likely to be mapped inaccurately. Such a map would probably be of little value to management. Each new stratum that requires sampling will increase inventory costs since it will individually require a sufficiently intense sampling to give a meaningful estimate of the stratum mean in merchantable volume or other parameter of interest.

If it is necessary to know merely how much of a particular type of country will be encountered and what volumes it carries, and it is not necessary to know the spatial distribution of the elements of a particular stratum, it may be possible to use post-sampling stratification to advantage. This type of technique has been recently employed by University of California in evaluating resources for environmental impact studies and by the Forestry Commission of New South Wales for resources inventory. In the latter case the technique has been further extended into a management/resources inventory of virgin and lightly logged eucalypt stands considered suitable for pulpwood production. In this inventory a 1500-yard grid was laid down over the study area and at each intersection point on the grid a photo assessment was made of the following parameters:

a) Species type
b) Slope class
c) Aspect
d) Apparent surface rock
e) Merchantable pulp + sawlog volume
f) Merchantable sawlog volume
g) Diameter class containing most volume

1260 points were evaluated in this way and at 83 of these field plots were established to check on the reliability of interpretation and, where possible, to provide data for establishing regressions to correct for bias in the manner described in Section 4.3.4.

From the photo plot information and a regression based on photo ratings for volume and diameter class it was possible to estimate the volume of pulpwood in various strata defined by combinations of slope, apparent surface rock and species type. For the broad long-term management planning contemplated in this inventory it was sufficient merely to have an estimate of volumes by the several strata without actually knowing the geographic distribution of the strata. The post-sampling stratification had achieved an estimate of the desired means without any particular goal of statistical efficiency having been met, but also without having required the very high cost of detailed type-mapping to delineate strata.

In point of fact, because the point sampling was carried out on a grid system, it was possible to prepare rudimentary type-maps to give a very approximate picture of the distribution of the various parameters. On a 1500-yard grid each point represented 465 acres. A computer program was written to display such an area as a half-inch open square on line-printer output. Within each square was printed a single symbol to indicate, for the parameter being mapped, the type (or stratum) assessed by interpretation at that point. The reliability of such a map depends on the accuracy of interpretation and the relationship between population variability and the intensity of sampling.

The extent to which the technique could be reliably applied in irregular eucalypt forest depends upon the limitations in aerial photography interpretation discussed above. But even in irregular forest it should be possible to use point sampling with photo plots to estimate the proportions of, and perhaps also to map, slope rock and species using post-sampling stratification but the further step to volume estimation using the same technique may be virtually impossible to achieve with adequate reliability. Nevertheless, if rock and slope are likely to provide particularly serious management problems, it may still be worthwhile to use the low-cost technique of point sampling with aerial photography to provide an approximate type map adequate for the stratification of a sample of field plots to estimate volumes. This type of approach could be expected to be very much cheaper than conventional type-mapping since it is itself a sampling rather than a whole measure approach.

Finally it is perhaps prudent to consider one other particular mapping and stratification problem, namely the attitude to roads in designing a sampling procedure. In an intensively managed forest the area occupied by roads may be quite considerable, as in the case of the Pine Creek State Forest where road and fire-trail formations probably occupy about 2.5 percent of the total area. This area could be regarded as an obviously unproductive stratum unworthy of sampling. The author considers, however, that the delineation and accurate mapping of such a stratum, with its great boundary length to area ratio, the calculation of nett areas and the possible bias in relocating plots to avoid roads, are problems of sufficient magnitude that it is recommended that sampling be laid down always on a gross area basis, with plots falling on roads to be treated as a normal part of the sample.

6.4 Estimation of map areas

The area of a region mapped by detailed ground survey can be calculated from the survey data itself. Nowadays, however, almost all forest maps are produced directly from aerial photography using only a broad network of control points located be detailed ground survey. The determination of map areas cannot be made by calculation from survey data. Because of the irregular shapes involved geometrical methods are generally impractical. A variety of methods has been devised to overcome the problem.

6.4.1 Proportional weights

One of the simplest methods has been to take a complete map of regular geometric shape, calculate its area, cut around the map boundary of the region of interest and derive its area by comparison of its weight with the total map weight. The problems encountered in this method are the long time needed to cut out complex areas, the risk of errors in cutting, the lack of uniformity in paper weight and the need for a sensitive balance if precision is to be achieved.

6.4.2 The Planimeter

Various forms of mechanical integrators, generally described as planimeters, have been devised for the measurement of plotted areas. Clark (1946) gives a full description of one type, Amsler's Polar Planimeter, and outlines in detail the background principle. The various forms possess the common feature that a point of the instrument is guided round the boundary of the area, and resulting displacement of another part of the mechanism is such as to enable the area to be recorded.

As a general rule the instrument is accurate and reasonably useful for taking out fairly large areas on a map. Forrest (pers. comm) advises that the Forestry Commission of New South Wales has found the use of the instrument far too time consuming for taking out the component areas of complex type-maps and now uses dot-grid sampling almost exclusively for this purpose.

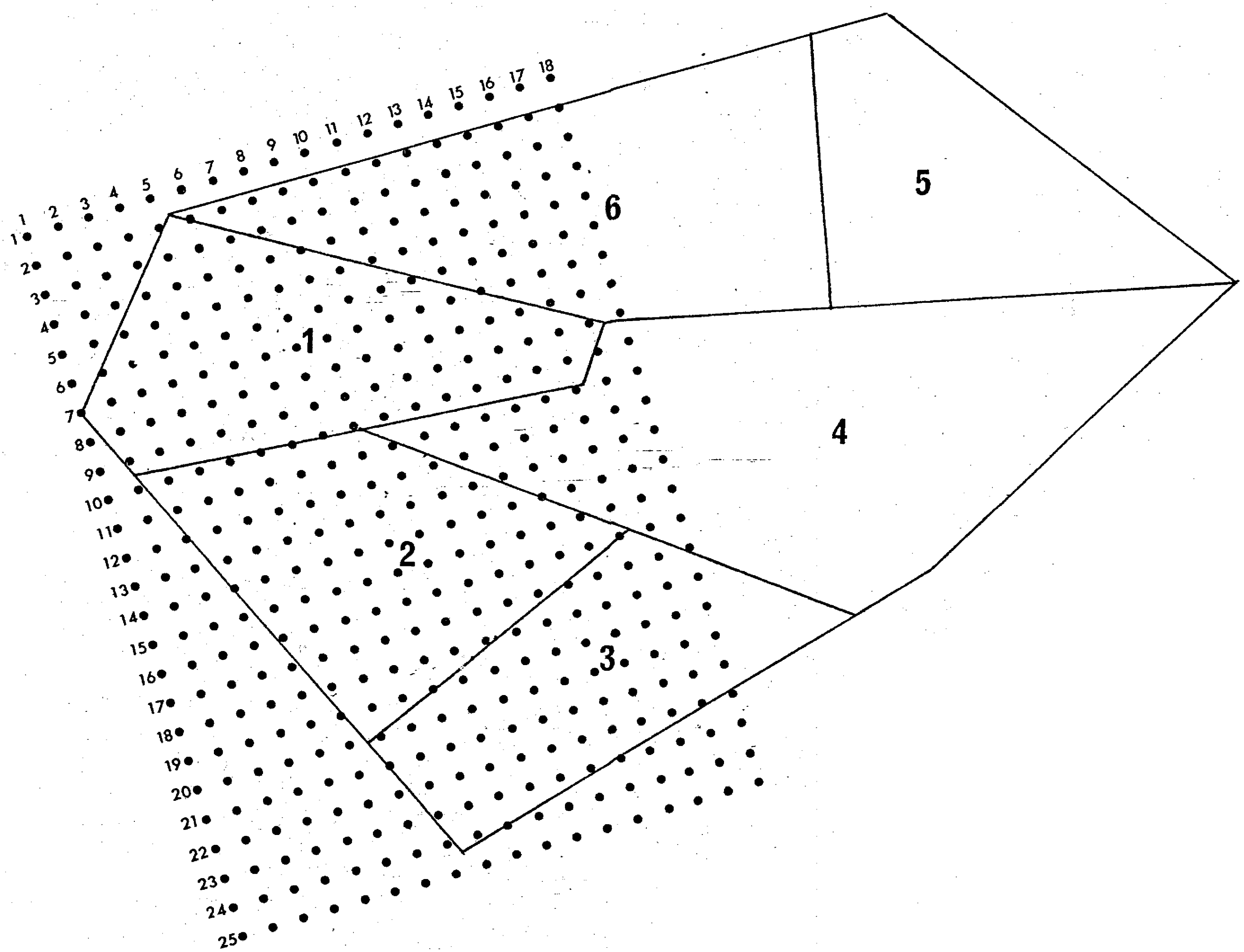
6.4.3 Dot-grid counting

Yet another method involves the theory of sampling with probability proportional to size, discussed in Section 4.4.4, and is known as dot-grid counting. It also involves the application of the theory of systematic sampling discussed in Section 4.3.3. The method is illustrated here by reference to the example in Figure 9, which shows a map at a scale of 1 : 15840 overlain by a grid with dots at a frequency of 25 per square inch. Each square inch of the map repesents 40 acres. In practice the dot-grid would be inscribed on a transparent sheet of celluloid so that it could be placed anywhere on the map.

Suppose that the total area of the grid is 18 square inches, making a total of 450 dots. If a compartment boundary enclosed 2 sq. in., it could also be expected to enclose 50 dots. The probability of any one dot falling within the compartment is 50 : 450. Similarly for a compartment represented by 1 sq.in., the probability of including a dot is 25 : 450. These probabilities are in the ration 2 : 1, which is the ratio of the compartment areas. Thus, the probability of selection is proportional to the size of the compartment. By knowing that the

Figure 9

DOT-GRID AREA ESTIMATION EXAMPLE



frequency of dots on the grid is 25 per square inch it is a simple matter of proportions to convert the number of dots counted for an unknown area to provide an estimate of the area. If 80 dots are counted, the area is estimated as follows:-

$$\text{Compartment area} = (80/25) \times 1 \text{ sq. in.}$$
$$= 3.2 \text{ sq. in (map area)}$$
$$= 128 \text{ acres (ground area)}$$

It is important to remember that the method is in fact a form of sampling. When the boundaries of the compartments are irregular the number of dots falling within compartments will vary with the location and orientation of the grid. for the estimate to be unbiased, the location and orientation of the grid must be randomly selected, which is the normal condiition for systematic sampling. Moreover, if an unbiased estimate of the precision of the estimate is required more than one systematic sample must be taken, and such interpenetrating samples must each have their own randomly selected origin and orientation.

In section 4.3.3 systematic sampling was considered as a particular type of two-stage sampling. Each systematic sample, or grid count, with its own random start, constitutes a first-stage sampling unit. The dots counted on the grid represent second-stage units. Attempts to increase precision could be made either by increasing the number of first-stage units, or counts made, or by increasing the frequency of dots in grid. The issue devolves into the usual cost/precision compromise and the allocation for greatest efficiency is probably best determined by experience. Barrett and Philbrook (1970) compare the results of interpenetrating samples with grids of varying intensity. Their general conclusion is also that the optimum allocation is best determined by experience but also point out that with several counts it is possible to detect any major mistakes, or incorrect counts.

Various practical problems surround the application of the dot-grid technique. Theoretically the method involves the counting of point sampling units within a defined boundary which conceptually involves the use of lines of zero width and dots of zero diameter. The problem is minimised by using lines and dots as fine as possible but it is still necessary to fix some objective criterion to select which dots touching boundaries are to be included. Yet another problem arises when the area of one large map unit, such as a State Forest, is estimated as the sum of a number of smaller units of which it is composed. There appears to be a common operator tendency to include rather than exclude dots which touch the boundaries. When this bias is repeated over a number of the sub-units the total bias in the large unit may be quite considerable. To overcome this problem it is suggested that the one grid position be maintained throughout a count of the complete map area and that counting be systematic down each column of the grid. A possible recording method for this procedure is given in Appendix VII using the illustration in Figure 9.

Recently, an instrument called the MK Area Counter has been developed on the principle of the dot-grid count. The intersections in a fine metallic mesh replace the systematic arrangement of dots. As an electronically sensitized pointer is passed over the grid a counter records the number of intersections crossed. The tedium of counting is greatly reduced.

6.4.4 Electronic scanning

Modern electronic technology has made it possible to link computers with instruments that can scan pictures and sense the difference between light and shade. By fixing the position of the picture and scanning along known paths it is possible to convert the boundaries of light and shade into digital co-ordinates related to the axes of the scanning paths. These co-ordinates may be read directly to a computer where they can be stored and used later to calculate the areas of the different picture types.

Some work has been done towards automatic picture interpretation by this process, using a scanner set to sense varying levels of light and shade. To achieve sufficient accuracy in map areas determined in this way it is probably desirable that only two or three shades be used on the one map so that the types are quite distinct. Unless only two or three types are to be represented on the map, the preparation of special sheets for scanning is likely to be very expensive. Moreover, although suitable scanning facilities are available at some computing installations, including the CSIRO Division of Computing Research in Canberra they are probably not as yet freely available at centres used by major forestry organisations. The equipment is extremely costly to purchase and can monopolise large amounts of computer time when in operation. But the general field is one for further examination in the future.

6.4.5 Digital representation by computer

The author gave a brief introductory note on this subject, (Phillis, 1970), under the title of 'The D-MAC Pencil Follower'. The instrument described in this article is used to convert map boundaries to digital co-ordinates for computer processing. The map is fixed on a special tracing table and the boundaries traced with a pointer device connected to an electronic control unit. Servo-mechanisms below the table surface follow the pointer, and positions are read from shaft encoders in the form of X and Y co-ordinates. Resolution is to 0.1mm. The instrument operates 'off-line' from the computer, punching the co-ordinates to paper tape for later input and processing in the computer at a convenient time. The D-MAC Pencil Follower is capable of keeping pace with normal tracing speeds.

The D-MAC Pencil Follower is made by Dobbie MacInness in Scotland and costs about $16,000 in Australia. One such instrument is installed at the CSIRO Division of Computing Research in Canberra. The Bendix Corporation has also produced an instrument of similar capability at the same order of price. Their instrument is called a 'Datagrid Digitiser'. The obvious disadvantage of these machines is their high purchase costs which would be difficult to justify for area estimation alone, but their use is mentioned here because area measurement is only one possible application of their potential. A few workers are beginning to develop computer systems for digital representation of complete maps. In Canada a highly complex system has been developed to maintain a national land inventory, although at this stage technical difficulties are still being encountered. Once systems for data representation and information retrieval have been developed instruments such as the D-MAC Pencil Follower provide a vital link in converting the map information to the digital form suitable for reading to the computer memory. The advantage of a computer mapping system is the opportunity for accurate storage and updating of large volume of information and the facility for automatic production of varous information summaries, including area summaries, according to a variety of specifications. The biggest problems involved are the very large computers required and the complexity of programming needed to develop the system. The field will undoubtedly increase greatly in importance in the next ten years.

The results of a precision trial with the D-MAC Pencil Follower and a comparison with dot-grid sampling are given in the author's paper, (Phillis, op.cit.) The map used in the trial was a plan of a plantation area of eight compartments mapped at a scale of 1 : 15840. With only very limited previous experience one operator used the D-MAC Pencil Follower to traverse the eight compartments six times in one hour. Subsequent computing cost was about 60 cents. Two operators applied dot-grid counting to the same area, one using a grid marked with 25 dots per square inch and the other a grid with 100 dots per square inch. With the lower intensity sample two full counts were completed in 16 minutes compare with 35 minutes for the 100 dot grid. In each case a further 5 minutes were required for calculation. The results obtained were as follows:a

	Area Estimate (acres)		
D-MAC Pencil Follower	946.43	±	2.26
25-dot Grid	947.2	±	6.4
100-dot Grid	954.3	±	0.7

The precision obtained with the D-MAC Pencil Follower is intermediate between the two intensities of dot-grid sampling and must be considered quite satisfactory. The bias of the estimates is more difficult to assess since there is no convenient way of determining the area as drawn. The actual ground area could be calculated from the original survey data but this does not provide a suitable standard in this case since it does not allow for drafting errors. There is no immediate reason to suspect bias in the D-MAC results. The author is more inclined to consider the result from the 100-dot grid to be biased, probably due to an operator tendency to include dots falling on boundary lines rather than to treat them in some strictly objective fashion. Using a grid with a high intensity of dots would increase the frequency of this decision for the operator, thus increasing the risk of bias. The variable costs in using the D-MAC and the dot-grids are comparable and the same sort of operator capabilities are required in each case. The obvious disadvantage of the D-MAC Pencil Follower is its high purchase cost but if it were in use as part of a programme for digital representation of maps the opportunity to calculate map areas accurately would provide an important side benefit.

CHAPTER 7

TREE VARIABLES AND THEIR MEASUREMENT

7.1 Introduction

Trees exhibit a great variety of complex forms and shapes; in large part it is this variety and complexity that make them so appealing to the eye. But the problems posed for the forest mensurationist in providing quantitative descriptions of trees are enormous. In general, quantitative description of trees is required principally for the regulation of commercial production and the prime task of inventory is therefore to attempt to describe and measure a tree in terms of variables likely to affect commercial production in some way. The number of possible variables may still be rather large, particularly in a eucalypt forest where the form of the trees is generally more variable and more irregular than in a conifer stand. The variables used fall into three broad groups:-

(a) Those describing commercial size and quantity.
(b) Those describing commercial quality.
(c) Those likely to be correlated with changes in commercial quantity or quality.

The succeeding sections of this chapter will discuss the measurement of tree characteristics under these three headings. Since most stand parameters are obtained simply by summing or averaging individual tree characteristics this chapter also concerns the estimation of stand parameters.

7.2 Variables describing commercial size and quantity

7.2.1 Diameter and Girth

The quantity of wood in a tree can be expressed either in terms of its volume or its weight. In the past, volume has been used more extensively than weight for wood measurement. The volume of a solid is most usually measured directly by displacement, but this technique is clearly impractical for a standing tree. Tree volume is therefore estimated through one or more parameters or variables which are related to volume and measured instead of volume. It is common knowledge that tree boles taper and it is the rate of taper from a given base that determines volume. The rate of decrease in the sectional area of the bole with increasing height, which is the rate of taper, determines the form of the tree. The literature contains numerous arguments over possible general mathematical expressions of form over the entire bole and the principal of these are summarised by Carron (1968). But as yet no single expression could be considered reliable for all species in all situations. The most reliable method of determining tree volume, therefore, is to measure the sectional area of the bole at several sample points along the stem and estimate the volume of the short sections between measurements. Lawrence (1960) offers a rationale for selecting the measurement points. His method is a qualification of a method generally described as the 'Graphical Method'.

Although the method of volume calculation just described is itself an indirect method, it is still too time consuming and expensive for many routine purposes. It is therefore useful to attempt to relate volumes obtained by the Graphical Method to parameters even more simply measured. Regressions for this purpose almost always involve diameter breast high over bark (dbhob) or basal area over bark (the sectional area of the circle on the diameter at breast height) Terms describing tree height and taper may also be used together with dbhob as an independent variable.

The reliability with which volume can be estimated through diameter measurement depends firstly upon the reliability with which diameter can be measured and secondly upon the reliability with which volume can be correlated with diameter and other independent variables. The question of diameter measurement will be considered first. A number of methods are available for measuring diameter but the only two in common useage are direct measurement by means of calipers and indirect inference of diameter through the measurement of girth by means of a graduated tape. The assumption in the second method is that if the tree section is circular, diameter is obtained from girth by dividing by 3.14159, the value of pi. If the tree section is not circular a positive bias is always incurred by this assumption but there will be consistency, or precision, in repeated measurements if they are taken at a constant height. By using calipers it is possible to average the varying diameters of a stem of irregular section by placing the calipers at a number of positions around the stem. Because the reading obtained with calipers varies with the position on the stem, repeated measurements may lack precision. There is a risk when repeated measurements are taken to study growth and the growth is small that the lack of precision may confuse or disguise the real growth. For this reason Europeans always mark the position of measurement with a caliper bar. Girth tapes are more commonly used for inventory in Australia.

Several other factors influence the precision of estimates of diameter changes. Hopkins (1968) demonstrated considerable short-term fluctuations in girth of regrowth eucalypts in mixed species foothill forest in Victoria. His study was based on weekly observations of dendrometers, or fixed girth bands, over a two-year period. He was able to demonstrate actual stem shrinkage during hot, dry periods. The effects of such variations are probably satisfactorily controlled by measuring in winter and leaving an interval of at least five years before remeasuring to obtain diameter increments. Of greater importance are possible irregular variations in bark thickness due to such things as mechanical damage in logging or silvicultural treatment.

Bias can easily enter into the measurement of diameter increment in several ways. To obtain precision in repeated measurements of a permanent sample it is desirable to mark the point of measurement in some way, even though this point should have been fixed by the standardised definition of breast height. Marking the position with wooden or metallic pegs or wires has been used on occasions but these methods, particularly the use of metallic materials, can cause severe localised swelling, thus making the point of measurement unrepresentative. A white paint line serves the purpose tolerably well for rough bark trees and has the added function of helping to delineate the boundaries of permanent plots. Care should be taken that the paint used is not likely to affect tree growth and the painting action does not remove excessive loose bark.

The action of fire in removing fibrous bark or in causing cracking in smooth bark can seriously affect the reliability of measurements of diameter over bark. Hoschke (pers. comm, 1971) speculates on the direct effect of fire in removing bark in the permanent inventory plots in Nambucca State Forest of New South Wales. The first remeasurement of the inventory took place in 1963 and a second remeasurement was carried out in 1970. At the 1970 measurement, apparent fire history was recorded. Full results are given in Table 16. Because a considerable period of growth is involved it is difficult to distinguish bark loss from any actual growth reduction due to the fire. But at least there is a clear indication that it is important to keep some record of fire history if reliable estimates of growth are to be obtained, since the growth estimate obtained by measuring over bark diameters will be greatly reduced if the tree has been burnt during the observation period. A possible means of surmounting some of the problem with fire is to work with dbhub, the breast height diameter under bark. Mesavage (1969) describes a method of measuring underbark designed to overcome many of the problems of an irregular bark surface. Unfortunately, however, bark gauges are extremely difficult to use reliably in the very hard bark of some eucalypts. In the processing of data for the Trentham Management Plan in 1969, the Forests

Commission of Victoria converted diameter over bark to diameter under bark by means of simple linear regressions. Different regressions were used for each of five species and three burning-history categories. They are tabled in Appendix VIII. It is interesting to note that when the Victorian regression for messmate is applied to the growth data for unburnt blackbutt of 20 inches, the apparent growth differences indicated in Table 16 are more than accounted for by the predicted differences in bark thickness for each condition of burning. The inference is not that the loss of crown in a fire will not cause a loss of growth, but rather that observations of actual loss of growth may be severely confused by diameter reduction due to bark loss.

7.2.2 Height

Conifer volume tables are commonly based on some expression of total tree height, whether it be the height of an individual or some expression of mean stand height. Furthermore, most conifers are relatively free of major defect and usually retain a strong apical dominance and single stem form so that the amount of the bole that could be utilised is limited by the minimum acceptable small-end diameter. From measurements of diameter along the stem the shape of the tree can be modelled, either mathematically or graphically, and from these models it is possible to determine what proportion of the total bole will lie between ground and any given minimum diameter. Such models are not always easily defined, nor is it ever easy to predict exactly the utilisation limit that will be applied in field operations, but at least the procedure can be expressed reasonably satisfactorily in objective terms. This is in contrast to the situation in mature eucalypt forest.

To begin with, total tree height is not a readily measurable variable in a eucalypt forest in which the trees are approaching sawlog size. Broad spreading, irregular crowns make it virtually impossible to determine

TABLE 16

EFFECT OF FIRE ON DBHOB GROWTH

Nambucca State Forest - Blackbutt - Merchantability Class 1
(1963-1970)

Annual DBHOB Increment Per Tree
(inches)

	12-16	16-20	20-24	24-28	28+	Mean	Number
UNBURNT							
Dominance Class							
1	-	0.36	0.23	0.37	0.24	0.27	35
2	0.22	0.22	0.23	0.24	0.23	0.23	89
3	0.18	0.22	0.19	-	0.29	0.20	42
LIGHT CONTROL BURN							
Dominance Class							
1	0.26	0.15	0.24	0.25	0.29	0.24	52
2	0.25	0.19	0.20	0.16	0.21	0.20	135
3	0.18	0.17	0.20	-	-	0.18	43
MODERATE BURN							
Dominance Class							
1	0.33	0.25	-	0.17	0.20	0.23	6
2	0.22	0.02	0.24	0.05	-	0.19	16
3	-	0.11	-	-	-	0.11	1
SEVERE WILD-FIRE							
Dominance Class							
1	0.16	0.19	0.03	0.12	0.27	0.16	16
2	0.12	0.11	0.12	0.38	0.35	0.14	51
3	0.11	0.02	-	-	-	0.08	7

with certainty the top of a large tree. This is an unfortunate difficulty since total height, being a biological characteristic of the tree, could be expected to be a parameter of tree growth. But, even were it possible to measure total height, it would still be difficult to use this variable in the determination of merchantable volume. Only in the use of smaller trees as round timber is the merchantable length of the tree likely to be consistently determined by the height to a minimum acceptable small-end diameter. In sawlog sizes the merchantable limit is likely to lie close to the base of the major persistent crown or at some point lower than this if major stem defects are present. Such defects can include mechanical damage, termite colonies, large rotten branch stubs and sharp kinks in the bole. The merchantable limit of the tree is therefore determined partly by the natural development of the tree and partly by the superimposition of utilisation standards not related to biological factors influencing the tree's development. Because the merchantable height is rather variable and because it is not easily related to other measurable features of the tree, it is usually included as an independent term in tables of merchantable volume, and must be measured for each tree.

The use of merchantable height, however, immediately presents several problems. First there is the very difficult problem of predicting the probable merchantable limit. Even under stable standards of utilisation the merchantable limit is not always readily determined from external indicators since there may be internal fungal decay or termite damage with no external symptoms. Almost all assessments of merchantable height in eucalypt management inventories in Australia have used a subjective estimation of the merchantable limit. The most notable attempt to substitute objective prescriptions is given by Paine (1968). Subjective estimation of the merchantable limit leaves much scope for operator mistakes and operator bias, since the decision is often difficult. It is undoubtedly desirable that the person performing the task should be experienced in estimating and should have a thorough knowledge of local utilisation standards. The task is not one for a raw forestry graduate not versed in local utilisation practice. In some State Forest Services it is a practice to require inventory parties to make regular observations of routine harvesting operations and to fell and check measure some trees in temporary plots. This should not only train the inventory party but should also engender greater interest in getting good results. But even then there can be sufficient difference between the judgements of inventory parties at successive remeasurements to cause considerable confusion in the determination of real growth.

Even the best estimates will be in error if there are changes in the utilisation standards. For relatively slight changes, such as a general tightening up of utilisation standards with the same end usage, it is perhaps possible to make adequate short-term correction to volume estimates by some flat rate percentage increase based on general observation. More detailed correction of merchantable height can be made at the next remeasurement of a permanent inventory but it will then be difficult, though perhaps not impossible, to distinguish real growth from apparent growth due to changes in merchantable height arising from improvements in utilisation standards. With repeated temporary inventories it would not be possible to distinguish the components of growth. If the changes in utilisation standards involve a major shift in product emphasis, say from sawlog to pulpwood, the change in merchantable length will almost certainly require a re-assessment. The effect is the same if changes in merchantability occur with changes in tree size. For example the merchantable limit for a tree being assessed as a pole or pile may be well into the crown but, as the tree grows and the crown expands, the merchantable limit may then be fixed below the base of the crown when use as a sawlog is intended.

In the course of a detailed analysis of tree and crown structure in Eucalyptus obliqua, Curtin (1970a) defines a quantity called 'bole length', which is the difference between total height and 'crown-length'. His description of 'crown-length' is as follows:

> The 'crown-length branch' is defined as the lowest healthy branch forming part of the main crown. It is not necessarily vigorous but should have a well foliated growing tip which extends outward as far as, or further than, any branch above. While this definition is subjective, it is consistent in practice and relatively free of observer bias.

The use of this type of height term in inventories designed to give detailed growth estimates would lead to more stability in these estimates by obviating a large part of the subjectivity associated with the use of the merchantable limit. The tree growth that is estimated will be a function of biological conditions without the confusion of a superimposed pattern of changing utilisation. Such stability is a desirable attribute for long term projections. It should be a relatively easy task to derive factors for converting average bole height to average merchantable height on the basis of current or expected utilisation standards for any given product. Sample trees could be assessed and felled for checking if necessary. Bole height has been measured in one or two very recent inventories in New South Wales but as yet the results are not available for testing.

The discussion in this section so far has been directed towards the definition and recognition of the point to which height is to be measured. There still remains the difficulty of measuring or estimating the height once the measuring point is selected. Dowden (1968) gives a lengthy and detailed discussion of trials he made with various instruments in a eucalypt forest in New South Wales. As the best compromise of convenience and reliability he was in favour of the Blume-Leiss hypsometer, the Haga altimeter and the

Suunto clinometer, which are the three instruments most commonly in use in New South Wales. These instruments are used to measure angles of inclination or declination to the agreed merchantable limit and to the base of the tree. The angles are converted to distances by applying trigonometric conversion factors to the length of the base line from the observer's eye to the tree along the horizontal. In forest with a heavy understorey this procedure may involve the clearing of a suitable line, usually about the same length as the height to be measured, to a point where the observer can see both the top and bottom points for measurement. Most users recommend that at least two observation points be used for checking. Dowden (op. cit.) also remarked that observations of the total height from different locations varied by up to 16 per cent, although much of this error may have been due to parallax error in sighting to the apparent top of a flat-crowned tree. This problem should be much less significant in observing to some point on the tree bole provided the same point is clear and unambiguous from both sides. Nevertheless, measuring the height of every tree from at least two positions can be extremely costly. For this reason an experienced person is often called upon subjectively to estimate merchantable height or bole height. Provided he is capable of recognising the proper height limit an experienced operator should have reasonable success in placing trees in 5ft merchantable height or bole height classes up to a height of about 50ft, particularly if he keeps a continuing check on his performance by using one of the instruments mentioned above. For estimates of the current growing stock, controlled subjective height estimation may be all that is warranted if merchantable height is used, since errors in selecting the merchantable limit are likely to be considerably in excess of errors in the actual height estimation. For long-term growth projections a more stable parameter than merchantable height should be used and for this purpose measurement would almost certainly be preferred to ocular estimation.

TABLE 17

COMPARISON OF ASSESSED AND ACTUAL MERCHANTABLE HEIGHT

Trees Felled in Compartment 26 - Pine Creek S.F.

Height Errors (feet)

	Underestimate					Overestimate			
Actual Height	17.5+	12.6-17.5	7.6-12.5	2.6-7.5	0±2.5	2.6-7.5	7.6-12.5	12.6-17.5	17.5+
20-	0	0	0	0	1	0	0	0	1
21-30	0	0	3	2	12	4	5	0	2
31-40	0	0	1	12	48	17	14	4	2
41-50	1	2	13	20	20	6	2	0	0
51-60	2	4	1	5	7	0	0	0	0
61+	3	0	3	2	3	0	0	0	0

The combined effects of operator tendencies in selecting a merchantable limit and estimating merchantable height are well illustrated by the data of Table 17. As part of the experimental work described in Section 2.5, 222 trees were assessed for merchantable height and then felled and measured in a commercial logging operation forming part of the silvicultural treatment. After making due allowance for stump, the assessed merchantable heights were compared with the actual merchantable heights. Because the assessed heights were only in 5ft classes the 91 trees (41 per cent) in the range 2.5ft either side of the true value must be considered correct estimates. A further 68 trees (32 per cent) fell into the next height class in both directions from the true value. But the pattern in Table 17 indicates an operator tendency to average out the stand by overestimating the short trees and underestimating the tall trees. A summary of the average errors is given in Table 18.

TABLE 18

<u>COMPARISON OF ACTUAL AND ASSESSED HEIGHT AND VOLUME</u>

<u>Pine Creek S.F. - Compartment 26</u>

Number of trees	222
Mean merchantable height (actual)	39.4
Mean merchantable height (assessed)	38.7
Error	0.7
Percentage error	1.8
Mean merchantable volume (actual)	607
Mean merchantable volume (assessed)	590
Error	17
Percentage error	2.8

Note: Volume errors are calculated solely from height errors.

Table 18 indicates that the height errors are nearly compensating, but that the volume errors due to height errors are not compensating to the same extent, although the difference is not great in this example. Had the height errors been correlated with diameter, rather than with actual height, the volume errors would not have been compensating. As mentioned in Section 5.3, detailed records of removals from permanent inventory plots provide a useful means for checking on this type of possible bias.

7.2.3 Stump height

Stump height measurement is a matter given very little attention in eucalypt forest inventory work, although the effect of stump height errors on volume estimates may be quite significant. Stumps in eucalypt forest are usually much higher than those generally left in conifer logging operations. In part, this is a legacy from the days of manual cross-cut sawing when there was a desire to avoid pronounced buttswell as far as possible in order to minimise the diameter to be cut. Moreover, many eucalypts are particularly defective in the butt and it may be desirable to exclude the defective portion from the log. In the days of the cross-cut saw the fellers would even climb the tree on planks to as high as 15 feet to avoid an apparently defective butt section without having to cross-cut the log on the ground. Nowadays defective trees are felled at a more conventional stump height and the butt cut off before snigging. But for yield calculation purposes the tree can still be regarded as having a high stump. A third reason for high stumps in eucalypts is one of safety and convenience. Eucalypts of sawlog size are large trees, often with unbalanced crowns and frequently grow in steep or overgrown situations where felling can be both difficult and dangerous. It is therefore desirable for the chainsaw operator to work in a reasonably convenient attitude.

In normal sawlog operations stump height will vary between 2ft and 4ft, with occasional trees having much higher stumps because of defect. The usual inventory practice is to assume some common average stump height and only record stump height estimates for those trees expected to have high stumps because of defect. It is important, however, that the general stump height assumed should be related to current utilisation practice. During the logging of the research plots mentioned in Section 2.5, records of stump heights were kept. It was apparent that the stumps for the smaller trees removed as poles and piles were regularly lower than those for the larger trees sold as sawlogs. The means for the two classes are given below.

	Poles	Logs	Total
Mean stump height (ft)	1.4	3.1	2.5
Standard error	0.15	0.07	0.09
Number of observations	74	148	222

These figures are for the actual height of felling. If rejected butt lengths are added to these figures the mean effective stump for sawlogs increases from 3.1 to 3.7 ft with a new standard error of 0.17.

The most common way of making use of the standard stump height assumption is to incorporate it in the volume table. The volume table used in Table 18 assumed an average stump height of 4 feet, which is an overestimate of 0.9 feet on the actual mean stump height of 3.1 feet. The average merchantable log length (but not merchantable height) is therefore effectively underestimated by 0.9 feet. The real increase in volume availability is at the butt of the tree where there is greatest gross volume per foot of length but the method of measurement for sale may preclude the full realisation of this volume in commercial sales. For example, in New South Wales measurement for sale of sawlogs is based on length of log and centre-girth under bark. An increase of log length of 1 foot at the butt end will displace the point of centre-girth measurement by only 6 inches towards the butt, with only slight effect on the centre-girth measurement. Any increase in volume will therefore be virtually proportional to the increase in log length.

To illustrate the order of magnitude of the possible volume error associated with stump height errors the Pine Creek Periodic Management Inventory data was processed, first with the assessed merchantable heights and then with all these heights reduced by 1 foot to simulate the situation where there was expected to be a general increase of 1 foot in the average stump height adopted. There was a reduction of 2.5 per cent in the estimate of standing volume over all sizes, and of 2.9 per cent in sizes greater than 20 inches dbhob. This is an approximation of the true correction; the proper correction would depend upon the derivation of the volume table.

7.2.4 Tree volume

The three preceding sections of this thesis have all made considerable reference to tree volume. This has been necessary because tree volume is a difficult quantity to measure as such; it is usually estimated through parameters like diameter, girth and height. But to be able to use such parameters it is first necessary to establish the relationship between the parameters and volume, which, in turn, requires that both the parameters and volume be measured on some trees. Carron (1968) discusses in detail a number of methods of measuring tree volume by making several sectional area measurements along the stem. The author of this thesis favours the so-called 'Graphical Method', described by Carron (op. cit.), since it does not presuppose any fixed mathematical expression of form over the entire length of the stem. Program 'FMGVC' was written by the author to process Graphical Method field measurements for the Forestry Commission of N.S.W. Similar computer programs are known to be in use by APM Forests Ltd and Forestry Commission of Tasmania. The necessary sectional area measurements may be obtained most easily from girth or diameter measurements on felled trees. Underbark estimates could be obtained by using a bark gauge but the author favours removal of bark and the use of girth tapes whenever possible. Measurements over and under bark can be obtained by climbing standing trees. Curtin (pers. comm.) has also been using a Barr and Stroud Dendrometer to measure upper diameters over bark in research plots.

Prior to the advent of digital computers the relationship of volume, the dependent variable, to the independent variables, such as height and diameter, was usually studied by graphical means. Curves were fitted to the plotted data by eye in order to 'smooth' the relationships. Values for the smoothed curves were then read off and collated to give 'volume tables'. Although some mathematical theory was available for fitting curves mathematically, the volume of calculation generally made such methods uneconomic without the aid of a computer. Nowadays, standard computer programs are available for mathematical fitting of regressions and volume tables can be expressed in a continuous rather than tabular form by means of regressions. Moreover, statistical estimates of precision can be applied to the regression fit.

The selection of a sample of trees to measure in order to establish a regression should be based on the principles discussed in Section 5.5. Broadly these are that it is essential to cover the likely range of variation in the independent variables and, after this proviso has been met, that it is desirable to concentrate the sample in the ranges of greatest interest and of greatest variability in the relationship between dependent and independent variables. Section 4.3.7 described the use of 3P sampling selection for this purpose. 3P sampling has not been used extensively in Australian forestry and is well deserving of much closer consideration.

It appears to the author that in Australian forestry there is a general reluctance to improve upon existing volume tables for eucalypts. The New South Wales Forestry Commission, for example, still uses a published blackbutt volume table based on the measurement of 106 trees and a spotted gum table based on only 37 trees. These have been modified and converted to regression form for computer processing of inventory data but the details of the original data appear to be lost in obscurity. Admittedly, there is considerable value in maintaining a constant volume table in studying the growth in permanent plots measured at several occasions. A change in volume table could easily confuse growth estimates. But, considering the large sums of money that are spent on measuring inventory and research plots, it seems only reasonable to set aside a small proportion for checking and reviewing volume tables.

The above discussion has sought to emphasize that errors can arise in the use of volume tables if the data used to compile them were insufficient or simply not representative of the trees to which the table is being applied. But in volume tables for eucalypts further confusion seems to arise in a failure to give a clear definition of the volume involved. For conifers it is a fairly standard practice to define the term as volume under bark from ground up to a given diameter under bark. This may be qualified to volume above a standard stump height instead of from ground level. Such a definition is entirely objective and simplifies comparisons of volume tables. But because the merchantable limit of a large eucalypt is not fixed solely by the minimum toe diameter of the log, volumes are more commonly defined as the volume above a standard stump height up to the assessed merchantable height of the tree.

Such a definition involves several problems. By definition, a tree which is not considered merchantable cannot have a merchantable height nor a merchantable volume. Moreover, merchantable height and merchantable volume can fluctuate considerably with both real changes in utilisation standards and also differences in operator assessments. It is therefore strongly recommended that inventories of eucalypt forests use some other volume expression, such as volume to bole height (defined in Section 7.2.2) so that all trees may be given a volume. This should give greater stability to volume growth estimates and to attempts at long term volume growth prediction. It should not be too difficult to devise factors for converting from bole volume to current merchantable volume, or to obtain additional merchantable volume estimates for currently merchantable trees. In using merchantable volume it should also be recalled that because of methods of measurement the actual sale value may not be equivalent to the underbark volume obtained by the graphical method.

Finally it is important to note that virtually all volume tables give only the gross volume of the tree and make no allowance for internal defect and the reduction to nett volume. Because of the variability of internal defect from area to area it would be difficult to produce reliable nett-volume tables unless it were possible to associate defect with some form of defect indicator assessable in the standing tree. It may be necessary to fell sample trees in order to assess the prevailing level of defect and, once again, 3P sampling technique should be a most efficient way of selecting the trees to be felled. Because yield regulation should be primarily concerned with nett volume, and because internal defect is at once extensive, variable and largely unstudied, the whole of a later chapter in this thesis is given to the subject.

7.3 The assessment of commercial quality

Very little work has been performed on the problem of defining variables which could be used in determining the commercial quality of standing eucalypts in native forest. Moreover, it is a particularly difficult, yet particularly important, problem. There are really three basic components of the quality problem, namely:

1. Is any part of the tree suitable for a particular purpose? Is the tree merchantable?
2. If the tree is merchantable, what proportion of it is saleable?
3. What is the quality of the saleable portion?

The author knows of no successful attempt to resolve the third issue, beyond the fact that some general estimate of probable quality can be made from a knowledge of the general utilisation characteristics of the different species. From the forest manager's point of view this is also the least urgent of the three problems, since he can do little in the short-term to control quality in the sound portion of the standing tree. From previous experience the utilising industry can derive a reasonable estimate of the general level of quality to be expected, and the quality of individual pieces, which will probably affect price, can be estimated more readily after felling.

On the other hand, the forest manager does have an immediate interest in estimating the quantity of merchantable wood available, since this will influence yield regulation. The factors which determine merchantability for a given standard of utilisation are of three types:

(a) size of tree
(b) location in forest and location of forest
(c) general bole quality

Minimum standards for acceptability are defined not by a simple minimum standard for each type of factor but by an interaction of the three. For example, a small, defective tree might be merchantable if located within a mile of the utilising plant, but unmerchantable if located in steep country 15 miles from the plant.

It is common for an inventory assessor to be required to make a subjective integration of all three types of factor to estimate merchantability. He is usually assisted by some objective estimates of size. Such an approach has two principal deficiencies. Firstly, if utilisation standards change, as they frequently do, the only way to determine the trees and the volume affected by the change is to reassess the forest, since the original assessor's judgements can only be valid for the conditions in which he was working. Moreover, if a change in the proposed end-use is contemplated, the standards for one product will most likely be inapplicable to the new product and the problem will be the same. The second problem associated with subjective assessments of merchantability is in the estimation of growth. When the estimates of successive inventories are compared, real changes in merchantable volume may be greatly disguised by apparent changes in merchantable volume resulting solely from differences in operator judgement at each inventory.

More objectivity of estimate would therefore be desirable to help overcome these problems. It would be useful for the forest manager to have objective quantitative descriptions of trees in parameters of size, location and quality. Without re-assessing the forest he would then always be able to determine which trees were merchantable under any definition of merchantability framed in terms of the same parameters. Parameters of size are usually objectively estimated, although some quantities, such as merchantable height, do involve an element of subjectivity. Assessments of location and accessibility are not commonly collected as such in the course of management inventory but may usually be determined with sufficient accuracy from maps and aerial photography. Squire (pers. comm.) has described the way in which he has performed extensive management and resource inventories of virgin eucalypt forest in N.S.W. using sampling strata based on assessments of accessibility as apparent on aerial photography. Generally the maximum allowable slope for accessible areas was 35° but the individual assessor was allowed some discretion depending upon the amount of timber apparently available. The general bole quality, however, is not as easily described quantitatively and it is here that a major inventory problem arises. In this context, general bole quality refers to the features which determine which portion of the bole is capable of utilisation. This is somewhat more general than the earlier reference to the finer elements of the quality of the utilisable portion.

Tree defects are of two types, those associated with the general form of the bole and those associated with the wood quality of the bole. The first group includes bends, sweep and similar considerations, and can be considered as external defects. To the author's knowledge, the only published attempt to quantify acceptable limits for external defect in eucalypts is given by Paine (1968) for the assessment of alpine ash sawlog trees. In his prescription, reduction in merchantable volume is always made through a reduction in merchantable length. The allowance for external defect was as follows:

> Bends and sweeps: cull 5-feet lengths involved in very sharp bends and cull straight lengths less than 10 feet between very sharp bends. No allowance for sweeps or slight bends.

The allowances that should be made would vary from species to species and, particularly, from one intended product to another. The reason that there have been few attempts to draw up quantitative standards for the assessment of external defect probably lies in the difficulty of making comparable objective assessments of internal defect.

Defect is commonly estimated in logs once the trees have been felled. Such estimates for each sawlog are an essential part of the complex hardwood stumpage appraisal system employed by the New South Wales Forestry Commission. The estimate for 'pipe', the central column of defect, is based largely on the extent of defect visible at each end of the log. Further allowance for bole damage, bumps and branches may be made by reducing the stated length of the log for sale purposes. Paine (1968) attempted to extend this approach into the assessment of standing alpine ash in Victoria. Again he specified fixed length reductions for various levels of bole damage, butt damage, bumps, green limbs, dry spikes and swellings. When trees assessed in this way were later felled, and the estimates checked, the method was found to give very reliable estimates of merchantable volume in good quality pure stands of alpine ash. When the method was extended to other forests, particularly forests with a greater mixture of species and a longer history of repeated selective logging, the results were found to be less reliable. Paine (op.cit.) also experimented with the use of a motor drill to examine the width of the defect column in the butt. Although estimators appeared to favour the use of the drill, data were not available to demonstrate the improvement in accuracy gained by using the drill.

Although the approach adopted by Paine is a most useful step towards increasing the objectivity of merchantability assessment, it still leaves several problems unresolved.

Firstly, since there is always some taper in the tree bole, the height at which the defect occurs will affect the actual volume culled if a fixed length is culled. This may not be particularly important, however, if a general averaging over all trees in the stand is considered sufficiently compensatory. Moreover, in the measurement for sale, any length allowance will probably be made without regard to position on the bole.

Secondly, the appropriate allowances should vary from place to place, from species to species and from one intended use to another. But they may also vary from time to time with changes in utilisation standards. If the merchantability assessments are being applied to trees in permanent inventory plots, this will present a problem in reappraising merchantable volume without the need to remeasure the inventory. To avoid the problem it would be necessary to record the height, the position and the nature of every important defect symptom so that new allowances could be made at any time. This would involve the use of extremely complex tree records.

Thirdly, the use of supplementary investigation by boring the tree stem involves some risk of introducing bias to the sample trees, either by introducing or spreading decay organisms in the trees or by stimulating some wound growth near the point of diameter measurement. Although the Victorian work suggested some management gain from the examination of drill cores, Dowden (1970) in a report on an investigation of the examination of boreholes by probe and an instrument called the 'Borescope', found that the technique was not successful in making detailed assessments of the extent and increase of defect in living trees.

The final, and perhaps the most important, problem is that in reality it is the percentage defect, rather than the final nett volume, that determines merchantability. Although on paper the defect volume can be removed by a simple reduction in the merchantable length, in reality the defect can only be removed at the point of utilisation in many cases. Between the standing tree and the mill, the defect volume will already have incurred costs in felling, snigging, loading and haulage. The break-even for the acceptable amount of defect in any given area depends upon the value of the useful part of the tree that can be recovered. Under the N.S.W. Forestry Commission hardwood stumpage appraisal system it is possible to determine the maximum acceptable defect percentages for various log sizes and species in various locations. Accordingly the Forestry Commission set up Research Working Plan H11 with a stated general aim as follows:

> To investigate the initiation, growth, detection and effects of defects in stands, trees and their products, in order to provide qualitative and quantitative data on which management may base its prescriptions for the reduction or control of defects.

Dowden (1968a), in supporting the establishment of this working plan, gives a good general background to the study of defect in eucalypts. In early experiments in attempting to correlate internal defect with external defect symptoms, Dowden soon found that progress was extremely slow. With the shortage of research staff the New South Wales Forestry Commission appears to have shelved this project temporarily. The author also began a pilot study along the same lines in order to examine the feasibility and likely cost of a more extensive project to correlate defect with defect symptoms. The principal result of the pilot study was to find that the cost and time likely to be required for any meaningful results would be well in excess of the resources of the current general inventory project. Some of the problems encountered are discussed in greater detail in a later chapter.

If it is sufficient for management to have an estimate of the current average level of defect in the stand, several approaches are available. The first of these is to estimate average defect percentages from previous log sales. This is a commonly used approach and is reasonably satisfactory for short-term use if logging standards remain fairly constant. Percentage defect will change with time, however, sometimes because of changes in standards of utilisation and tree-marking and sometimes because of real changes in the level of defect in the forest. In Coopernook State Forest in New South Wales, an area with a long history of selective logging, the average percentage defect in log sales has been observed to be increasing rather than decreasing. Much more marked changes would occur, however, if there were a definite change in utilisation, say from sawmilling to pulping, and this is an imminent problem in several areas of eucalypt forest in Australia. An alternative approach is to fell a sample of trees and estimate the defect from examination of cross-sections. Paine (1968) describes the use of double sampling in this kind of approach, and the value of 3P sampling in a similar problem is discussed in

Section 4.3.7. This is probably the best approach available if little is known of defect from previous operations or if a major utilisation change is contemplated. It does suffer from the disadvantages of being both costly and destructive. The remaining alternative is to develop a method for quantitative assessment in standing trees in the expectation that it would be largely non-destructive and probably cheaper to apply.

However, if an assessment of the likely rates of change of defect is important, there is probably no useful alternative to assessments of standing trees. Estimates of defect growth are likely to have a very low level of precision unless the observations on successive occasions are dependent. Dependent estimates require permanent sampling units; permanent sampling units require that the method of defect estimation be non-destructive so that the same trees can be observed on several occasions. The increases in precision through using dependent samples are detailed in Section 5.3. Moreover, if it proved that consideration of the rates of change of defect in individual trees had important financial implications in the preparation of tree marking prescriptions, it would be necessary to have a non-destructive method of estimation which could be rapidly applied in the course of tree-marking for logging. This important consideration is investigated in a later chapter, using the complex stumpage appraisal system applied in New South Wales.

7.4 Variables correlated with growth

It is generally recognised that the growth of an individual tree must be the result of an interaction between its genetic constitution and its environment. To achieve a reliable prediction of tree growth it is necessary either to be able to assess or control the environment or the genetic constitution of the tree.

In plantations some immediate control of genetic constitution may be imposed by planting only one species.

Further control may be instituted through planned seed-collection and tree-breeding. In irregular eucalypt forest, maintained by selection logging and natural regeneration, it is not only impractical to impose the latter forms of genetic control, but it will also be necessary to work with more than one species at a time. In Pine Creek Forest, for example, there are nine important species of eucalypt, two important commercial non-eucalypts and various other non-commercial tree species. Consideration of each of these many species separately in the estimation of stocking and the projection of growth is perhaps too complex an endeavour for current studies in inventory problems in irregular forests. The extent to which they may be satisfactorily grouped depends upon the similarities between species and the relative importance of individuals. Appendix XI indicates the prevalence of blackbutt in the ridge stratum of Pine Creek and of flooded gum in the gully. The remaining species are represented in varying proportions, usually less than ten per cent by numbers. Both blackbutt and flooded gum generally exhibit faster growth rates than the other species. For this reason, and also because of the commercial importance of those species, blackbutt and flooded gum were separated from other species in the preparation of some stocking and growth summaries for Pine Creek. The remaining species were divided into two groups on the basis of expected growth rates.

Figure 10 indicates the average growth rates of the different species groups at Pine Creek. The figures are derived from all the available measurements of trees assessed as merchantable and are taken from establishment to 1967 or to time of removal. The weights against each of the class-mean points are for the number of tree-year observations. A tree observed for a period of nine years in the one class would contribute 9 tree-years to the weighting. The hand-fitted curves are intended only to highlight the data and not to imply a particular form of relationship. Figure 10 does indicate a considerable difference in the average growth rates of the different species groups.

Figure 10A

PINE CREEK PMI — RIDGE TYPE

Increment by Species Group

hand fitted curves

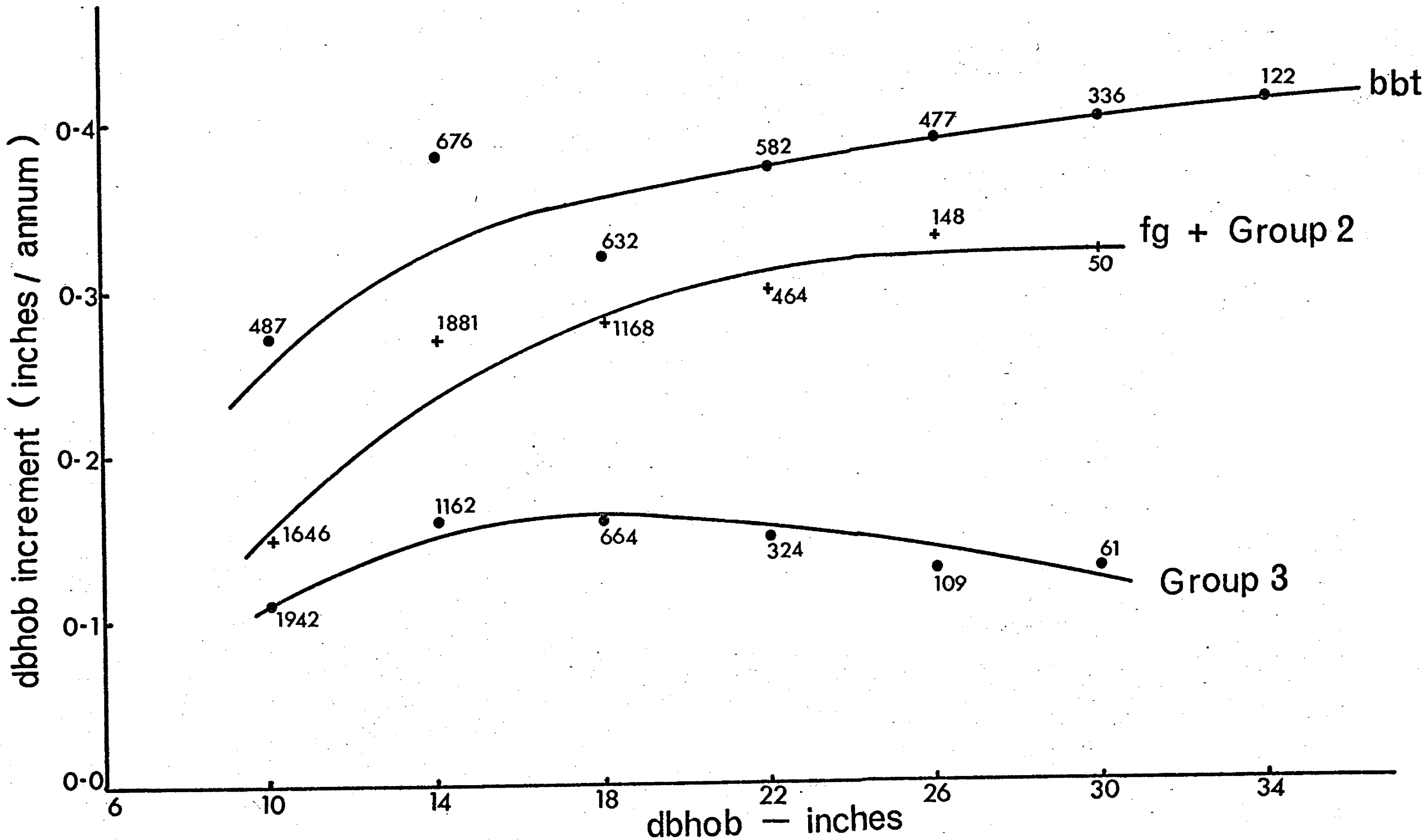
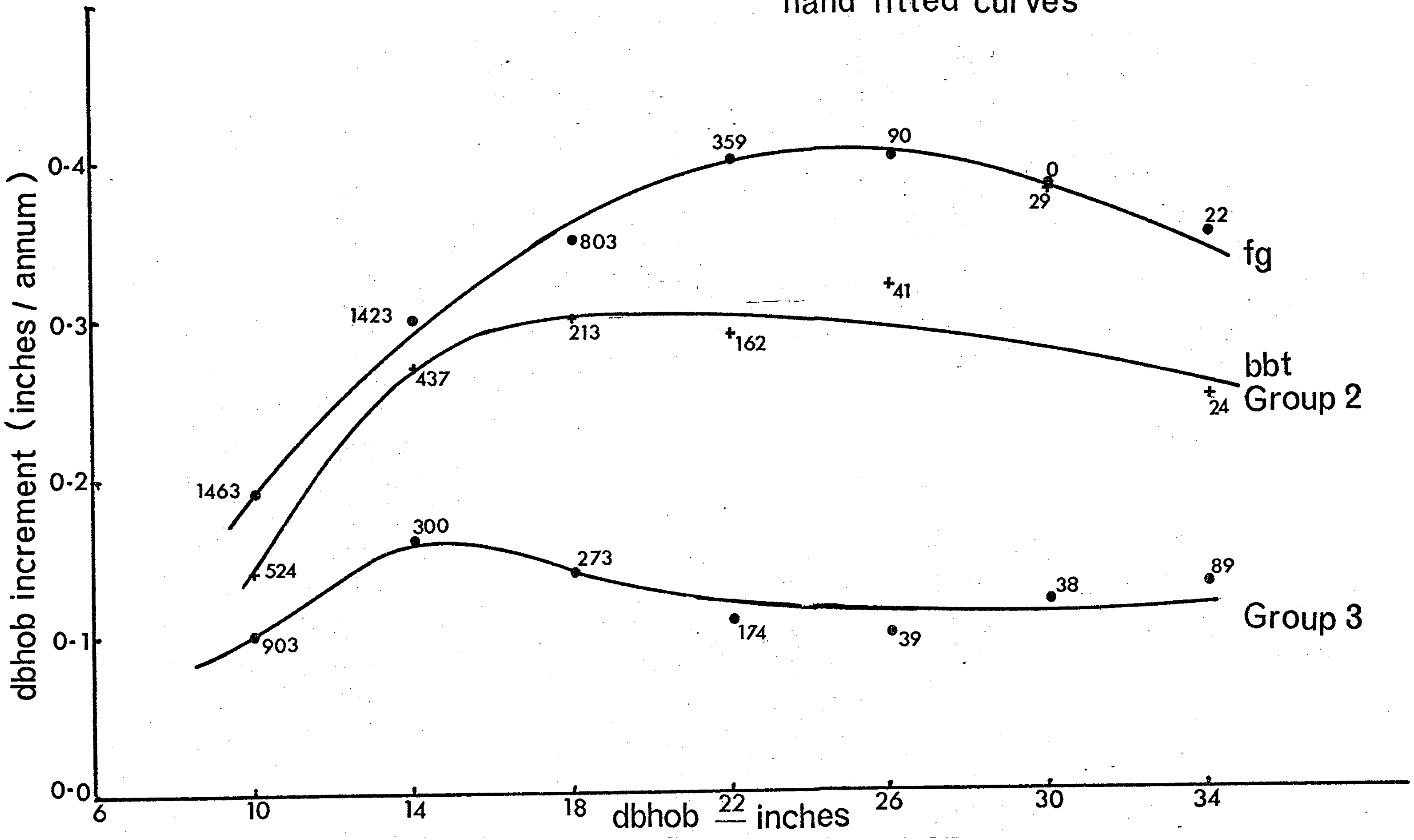


Figure 10B

PINE CREEK PMI — GULLY TYPE

Increment by Species Group

hand fitted curves



In Figure 10, diameter growth rate appears to increase with increasing diameter up to about 20 inches dbhob. The effects however, are not indicated by these data, and it appears that competition does contribute strongly to the depressed average increment in the smaller sizes. Competition is not easy to define quantitatively in an irregular forest. In the limited range of variability in even-aged forest it is possible to express current competition in terms of such quantities as basal area per acre, number of stems per acre or in more complex parameters such as 'relative spacing', (Beekhuis, 1966). Many of these terms, particularly those involving numbers of trees per acre, are not satisfactory for irregular forest, principally because of the great variability in ages, sizes, species and spacings. Moreover, it is not sufficient to consider only current competition, since recent selective logging or silvicultural treatment may have reduced previous competition which may not only have suppressed past growth but which may also have rendered the remaining trees incapable of rapid development following release. Vigour must therefore be estimated, not through size for a given age, since age is unknown, but through parameters reflecting past and present competition.

In most inventories of irregular eucalypt forest in Australia the parameters used to estimate competition have involved a certain element of subjectivity. Current competition is defined by estimating levels of dominance on an arbitrary scale, usually by applying integer ratings in the range 1-4. Similar ratings have been applied in other countries and their use is discussed by Trimble (1969). Much of the subjectivity of the rating procedure can be eliminated by using clear definitions, such as the following given by Trimble (op.cit.):-

1. <u>Dominant</u>

   Trees with crowns extending above the general level of crown cover and receiving full light from above and partly from the sides; larger than the average trees in the stand and with crowns well developed but possibly somewhat crowded on the side.

2. <u>Codominant</u>

   Trees with crowns forming the general level of the crown cover and receiving full light from above but comparatively little from the sides. Usually with medium sized crowns more or less crowded on the sides.

3. <u>Intermediate</u> (Subdominant)

   Trees shorter than those in the two preceding classes but with crowns extending into the crown cover formed by codominant and dominant trees; receiving a little direct light from above but none from the sides; usually with small crowns considerably crowded on the sides.

4. <u>Overtopped</u> (Suppressed)

   Trees with crowns entirely below the level of the crown cover, receiving no direct light either from above or the sides.

The terms used are not new, having been coined in the last century for even-aged forests. The definitions are repeated here to show that they do not presuppose an even-aged stand structure even though it may be argued that growth would be more <u>consistently</u> correlated with dominance in even-aged stands. When trees are classified according to such a system in an inventory of an irregular forest there is a pronounced differentiation of average diameter growth rate per tree. The sorting is a logical one, with greatest growth in the dominant trees and least in the suppressed. Figures 11 and 12 show the pattern for blackbutt at Pine Creek and Kendall State Forests on the north coast of New South Wales, whilst Figure 13 illustrates a similar pattern for spotted gum in Benandarah State Forest on the south coast of New South Wales.

Figure 11

PINE CREEK P.M.I. — BLACKBUTT
Increment by Dominance Classes

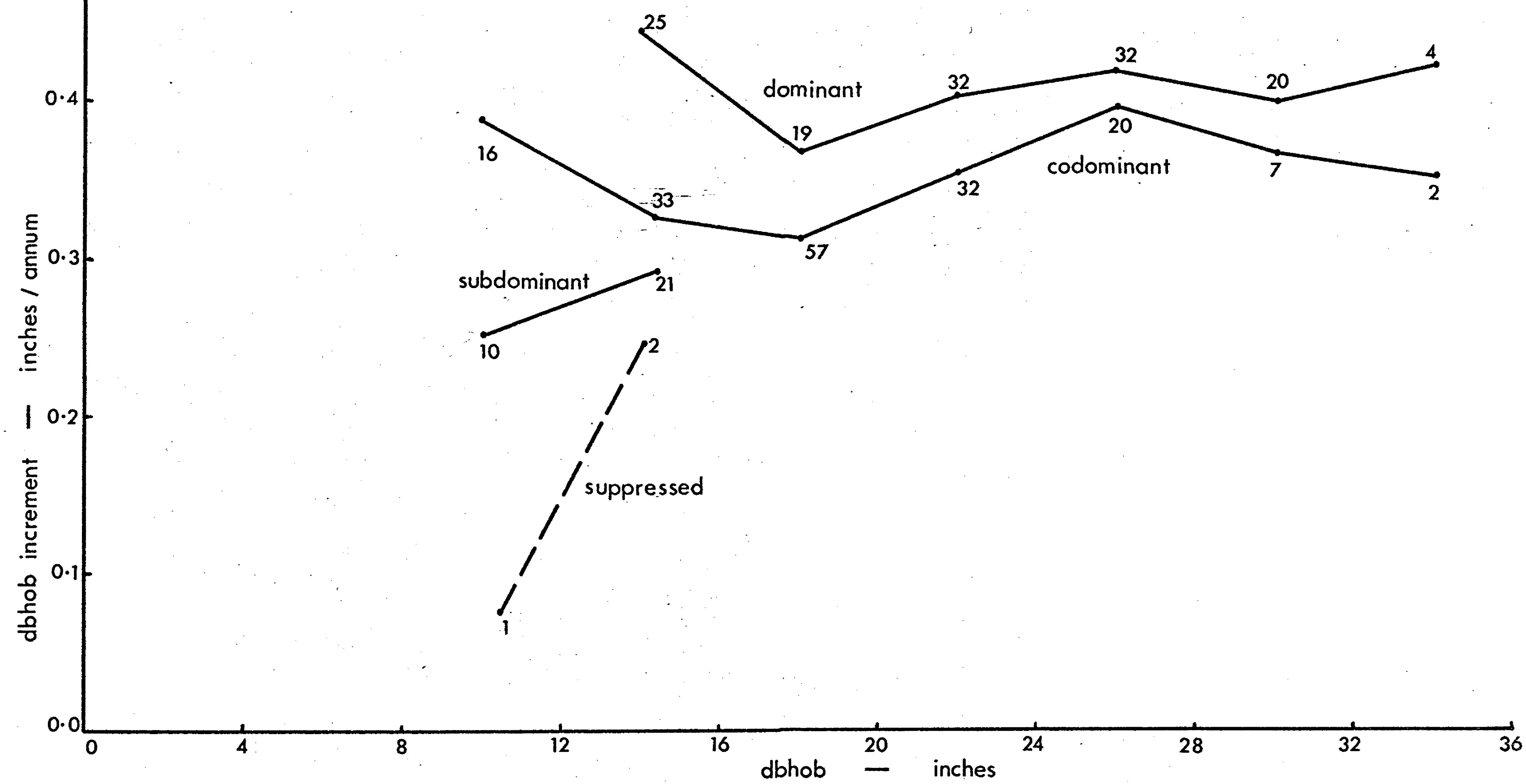


Figure 12

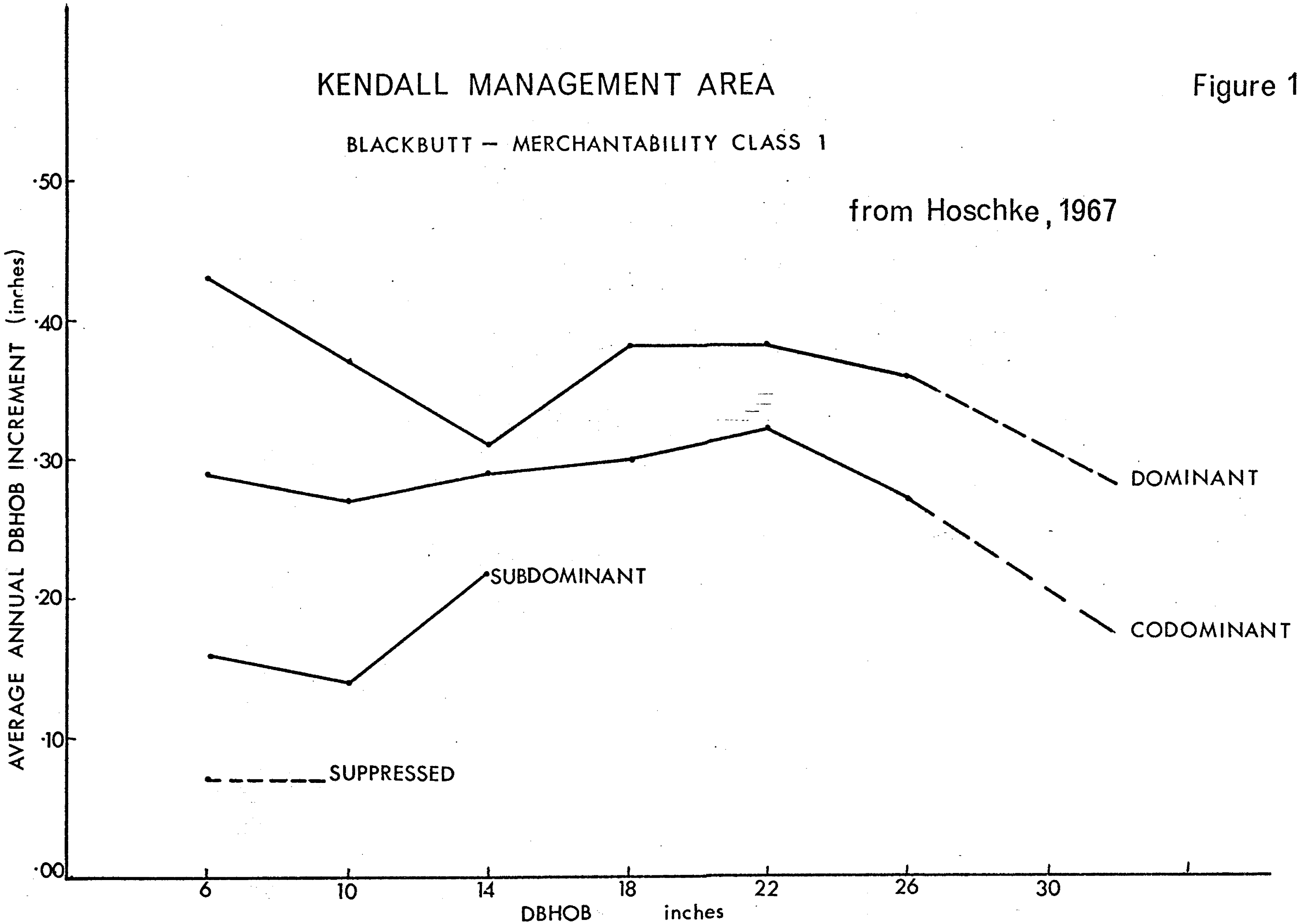
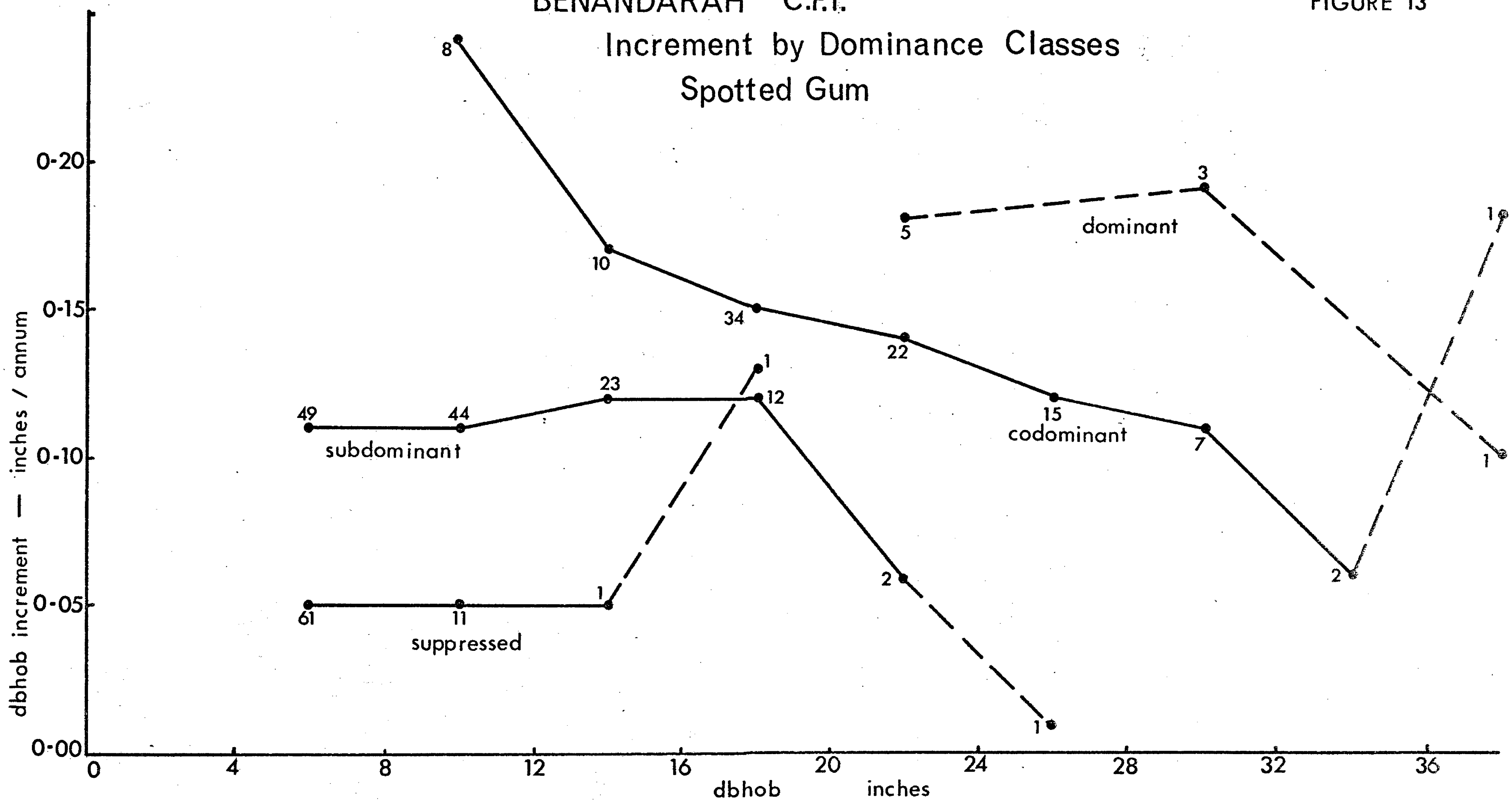

KENDALL MANAGEMENT AREA
BLACKBUTT – MERCHANTABILITY CLASS 1
from Hoschke, 1967
AVERAGE ANNUAL DBHOB INCREMENT (inches)
·00
·10
·20
·30
·40
·50
DBHOB inches
6
10
14
18
22
26
30
DOMINANT
CODOMINANT
SUBDOMINANT
SUPPRESSED

FIGURE 13

BENANDARAH C.F.I.
Increment by Dominance Classes
Spotted Gum



The great differences in growth rates between the dominance classes explains the depressed increments at smaller sizes in the average curves for the species groups as shown in Figure 10. Subdominant and suppressed trees form a prominent component of the inventory sample among trees smaller than 20 inches dbhob. Their low growth rates strongly depress the average for the species at the smaller diameters. In Figures 11 and 12 there appears to be little correlation between dbhob and dbhob increment. In Figure 13 there is some slight suggestion that increment may decrease with increasing diameter, although it may be that the only large trees remaining are the poorer remnants from previous selective logging operations. These findings agree closely with Trimble (1969) for some North American hardwood forest.

It could be argued that, in an irregular forest, dominance alone may be an unreliable parameter of growth since it does not necessarily reflect previous competition. For example, a suppressed tree must become a dominant if all the surrounding competition is removed in the course of logging. Whilst the more tolerant species may be able to recover from suppression and develop rapidly as a dominant when released, the same is probably not true of less tolerant species such as the eucalypts in general. The most intolerant species, particularly flooded gum, will not survive intense suppression and will quickly die. Some of the more tolerant eucalypts can continue to survive under a closed canopy but they appear to lose their capacity to respond to subsequent release. The intensity and duration of suppression needed to produce this effect in different species has not been determined, nor is the exact reason for it fully understood. A considerable period of suppression, however, will usually manifest itself in an unhealthy crown. Some assessment of crown quality may therefore be expected to be a useful measure of past competition even after that competition has been removed and is no longer estimated by dominance. Several permanent inventories in New South Wales have used estimates of crown quality in three arbitrary categories, namely good, fair and poor. Instructions to students engaged in silviculture exercises at the Australian National University have sought to qualify these categories with the following detail:-

1. <u>Good crown</u>

   Well-shaped, vigorous, obviously expanding crown; mainly primary crown; few, if any, dead branches and no mistletoe.

2. <u>Fair crown</u>

   Not a well-shaped, vigorous crown, nor could it be called deformed or badly balanced; mainly primary crown; not vigorous in appearance but crown expansion taking place. Some dead branches or branchlets and a minor incidence of mistletoe may be accepted.

3. <u>Poor crown</u>

   Poor crown shape, deformed or unbalanced; low crown density, non-vigorous; not expanding and apparently incapable of expansion; mainly secondary crown, dead branches common; mistletoe may be present.

Figure 14 shows the separation of average diameter growth rates that was achieved in the application of such a classification to blackbutt in the continuous inventory of the Kendall Management area. Again, average diameter increment appears to be fairly independent of diameter within crown classes. This result resembles the result for dominance alone. A similar result for spotted gum is illustrated in Figure 15, although in this species there is perhaps a slight tendency for increment to decline with increasing diameter.

Figure 14

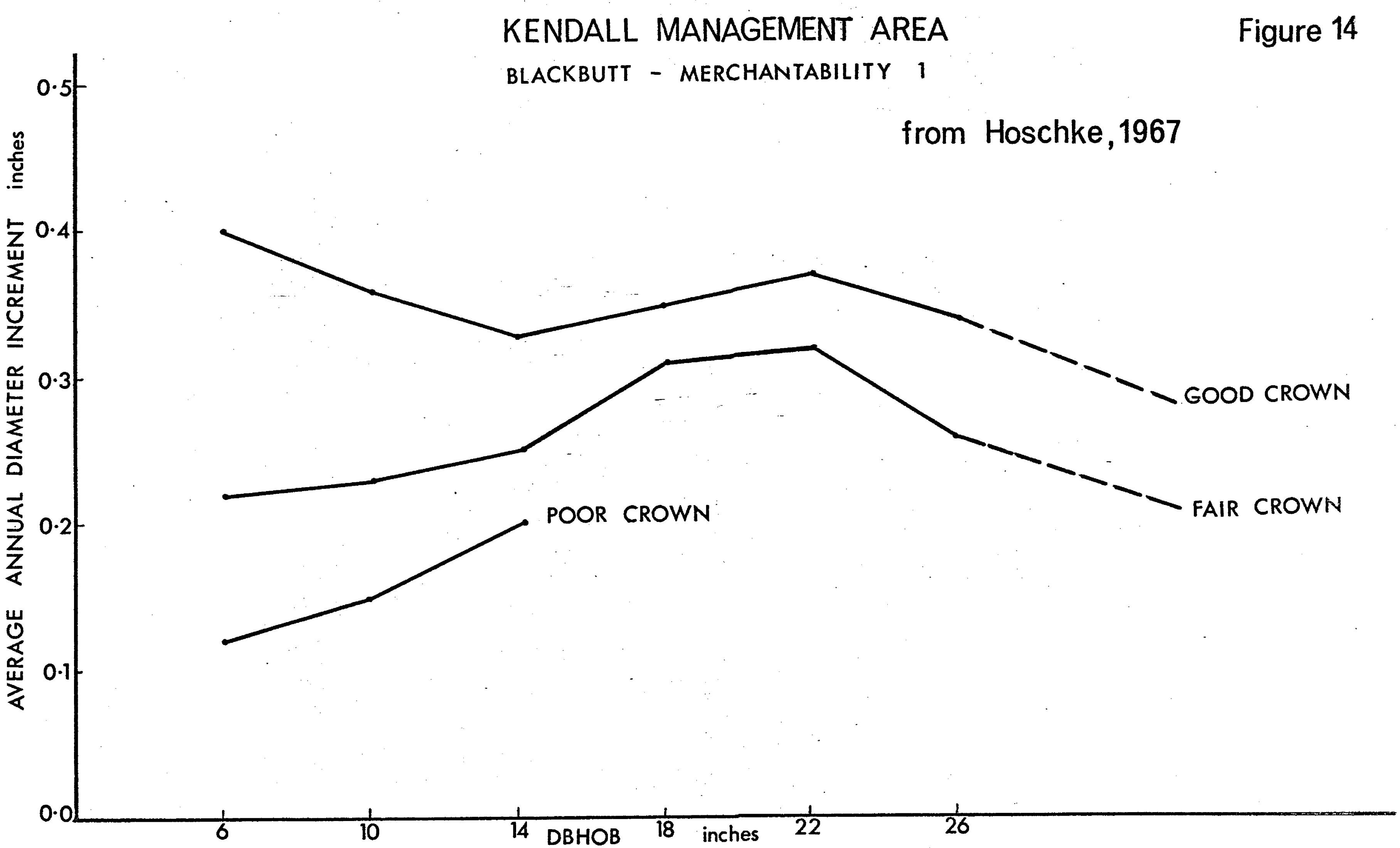

KENDALL MANAGEMENT AREA
BLACKBUTT - MERCHANTABILITY 1
from Hoschke, 1967
AVERAGE ANNUAL DIAMETER INCREMENT inches
0·0
0·1
0·2
0·3
0·4
0·5
6
10
14
18
22
26
DBHOB inches
GOOD CROWN
FAIR CROWN
POOR CROWN

FIGURE 15

BENANDARAH C.F.I.
Increment by Crown Quality Classes
Spotted Gum

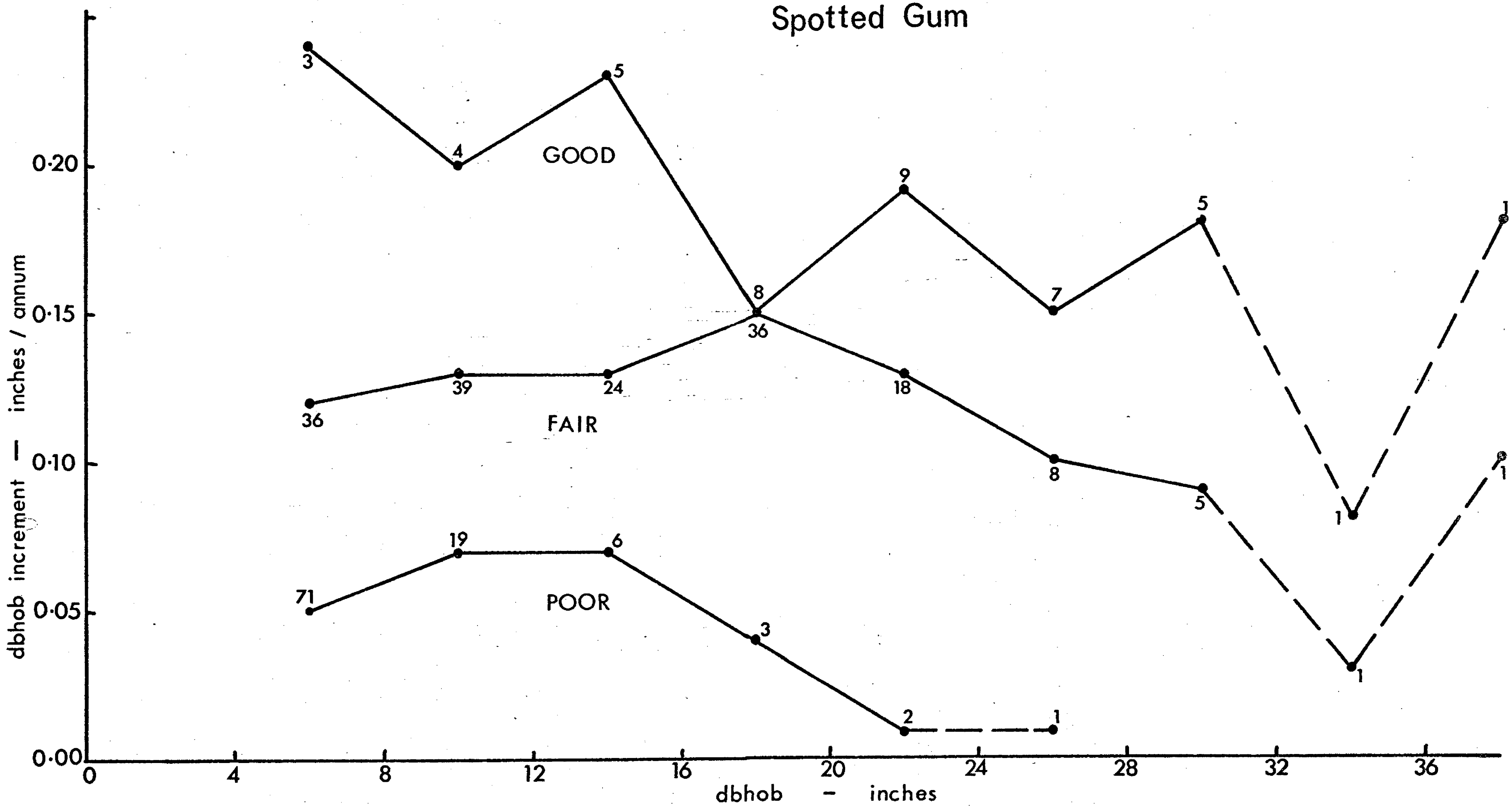
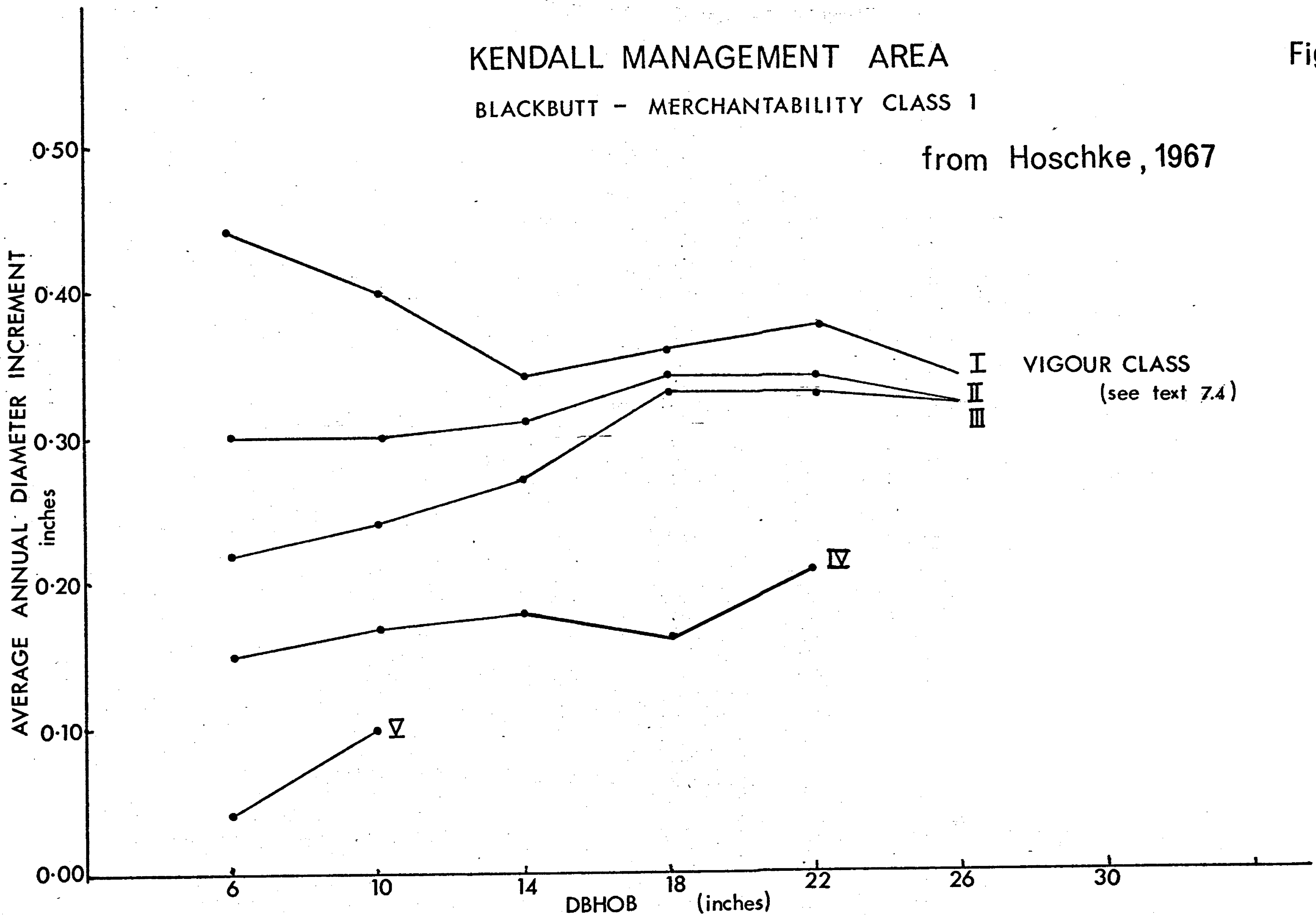


Figure 16


KENDALL MANAGEMENT AREA
BLACKBUTT - MERCHANTABILITY CLASS 1
from Hoschke, 1967
AVERAGE ANNUAL DIAMETER INCREMENT
inches
0·50
0·40
0·30
0·20
0·10
0·00
6
10
14
18
22
26
30
DBHOB (inches)
I
II
III
IV
V
VIGOUR CLASS
(see text 7.4)

The similarity between the separation of growth rates by dominance classes and by crown classes is not surprising, since for those trees whose current dominance reflects their past competition, it would be expected that the dominant and codominant trees would have the most vigorous crowns. As discussed earlier, however, the average increment of dominant trees may be depressed by the inclusion of trees made dominant only by the removal of a dominant overstorey that previously suppressed them. It may well be argued that crown quality alone would be a better parameter of growth than dominance. On the other hand, the apparent quality of a tree crown may receive a somewhat temporary setback from fire, wind or insect damage. Although such a tree would receive a low crown rating in an inventory, if it were a vigorous dominant it would probably be capable of rapid regeneration of the crown and re-establishment of growth.

In the light of the above discussion the approach adopted by Hoschke (1967) in combining dominance and crown assessments seems very reasonable. The Kendall C.F.I., examined by Hoschke, had already been assessed for dominance and crown quality in the manner outlined above; there was therefore no consideration of a single combined assessment at that time. Hoschke derived a vigour rating by combining the individual dominance and crown quality assessments in the following way:

$$\text{Vigour} = \text{Dominance} + \text{Crown} - 1$$

As the dominance rating varied in the range 1 - 4 and the crown quality rating in the range 1 - 3, this gave vigour ratings in the range from 1, for a dominant with good crown, to 6 for a suppressed tree of poor crown. The pattern of average diameter increments within vigour classes for blackbutt at Kendall is given in Figure 16. The separation of average growth rates is in a logical sequence and is most marked at lower diameters. Beyond 18 inches dbhob there is very little separation between the upper three vigour classes. As Figure 12 indicates, very few of the subdominants persist beyond 18 inches dbhob, so that beyond this size only the dominants and codominants are represented. Figure 14 also suggests that in Hoschke's data very few trees of poor crown persisted beyond 18 inches. In the larger sizes, therefore, only the dominants and codominants of good or fair crown are represented, and all of these would be expected to be vigorous. The case of the liberated dominant with poor crown through previous suppression does not occur in the larger sizes.

Figure 16 does serve to indicate the considerable growth advantage in ensuring that sufficient of the intended final crop trees are left adequate growing space to maintain dominance and good crowns. The penalty for suppression and poor crowns is clearly very severe.

The results discussed in this section agree quite closely with those of Trimble (1969) for some North American hardwoods. Trimble, however, was somewhat concerned at the arbitrary nature of the competition ratings and attempted to improve the prediction of growth through more objective crown parameters. The following quote from Trimble's paper is a concise summary of his findings. (His reference to crown class is the same as the dominance class used in the above discussion.)

> When trees were not separated into crown (dominance)* classes, but only into species-site groups, crown diameter and the product of crown-length by crown diameter were significantly correlated with dbhob growth for most species-site combinations. For about half of the combinations, crown length was correlated with dbhob growth. Crown ratio was correlated with growth in none of the combinations. When trees were grouped by crown (dominance*) class within a species-site combination, we found little relationship of any of these crown variables to dbhob growth. For purposes of predicting dbhob growth, these variables add but little to crown (dominance*) class alone.

* author's interpolation.

It is also particularly interesting to note that Trimble (op.cit.) could not obtain satisfactory growth predictions from estimates of competing basal area. Some weak correlations between growth and competing basal area alone were observed but when the trees were sorted into dominance classes no significant correlations of this kind were found. Trimble concluded that, in the heterogeneous stands with which he was working, the arbitrary dominance rating was a much better reflection of competition than basal area. Yet Curtin (1966) is able to show some influence of stand basal area on diameter growth among dominants and codominants at Coopernook. His results are summarized in Figure 17. They do not take crown quality into account and, as discussed earlier, this parameter may also be an efficient predictor of growth in eucalypts. Trimble combined dominance and crown quality assessments to produce vigour classes, as defined in Appendix XII, yet he found that they gave no better results than dominance alone, and were considerably more cumbersome to use.

The clearest fact to emerge from all the above discussion is that the factors determining the growth of individual trees in eucalypt forest are not well understood. Assessment of crown quality and dominance can lead to considerably improved growth predictions for individual trees, but there is still considerable variability about the average relationships observed. Moreover, any relationships observed have been only in restricted areas. A general model for growth prediction will only come with the superimposing of climatic and edaphic factors for different areas. The matter needs considerably more investigation for irregular eucalypt forest.

This section so far has dealt only with diameter growth. Figures 18 and 19 indicate average relationships of merchantable height to diameter, and suggest that, within the range of sawlog sizes, there appears to be no general trend for merchantable height to increase with increasing diameter. The merchantable height for a sawlog appears

Figure 17

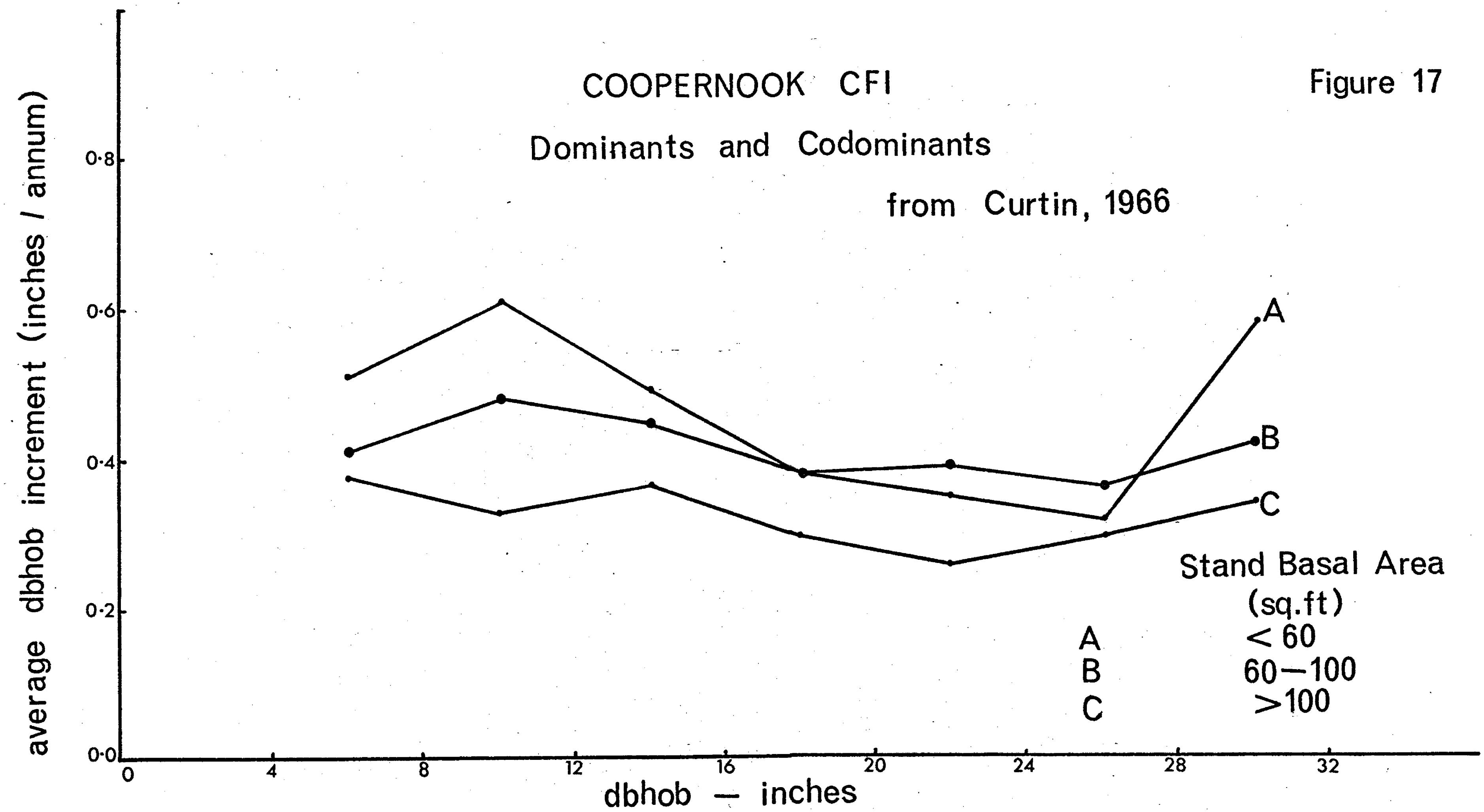

COOPERNOOK CFI
Dominants and Codominants
from Curtin, 1966
average dbhob increment (inches / annum)
0·0
0·2
0·4
0·6
0·8
0
4
8
12
16
20
24
28
32
dbhob — inches
A
B
C
Stand Basal Area
(sq.ft)
A < 60
B 60—100
C >100

FIGURE 18

Pine Creek Ridge Stratum

RELATIONSHIP OF MERCHANTABLE HEIGHT TO DBHOB

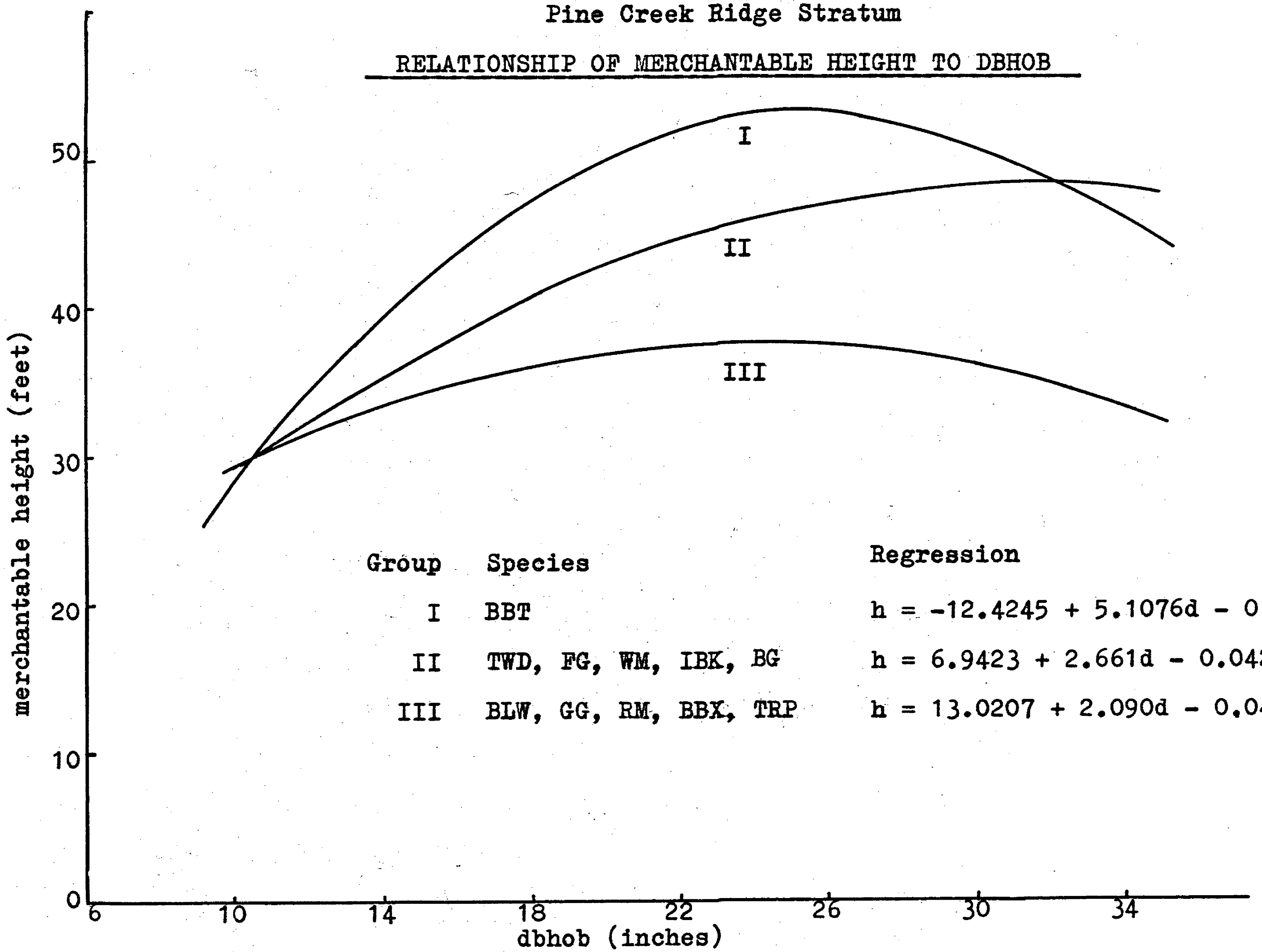
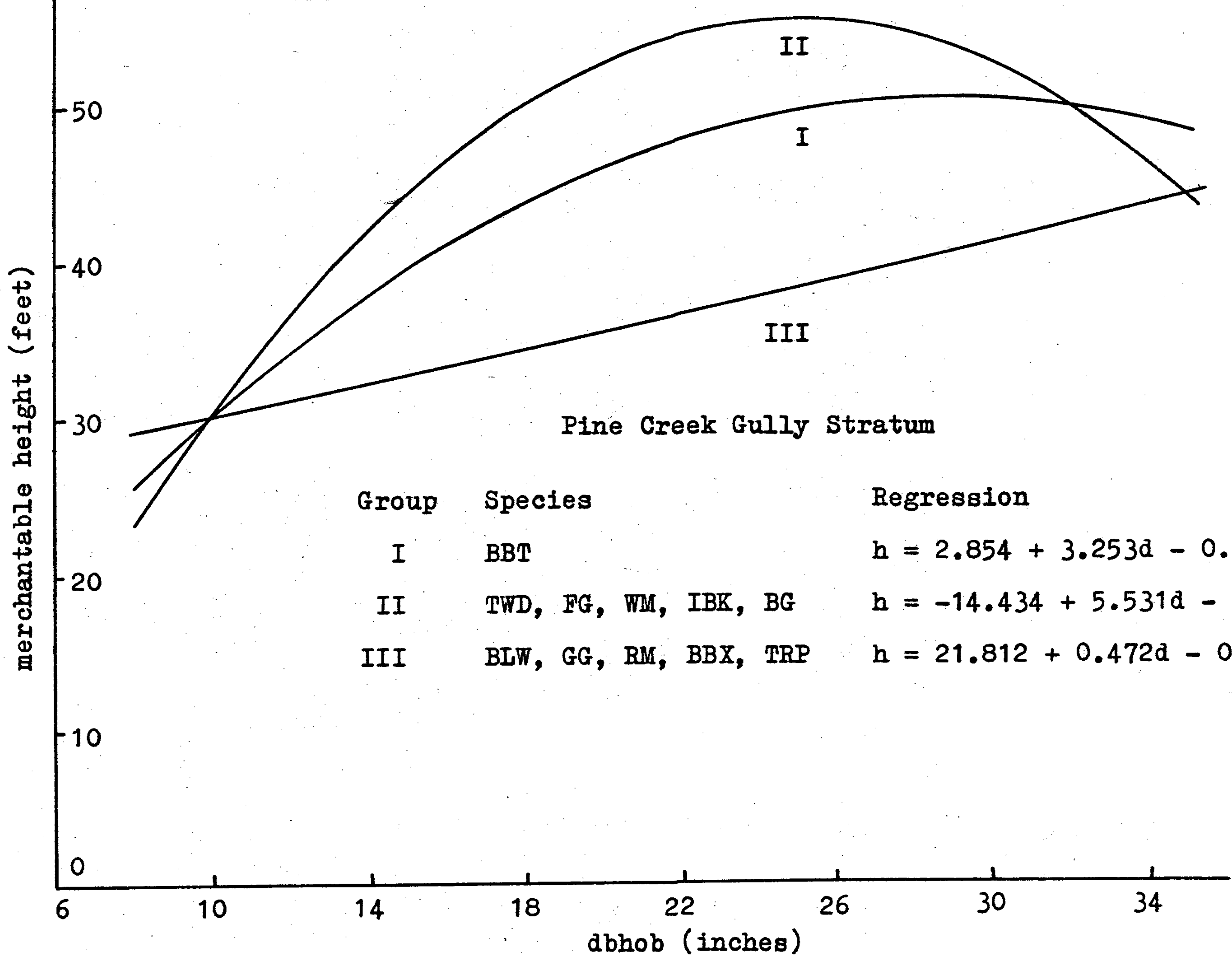


FIGURE 19

RELATIONSHIP OF MERCHANTABLE HEIGHT TO DBHOB



to be fixed to some extent in the sapling or pole stages of development, either by heavy branching in the crown or by the development of some bole defect or defect symptom. Trees may nevertheless continue to increase in total height. The prediction of height growth is therefore not a particularly pressing problem for trees of sawlog size. It may be of considerable importance if intensive pulpwood utilisation in small sizes is contemplated.

As outlined in Section 7.2.4, volume is usually estimated through a regression relating merchantable height and dbhob. If height is assumed constant, the problems of predicting volume increment per tree are effectively those of predicting diameter increment, and these have been discussed in detail above. The problem of predicting defect increment is reserved for discussion in a later chapter.

CHAPTER 8

AVERAGE IRREGULAR FOREST AND THE REVERSE-J DISTRIBUTION

Even-aged stands, as they are defined in a silvicultural sense by Smith (1962), are characterised by being fairly uniform in respect to age, tree size, species composition etc. In general, the 'stands' which are assessed in management inventories of irregular eucalypt forest do not comply with these descriptions. They are simply sampling plots defined on a purely arbitrary basis in the field. True stands in the silvicultural sense exist in the irregular forest as small, even-aged regeneration groups but these are not easily defined, particularly as they grow older, and are too small and too numerous to be mapped and assessed individually. A sample plot may incorporate parts of several different stands and may thus take on quite a complex structure. In these circumstances fairly simple averages, such as mean number of trees per acre or mean tree diameter, on their own are not likely to provide consistent descriptions of stand condition or to be reliable parameters of growth and yield. This problem is discussed further in Section 10.2.3.

Despite this complexity of structure in the irregular forest, some attempts have been made to describe the average condition of whole irregular forests in terms of fairly simple numerical distributions. The most important of early exponents of this approach was de Liocourt (1898) who observed that in well-managed irregular forests the ratio of numbers of trees in successive diameter classes was nearly constant. A distribution with this property fits the general form of an exponential curve:-

$$y = kb^{-x}$$

If N_1 is the number of trees in a given diameter class and N_2 is the number in the class of next larger diameter, then:

$$q = N_1 / N_2$$

where q is termed the de Liocourt quotient. Sammi (1961) transforms the general form of the relationship to provide a more suitable expression for the forest situation, as follows:

$$N = kq^{-\frac{D}{i}}$$

where:

D = the mid-diameter of a diameter class

N = the number of trees in the class

i = the diameter class interval

q = the de Liocourt quotient

k = the regression constant

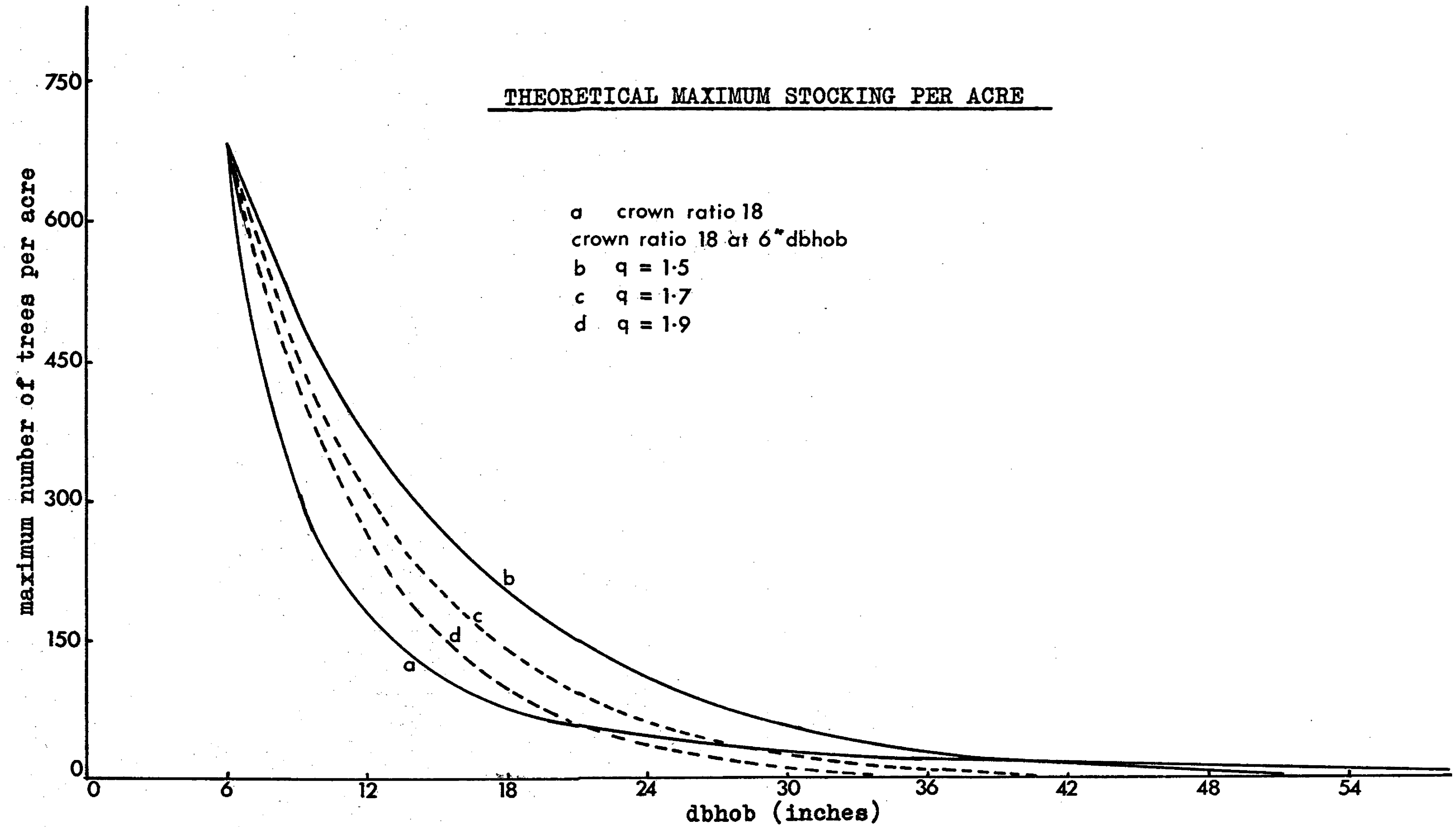
Leak (1965) makes a detailed mathematical study of the probalistic properties of the reverse-J distribution but makes little attempt to consider any management applications it may have.

Before moving on to consider the possible management implications of the distribution it is worth considering the way in which such a theoretical distribution could arise in reality. It is easiest first to consider a greatly simplied example involving even-aged stands. Suppose the forest were being managed to provide a constant annual yield by felling only the oldest stand. To maintain a constant annual yield every age class would have to be equally represented in stand area on equal sites. For this example, suppose that not only is diameter growth constant over the whole life of the tree but that diameter growth is the same for every tree. Each of the age classes would then represent a diameter class with zero deviation about the mid diameter. The various diameter classes would occupy equal areas of forest. If crown ratio were also assumed to be constant, it would be possible to calculate the crown area for a tree of any given diameter. By dividing the area occupied by each diameter class by the crown area per tree it would be possible to calculate a theoretical maximum stocking for each diameter class, assuming a complete canopy cover and only one level of canopy.

Table 19 and Figure 40 show the theoretical maximum stocking per acre calculated in this way for nine diameters and using a constant crown ratio of 18. For example, a tree of 6 inches dbhob has a crown area of 63.6 sq.ft, giving a theoretical maximum stocking of 684.7 trees per acre. The frequency distribution generated in this way resembles the de Liocourt distribution but q is not constant and in fact decreases with increasing diameter. Table 19 and Figure 40 also show a theoretical de Liocourt or reverse-J distribution using a constant q-value of 1.5 and a crown ratio of 18 at 6 inches dbhob only. To achieve this distribution crown ratio first decreases from 18 at 6 inches dbhob to 11 at 20 inches dbhob, rising again to 14.4 at 38 inches. It should perhaps be noted here that the range in crown ratio from 11 to 18 is probably close to the normal range for eucalypts under forest conditions. A crown ratio of 18 would be found mostly in younger more vigorous trees. A crown ratio as low as 11 would usually reflect some element of past or present suppression. It is now necessary to examine the relationship between the above highly theoretical example and the realities of actual forest growth. To begin with, not all the trees in a stand maintain the same diameter growth rate and for any age class there will always be a spread of frequencies around the mean diameter. Early in the life of the stand the distribution of frequencies about the mean may be nearly normal but in general, as stands age, the distribution becomes more skewed. Some trees assert themselves as dominants and codominants and may grow on at a fairly constant diameter growth rate, perhaps maintaining a high crown ratio. Other trees gradually succumb to competition and undergo a slow process of suppression. Even the relatively intolerant eucalypts do not die immediately but linger on, growing slowly and probably maintaining a low crown ratio. The frequency distribution for each age class so becomes attenuated towards the smaller sizes. Thus for the special case of an even-aged forest, with all age classes represented equally on an area basis, it would be possible for the theoretical reverse-J distribution to develop whilst

FIGURE 40

THEORETICAL MAXIMUM STOCKING PER ACRE



maintaining the theoretical maximum stocking. The frequency of dominants and codominants may decrease more or less according to the theoretical distribution for a constant crown ratio. The additional trees needed to keep a constant q-value at the smaller sizes could be fitted into the stand partly through having low crown ratios but more particularly because many of them would be occupying crown space below the level of the dominants and codominants.

It may be argued that even in the best managed forests trees are not usually packed together in such a way that all the possible canopy space is fully occupied. This need not mean that a different type of distribution would eventuate. It may simply mean that the reverse-J pattern of distribution would be repeated but at lower frequencies than those postulated for the theoretical maximum stocking. Whilst the reasoning applied in the above line of argument is not complete in considering every possible influence on stand structure, it nevertheless seems to the author to be a reasonable approach to the consideration of decrease in stocking with increasing diameter. It should be particularly noted that to this point the argument has only been applied to the <u>average</u> stocking of a well ordered forest made up of even-aged stands. If an objectively selected sample of plots were established in such a forest, the average estimate of stocking distribution should be of the reverse-J form, even though each of the plots should reflect the skewed normal distribution of the stand into which it fell.

It has therefore been suggested by this argument that a reverse-J distribution does not <u>per se</u> imply an irregular forest. The question now is: does such a distribution ever apply to an irregular forest? If equal areas of selection forest are logged each year to provide regeneration openings, the effect should be the same as establishing equal areas of even-aged forest each year, except that in the irregular forest the age classes would not form contiguous blocks of equal area. The actual frequency distribution by diameter classes should still be reverse-J and this should be reflected in the average of a number of sample plots. The stocking of the individual plots, however, could be expected to be much more variable than in the even-aged forest, depending on how many parts of small even-aged groups were represented in each sample plot.

In contrast, the occurrence of an average distribution that does not strictly comply with the standard reverse-J does not necessarily imply any particular type of structure. It may suggest that the distribution of age classes is not particularly well balanced. For example, one would expect an abundance of small trees after a period of particularly heavy logging had created a disproportionately large area of regeneration openings. As the regeneration aged it would cause a 'hump' to flow on through the frequency distribution, with some other sizes being correspondingly less well represented. This pattern of development would occur whether the logging had been a broad scale clear felling or a heavy selective logging.

Furthermore, Carron (unpublished MSS) is able to show that the existance of a reverse-J distribution does not necessarily imply a balanced distribution of age classes. He shows that the average stocking of inventory plots in Wombat Forest in Victoria is reverse-J, even though the forest is essentially two-aged.

In considering the implications of the reverse-J or exponential distribution for management, the most important thing to realise is that if such a distribution is found only by averaging the stocking in a number of plots and is not repeated through most of the plots, it may have little or no silvicultural or management significance. If the harvest is only to be obtained from sawlog trees, with no intermediate yields, the most important aim must be to ensure that those trees which are going to grow on to saleable size are given the maximum opportunity for growth at all times. Since only a small number of such trees will constitute maximum stocking at large sizes, only a small number of vigorous dominants and codominants are required at small sizes. Silvicultural treatment for regeneration and promotion of growth of additional trees is useful only in supplying some reserve for natural mortality and in providing conditions conducive to the development of good stem form. Over the whole forest the distribution of dominants and codominants essential to the maintenance of a continuing yield in large sizes may still be of the reverse-J form but with a de Liocourt quotient only a little greater than 1. The fact that the average stocking for the rest of the forest is also a reverse-J distribution, but with a higher value of q, is almost inconsequential as far as the maintenance of the sawlog yield is concerned. There is no great economic advantage in maintaining maximum stocking in all sizes in this situation. In the individual even-aged groups or stands which constitute the irregular forest silvicultural treatment will involve the manipulation of skewed normal distributions to ensure the rapid growth of some of the more vigorous trees.

Methods for attempting to predict growth and yield using average forest diameter class distributions are discussed further in Section 10.2.2.

TABLE 19

THEORETICAL DISTRIBUTION OF MAXIMUM NUMBER OF TREES PER ACRE

A. Maximum stocking with crown ratio of 18 at all sizes.

B. Maximum stocking with crown ratio of 18 at 6 inches dbhob and de Liocourt quotient 1.5.

	A			B		
dbhob	stocking no./acre	crown ratio	q	stocking no./acre	crown ratio	q
6	684.7	18		684.7	18.0	
10	246.5	18	2.78	456.5	13.2	1.5
14	125.7	18	1.96	304.3	11.6	1.5
18	76.1	18	1.65	202.9	11.0	1.5
22	50.9	18	1.50	135.3	11.0	1.5
26	36.5	18	1.39	90.2	11.5	1.5
30	27.4	18	1.33	60.1	12.2	1.5
34	21.3	18	1.29	40.1	13.1	1.5
38	17.1	18	1.25	26.7	14.4	1.5

CHAPTER 9

EFFICIENT DATA PROCESSING

9.1 General

The management of large forest areas for commercial production, whether under public or private ownership, involves the ordering of activities within a complex business structure. Inventory forms only one part of the information system which provides a necessary backing for efficient management. The periodic process of taking stock in the field is usually supplemented by other information sources such as compartment history sheets, yield records and costing records. Very little of the information is of immediate use at the time it is collected and in the form it is collected; much more commonly, numerous small items of information must be collated and processed in order to provide secondary information to influence decision making.

In general, there are three principal facets of an information system, namely:

(a) Information recording

(b) Information storage

(c) Information processing to give secondary results.

These three processes are interactive and the requirements and limitations for any one of them will undoubtedly affect the others.

Ten years ago it may have been necessary in a thesis such as this to advocate a rapid conversion to electronic data processing for forest inventories. But it is now clearly recognised that computers are of immense value in this role and their use is already well-established. What is not apparently as clear to many is that without a proper planning of the integration of the computer in the inventory system considerable efficiency may be lost.

The influence of the design for data handling in the computer should flow right back to the measurement of the trees in the field. Dargavel (1969) sums up a critical examination of inventory procedures for A.P.M. Forests Ltd by saying that 'it has become increasingly apparent that the task is not merely to automate the present methods but that it is necessary to redesign every method, form and record'.

9.2 Information recording

Before any information is collected in the field there must be agreement on the items to be assessed. Although required levels of reliability may vary from one job to another, depending on the particular objectives of management, nevertheless there can be considerable similarity in the general types of information required. This similarity should lead naturally to standardised approaches to data processing and, in turn, to standardised formats for data recording. There are considerable gains to be made from such standardisation, from the training of assessment parties, through the provision of stationery for recording results to the compatibility of the data format with standard data processing computer programs. The latter feature is particularly important, since the development of special processing programs for single inventory jobs can add very considerably to costs.

Since almost all data is likely to be processed by computer, the planning for data recording must give close attention to the mode of data input to the computer. The most common form of primary input for large volumes of data is by card reader, even though the card images may be transferred to magnetic tape or disk for later processing. The use of paper tape punches or even direct entry from a keyboard are generally too cumbersome for the volumes of data recorded in a forest inventory. Preparation of computer punch-cards can be a time-consuming and costly part of the total data processing operation. Moreover, despite the standard practice of verifying cards after punching, errors can still occur in the transcription. For speed and accuracy it is therefore essential that the original data sheets be clear, unambiguous and in a form which lends itself to easy punching direct from the sheets. Additional costs and risk of mistakes in transcribing from field sheets to card code forms should be avoided if possible. This is probably best achieved by properly laid out information formats on field sheets made of material durable enough to withstand the wet and rough conditions often encountered in inventories of sclerophyll forest. One possible means of overcoming the problem is to record the information directly to computer cards, either by means of a portable card punch or by using pre-punched cards. Whilst the author has no direct experience of either technique he has gained the impression that neither has ever proved particularly effective in difficult conditions. A second approach would be to record data on a portable tape-recorder for later use in a 'dictaphone' set at the time of card-punching. Again, the author has not had an opportunity to test this approach, but feels that it is probably deserving of greater attention in the future.

For permanent sampling units it is also worth considering the part that information from previous measurements should play at the new remeasurement. Obviously the assessment party must carry some record of previous assessments in order to be able to relocate the plot and the trees correctly. The author recommends that the operator recording the data be also given a full list of previous measurements so that in the field he can check for obvious mistakes at a time when they can be conveniently corrected. Such listings may be simply produced as part of the routine data processing in the computer. If the co-ordinates of tree positions have been recorded on the computer cards it may also be economical to use a graph-plotter attached to a computer to prepare up to date copies of tree location diagrams. Although it is suggested that the recorder be given a copy of previous information, it is strongly recommended that the operators performing the assessment only be informed of a previous measurement if the recorder detects an apparent mistake. Without this precaution the current assessment could be strongly biased by previous observations, particularly wherever the assessments must be subjective.

9.3 Information storage

Prior to the use of electronic computers all information was stored on paper, often in a fairly bulky form. The preparation of copies for security and other reasons could be extremely slow. In general, information retrieval was slow and cumbersome. Computers provide several new media for data storage. Of these the most compact and the most efficient for computing are the magnetic tapes and disks. For example, the data for several remeasurements of more than 5000 trees in the Pine Creek Periodic Management Inventory fits conveniently on 600 feet of magnetic tape whose purchase cost was less than $15. Eighty information characters, equivalent to one standard computer card, are stored for each tree. Computers in general service are capable of retrieving information from such magnetic storage at the rate of 96,000 characters per second. Another more tangible, but somewhat less efficient, means of storage is on 80-column computer cards. Card readers in general service scan these at a rate of 1000 cards per minute, equivalent to a data input rate of 1333 characters per second.

Both computer cards and magnetic tapes are easily duplicated. It is strongly recommended that such duplication be performed as soon as possible in the course of data processing in order to provide the security of duplicate documents stored in separate locations. When consideration is made of the cost of field work, the cost of data preparation for computer input and of the cost of any subsequent processing, the record of information becomes an extremely valuable document, too valuable indeed to run the risk of any loss or damage to a sole master copy.

In addition to the above compact forms of storage for computer processing, it is also desirable to produce printed listings of raw input data for later 'manual' reference when needed. Once the basic data has been fully transcribed to a computing medium and has been thoroughly checked it is probably better that printed listings replace the field sheets. In general they are more compact, easier to file and perhaps a little easier to follow since they involve no handwritten entries.

At this stage it is particularly important to note that, although compactness, brevity and uniformity are desirable features for information records, they should not be achieved at the expense of maintaining a proper explanation of the meaning of each item of information. With the advent of computer processing this has become particularly important since many descriptive items are converted to numerical codes for ease of processing. Yet the author has often observed computer printed output on which the figures were virtually meaningless to all but the computer programmer because of insufficient documentation. This is particularly important for forest records which must often be kept for long periods of time. It is probably not desirable to clutter card records or magnetic storage with this type of information but it is essential that it be clearly included in printed results. Proper documentation may slightly increase printing costs and storage costs, but these will be surely offset by more efficient later useage.

9.4 Data processing programs

With ever increasing capability in new computers, and with the rapidly increasing availability of computing installations, the relative cost of actual machine-time for a given size of job is decreasing. The computer time required can also be minimised by good programming practices. Several aspects of program design are worthy of particular consideration.

First there is the need for standardisation. The development of individual programs for individual jobs can be costly in terms of the man-hours required for programming and in punching the program deck and in terms of the machine time needed for compilation and testing. But it is perhaps even more important to consider the usefulness of standardisation in the printed results. Conformity of output facilitates relevant comparisons with other inventory results or with results from other remeasurements of the same inventory. This is particularly important since the inventory for one forest area is likely to form only part of a much larger information system involving other inventories and other forms of data collection. Moreover standardisation of processing programs facilitates standardisation of data input thus reducing costs in recording and storage (Section 9.2).

The standardisation of processing programs, however, requires careful design to achieve the flexibility to handle a limited degree of variation in the input data. For example, the production of summaries of information for each inventory plot may be a standard procedure for all inventories but between inventories there will probably be variations in plot size, number of trees per plot, species encountered and so on. The design of the program should be such that the particular variations for any one inventory can be defined in the data input. This is clearly a more satisfactory approach than making minor modifications for each run. The input definitions of data variations are a virtual necessity. What is often overlooked, however, is the need to display these variations clearly in the printed output so that anyone using the results is never in any doubt of their meaning. In large part definitions of species, plot sizes and similar features can be displayed as headings in printed tables but it is also strongly suggested that opportunity be given to provide data for a short explanatory document to be printed before the results. Explanations of volume tables, merchantability codes and other features could be provided in an alphabetic card deck and listed in this document. It could be argued that such explanations can always be typed manually when the results are incorporated in a management plan or some other report, but it is the author's experience that such explanations are seldom stored with the computer output and that in these circumstances it can be difficult to check back on the true meaning of results. Again, it could be argued that the printing of various explanations in the computer output will increase computing time. Yet, with standard programs, actual computing time is unlikely to exceed 30 minutes, which would cost about $100. This cost will be relatively insignificant when compared to the costs of measuring in the field, preparing the data for input and later interpreting the results.

The preceding discussion has stressed the importance of standardisation yet argued the need for some flexibility in the procedure for data input. From time to time it will also be necessary to be able to add to or to vary the standard summaries produced, either because of some peculiarities in the information requirement or perhaps for research purposes. Because of the great time and cost involved in measuring and processing forest inventory data, much of the inventory research, as in this project, must be performed with data collected in the course of routine inventories. To facilitate special alterations, the basic program should be of carefully planned modular design, with the modules, or subroutines, being as self-contained as possible in order to permit variations or deletions with minimum disturbance to other routines. With proper program design and clear documentation of structure it should be possible to achieve considerable flexibility while adhering to the concept of one general program for a number of inventory jobs.

CHAPTER 10

APPLICATIONS OF INVENTORY DATA

10.1 Introduction

Preceding chapters of this thesis have discussed various techniques used in forest management inventory and have, in passing, alluded to various applications of the information obtained. The management of large forest areas for commercial production, like other large commercial enterprises, requires a continuing flow of information from numerous sources if proper control is to be maintained. This information finds four principal types of application:-

(a) Reviewing past performance with a view to improvement.
(b) Regulating current operations.
(c) Providing basic data for product promotion.
(d) Planning for future development.

Whilst inventory can perhaps provide information for all four types of application simultaneously, design requirements for maximum efficiency in providing each type of information will differ considerably. It is therefore instructive to consider the way in which inventory information is most likely to be used, since the only real test of a particular procedure is a measure of the utility of the results for the cost expended.

Most usually, past management inventories of irregular eucalypt forest have been applied principally to providing information for the determination of 'allowable cut'. The rate of harvesting in forests is usually delineated either by the area to be logged per annum or by the volume to the cut per annum. Because of the variability of irregular eucalypt forest it is more common to restrict the volume to be cut, although some secondary area restriction may also be applied. Management plans have often specified that the principal objective in managing a forest shall be 'to achieve maximum sustained yield in perpetuity'. The maximum allowable cut has therefore been set equal to the estimate of current volume growth in the forest, in the expectation that this level of cut would not deplete the growing stock. If a subsequent inventory revealed a greater or lesser growth under such a cut, adjustment to the allowable cut would be made accordingly. Seldom have management plans contained estimates of the probable maximum yield under varying strategies.

Obtaining timber yields, however, is only one possible sphere of interest in the forest. Section 2.4 considered several other uses. But even within the realm of timber production there are more possible goals than simply maintaining present levels of volume production in perpetuity. The technique of Linear Programming provides a useful framework of logic for management planning. A linear programming model requires the specification of a single objective to be optimised. Various management factors are then expressed as mathematical constraints on the attainment of this objective so that the solution found will be acceptable to management. Linear programming, however, is conceived basically for a static system, whilst forest management objectives always involve a time element in a dynamic system. Possible objectives for forest management would be to maximise total volume yield over a fixed planning period, to maximise sawlog yield, to maximise total revenue, to maximise nett revenue or to maximise the present nett worth of the forest at the end of a fixed planning period. The means of attaining these objectives could be restricted by the application of constraints such as restriction of annual expenditure and of minimum annual yields.

To apply a linear programming technique it would be necessary to reduce the benefits of all the many strategies available through time back to some common time. The selection of an optimum strategy occurs only at the common time base. Even when only a limited number of strategies may be adopted each year the permutations of all possible strategies through time will be very great since there is no process of eliminating sub-optimal strategies each year. It appears that the data matrices generated will be beyond the capacity of linear programming models for conventional computers. A technique known as dynamic programming is being developed by systems analysts for optimising through time but as yet it appears that this kind of approach also will lead to prohibitive amounts of computing for the numerous strategies and time intervals of real problems.

But even if the forest manager cannot yet be provided with complete mathematical approaches to the optimisation of management strategies, he still requires good information on the volume and financial yields he can expect under the different strategies he may select subjectively. In any one year, the possible strategies are likely to be constrained by limitations of volume and value yields. The opportunities to vary management strategies will lie in the prescription of an order of working and of the trees to be cut. From year to year, the value of different strategies will depend on subsequent growth.

Ideally, therefore, management inventory will provide sufficient information for the prediction of growth and of yield for various orders of working with various types of tree to be cut. Predicted growth will govern the planning for future development, yield information is essential to the regulation of current operations and for effective product promotion, and periodic inventory will be necessary to maintain a continuing check on past performance and the reliability of predictions.

10.2 Growth projection and allowable cut

For effective management, predictions of future yield should involve three principal components:-

(a) The quantity of the yield.
(b) The nature of the yield.
(c) The location of the yield.

This section is concerned primarily with the first of these components, with somewhat less reference to the second. The third aspect is dealt with in a later section.

Without a detailed knowledge of every one of the thousands of forces that must act on tree growth and forest growth, the prediction of growth must remain somewhat empirical. Future growth must be predicted from observations of past growth. Because these observations must usually be made on only a sample of the forest, the reliability of the growth prediction depends partly on whether the sample observed is representative of the population as a whole. It is also particularly important to remember that the reliability of growth predictions from past observations will depend on the degree to which it has been possible to observe growth under the conditions likely to obtain in the future.

The actual growth of the commercial wood quantity in the forest takes place in individual trees but for many purposes it is useful to consider the growth of groups of trees in stands. The following four types of observation have at times been used to predict future growth:-

(a) The past average growth of a number of plots without regard to factors associated with differences between the plots.
(b) The average growth of the forest obtained as the sum of the growth predictions for arbitrary components of an 'average stand'. The predictions are based on the mean of observations of past growth for the same components in a number of plots.

(c) The average growth of the forest obtained as the sum of the growth on individual plots projected by regressions based on stand variables.

(d) The average growth of the forest obtained as the sum of the growth predictions for individual trees within plots using regressions based on tree variables.

Each of these approaches to growth prediction will differ in the flexibility allowed for yield prediction. In some cases reliable growth and yield estimates will only be provided when allowable cut is set equal to current growth and the management of the forest is not varied. Other methods do permit the prediction of growth even when allowable cut and techniques of management are varied to some extent. Only the latter group of methods provide information needed for optimising future management.

10.2.1 Average total growth

Three basic sampling techniques for the estimation of average total growth were illustrated in Chapter 5. These were:-

(a) Sampling with temporary units (Section 5.2)

(b) Sampling with permanent units (Section 5.3)

(c) Sampling with partial replacement (Section 5.4)

It was argued that the precision of the growth estimate would be much greater when using permanent plots but that the cost for a given level of precision in the estimate of stocking at each occasion would probably be greater for permanent plots than for temporary plots. In favour of the use of permanent plots was the opportunity to check measurement bias, control mistakes and possibly to use the plots for monitoring silvicultural treatment, but against this was the possibility that the sample of permanent plots would become biased through receiving preferential treatment in routine forest operations.

Sampling with partial replacement of units was suggested as a possible compromise of all these factors.

The arguments listed briefly above deal principally with the compromise between cost and statistical reliability but do not consider the utility of the results as a prediction of future growth for the regulation of yield. In attempting to sustain a future yield at the level of past average growth the argument is that past growth will equal future growth, which further implies that past conditions of stocking, weather, and treatment will be the same in the near future as they were in the immediate past. Clearly it can only be realistic to make these assumptions for the short-term future but even then they merit careful consideration.

In the first place, the difference between stocking assessments on successive occasions will depend directly on the level of cutting carried out during the period of observation. To some extent this problem is corrected by working with estimates of gross growth rather than with nett increase. Gross growth and nett increase in volume are defined by the following expressions:-

$$\text{Nett increase} = V_2 - V_1$$

$$\text{Gross growth} = V_2 - V_1 - I + R$$

where:

V_1 is the stand volume at the first measurement.

V_2 is the stand volume at the second measurement.

I is the volume of ingrowth during the period.

R is the volume removed during the period.

When the plots are permanent, ingrowth and removals can be estimated as part of the inventory sample. If the sampling units are temporary, ingrowth and removals must be estimated from records other than those of the sample observations and their applicability to the sample estimate is less certain.

Apart from the direct effect of cutting and ingrowth in the calculation of the growth estimate, the intensity of cutting and the manner of cutting, both in harvesting and silvicultural treatment, will have an effect on the actual growth of the trees in the field. As a general example, overcutting will lead to understocking, generally with a reduction in total stand growth although the growth of individual trees may be stimulated. Moreover, if the cutting takes place only in the vigorous trees then stand increments should also be depressed.

Not only will the manner of cutting affect the total growth, but the effect may be unequal through various components of the stand. The removal of unmerchantable trees during silvicultural treatment should make way for greater development of the merchantable fraction of the stand. Berklund (1960) attempts to detail the growth estimate by observing the following thirteen tree-status classes:

1. Sound trees can remain the same.
2. " " " be cut and used.
3. " " " be cut and left.
4. " " " become natural mortality.
5. " " " become cull.
6. " " " grow into sawlog size.
7. Cull trees can remain the same.
8. " " " become sound trees.
9. " " " be cut and partially used.
10. " " " be cut and left.
11. " " " become natural mortality.
12. New sound trees can grow into size (ingrowth).
13. New cull trees can grow into size (ingrowth).

But the expressions of growth that Berklund derives, despite the detail of their allocation of growth into the above groups, still only reflect the probable future growth if conditions remain constant. No attempt is made to include factors which could predict the likely growth of the various components if conditions were to change.

The value of yield predictions based on average total growth lies principally in fixing a total permissible yield which could, in certain circumstances, maintain the present level of production. This is the basis of the much revered 'Sustained Yield Concept', which aims at the sustaining of the present level of production of an area in perpetuity. The implied assumption is that present production is optimum regardless of whether it is at a maximum or whether value production is at either a maximum or an optimum. From earlier discussion, (Section 2.3.3, 2.3.4 and 2.5), such an assumption would appear to be generally untrue in the irregular eucalypt forests, particularly in areas containing a large proportion of the more tolerant species and in areas where the market is mostly confined to sawlog sales. Florence and Phillis (1971) suggest that, in mixed species eucalypt forest, only a fairly intensive logging and treatment is likely to lead to any great increases in commercial productivity. If such a radical treatment were to be applied the yield obtained in the course of logging in the short-term future would probably be unrelated to the current average growth of the existing stand. Moreover as the treatment began to take effect the longer-term commercial production would be expected to increase. However, if logging and silvicultural treatment were confined to the present standards, whether conservative or favouring a more intensive cut, it is possible that the current level of yield could be sustained at the level of the immediate past growth.

But even if the previous growth does reflect the possible future total growth, the information is of little value to the forest manager in regulating field operations to obtain the yield. Neither does he know where to obtain the yield, so that he can establish an order of working, nor does he know which trees to cut, in order to define a tree-marking schedule. Not only are these prescriptions useful for administrative purposes but they are also likely to have a profound effect on the level of growth that will be achieved. The necessary information for their formulation must either be derived from other sources or from a more detailed examination of the inventory sample. If it is possible to consider the inventory sample in greater detail, it should also be possible to examine past growth and predict future growth in greater detail.

10.2.2 Projection of components of an average stand

10.2.2.1 General

Selection logging is essential to the maintenance of an irregular forest structure. In the course of selection logging the harvesting operations move systematically through the forest leaving behind a range of size classes and, hopefully, conditions suitable for the regeneration of new trees in the place of those just removed. The achievement of satisfactory regeneration is often promoted by post-logging silvicultural treatment. In time, all of the forest will be logged in this way and it will be necessary to return to areas previously logged. The time taken to complete one systematic cut of the forest in this way is termed a cutting-cycle.

In an attempt to rationalise the calculation of the yield obtained under this cyclic system of harvesting a method of yield calculation called 'cutting cycle analysis' has been developed. The exact origin of the method applied in Australia is uncertain and, in fact, the only major reference to it in the literature is the discussion of cutting cycle analysis in the prescription of yield from previously unmanaged forests given by McGrath and Carron (1966). Their discussion, however, does not deal in full with all the implications of the assumptions inherent in the method. My interest in the approach was aroused by the fact that cutting cycle analysis is used for yield calculation for irregular eucalypt forests in Queensland and New South Wales. Moreover, when I was called upon to brief a computing research officer on the details of the method so that he could write a computer program (subsequently named FORTIM) to handle the calculations for the Forestry Commission of New South Wales, I was forced to consider the method very carefully. Later I modified the approach somewhat to write my own program, (called CUTAN) which will be discussed later.

There are five basic assumptions that reflect the limitations of the method as applied in Australia. The first is that the progress of selective logging is strictly cyclic. The order in which the compartments are worked in the first cycle will be repeated exactly in the second and subsequent cycles. The second assumption is that the composition, stocking and structure of the forest are uniform throughout. If the current stocking of the forest is represented by a stand table, being a table of the number of trees in the various diameter classes, this table is assumed to represent the standard structure of the forest. In passing, it may be remarked that such a stand table would usually be drawn up by averaging the stockings of a number of plots, none of which need have a stocking even approximating that of the combined average. Thirdly the method assumes that the cutting prescription will require strict adherence to removal of all trees larger than a specified minimum cutting diameter, although the cutting limit may be changed from cycle to cycle. The fourth assumption is that, over the period of one cutting cycle, the diameter growth rate of all trees in any one diameter class will be constant. Finally, although in some applications scant regard has been paid to mortality, to make much sense the method really requires a fifth assumption that the mortality rate will be constant within any one diameter class over the period of a cutting cycle.

These five assumptions are listed briefly for later reference:-

(a) Strictly cyclic order of working.
(b) Uniform stocking over the whole forest.
(c) Strict adherence to a prescribed minimum cutting diameter.
(d) Constant diameter growth rate within a diameter class over a cycle.
(e) Constant mortality rate within a diameter class over a cycle.

These assumptions are implicit in the manner of projecting the forest growth and predicting the yield. Obviously, they represent a theoretical ideal for calculation which would rarely, if ever, be realised. Moreover, in many real circumstances, it would not be desirable to adhere rigidly to a prescribed minimum cutting diameter or not to vary the order of working to meet some particular need. The effects of various deviations from the basic assumptions are difficult to determine. To some extent it may be possible to subdivide the stand to give the assumptions greater validity. For example, greater uniformity of stocking may be achieved by excluding from the stand table data derived from atypical parts of the forest, such as occasional fire-regenerated even-aged stands. The yield for these areas could be calculated separately from the main cutting cycle analysis for the irregular forest. Again, greater uniformity of growth rates may be achieved by dividing the total stand table into tables for different dominance classes. Separate parallel cutting cycle analyses could be run to calculate the yield from each class.

10.2.2.2 Worked example of cutting cycle analysis

Some explanation of the method of calculation seems to be required since it appears nowhere in the literature and there often appears some uncertainty of the exact procedure to be used. Because of the involved nature of the procedures, the explanation is made by means of a worked example.

Consider a forest, typical of the north coast of New South Wales, having the following average statistics:-

TABLE 20

TYPICAL STOCKING FOR 500 ACRES OF IRREGULAR FOREST

dbhob class	number of trees	annual dbhob growth/tree	merchantable height
8 - 12	1350	0.35	50
12 - 16	1210	0.35	50
16 - 20	1040	0.35	50
20 - 24	945	0.35	50
24 - 28	805	0.35	50
28 - 32	550	0.35	50
32 - 36	140	0.35	50
36 - 40	60	0.35	50
40 - 44	30	0.35	50

The tree volume table for this demonstration example is as follows:-

$$V = 0.7583-0.3592H-0.00879H^2+S(-18.9745+6.532H-0.0235H^2)$$

where:

V = gross volume per tree (super feet Hoppus)

S = basal area over bark (square feet)

H = merchantable height (feet)

The problem is to determine the yield for two cutting cycles of ten years each, during which it is intended to remove all trees which are encountered at diameters greater than 30 inches dbhob. In other words, the cycle length is 10 years and the cutting limit 30 inches.

FIGURE 20A

CUTTING CYCLE ANALYSIS EXAMPLE

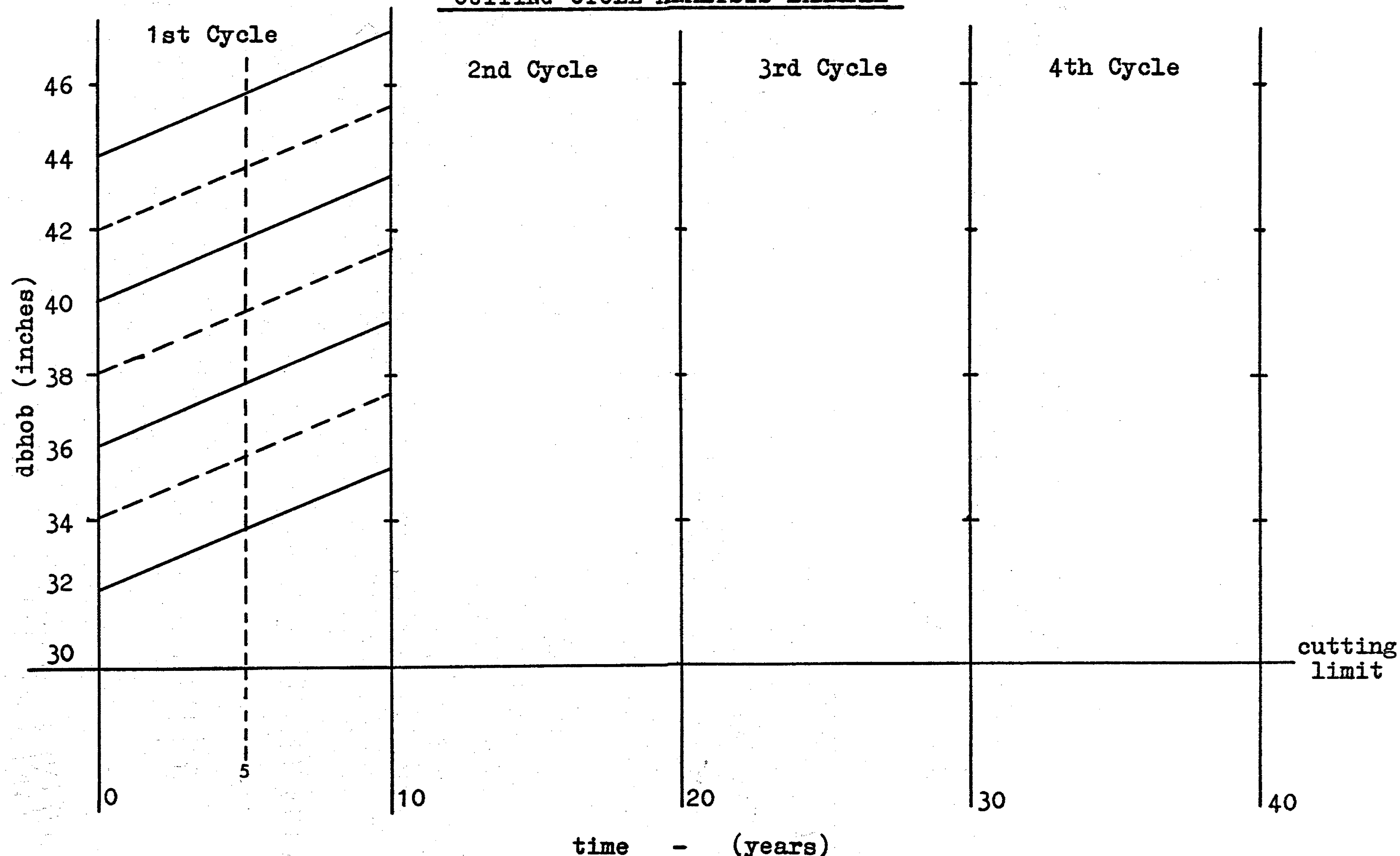


FIGURE 20B

CUTTING CYCLE ANALYSIS EXAMPLE

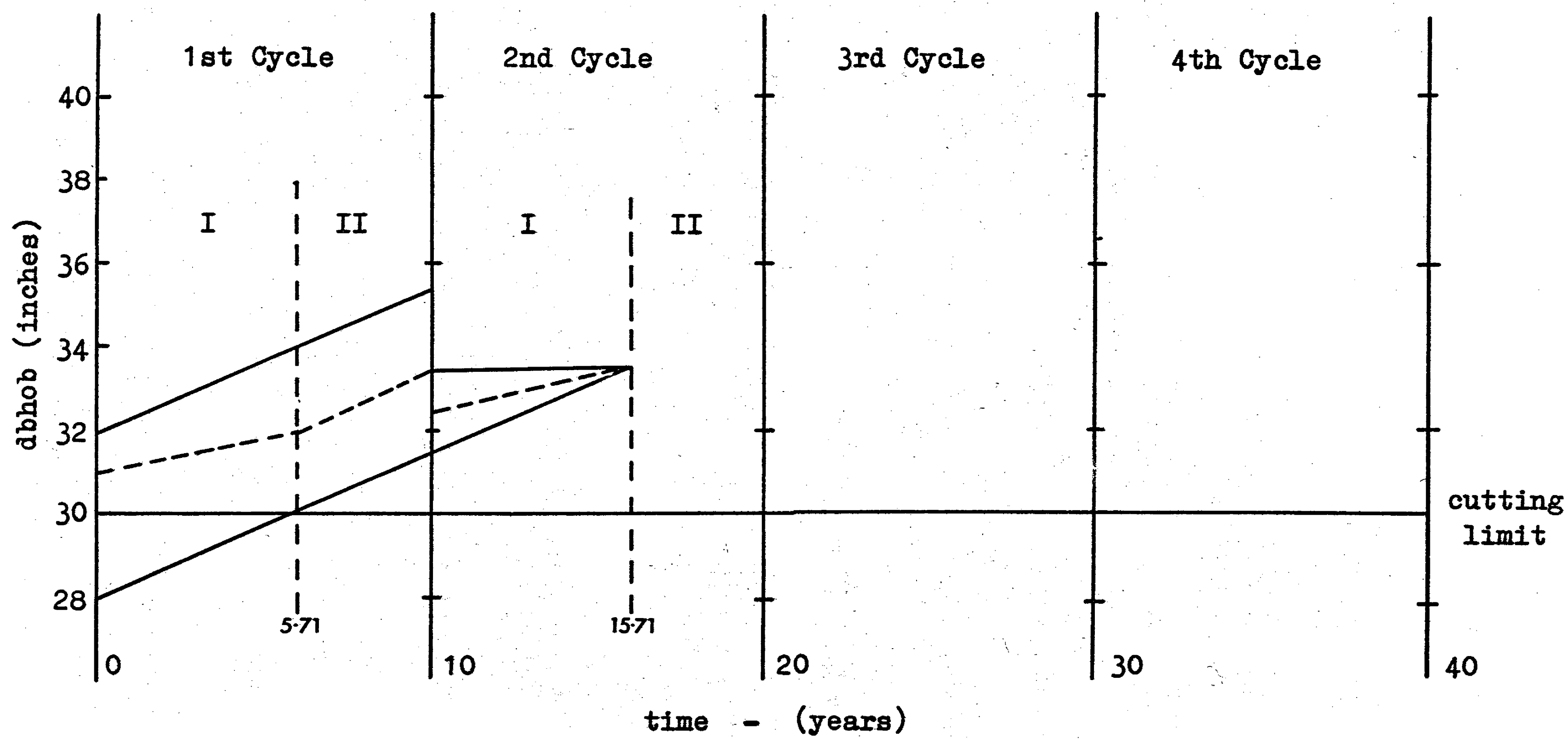


FIGURE 20C

CUTTING CYCLE ANALYSIS EXAMPLE

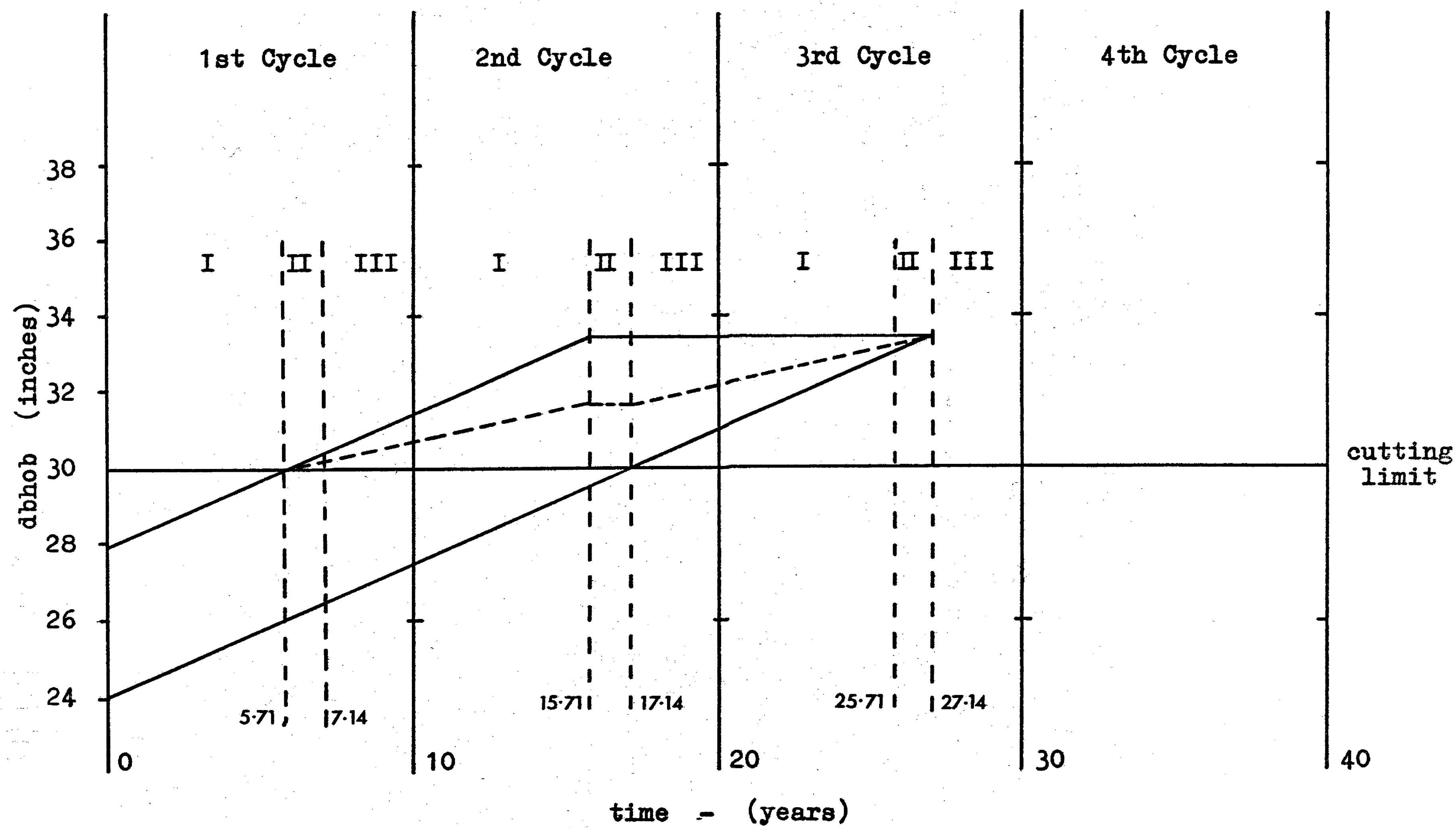
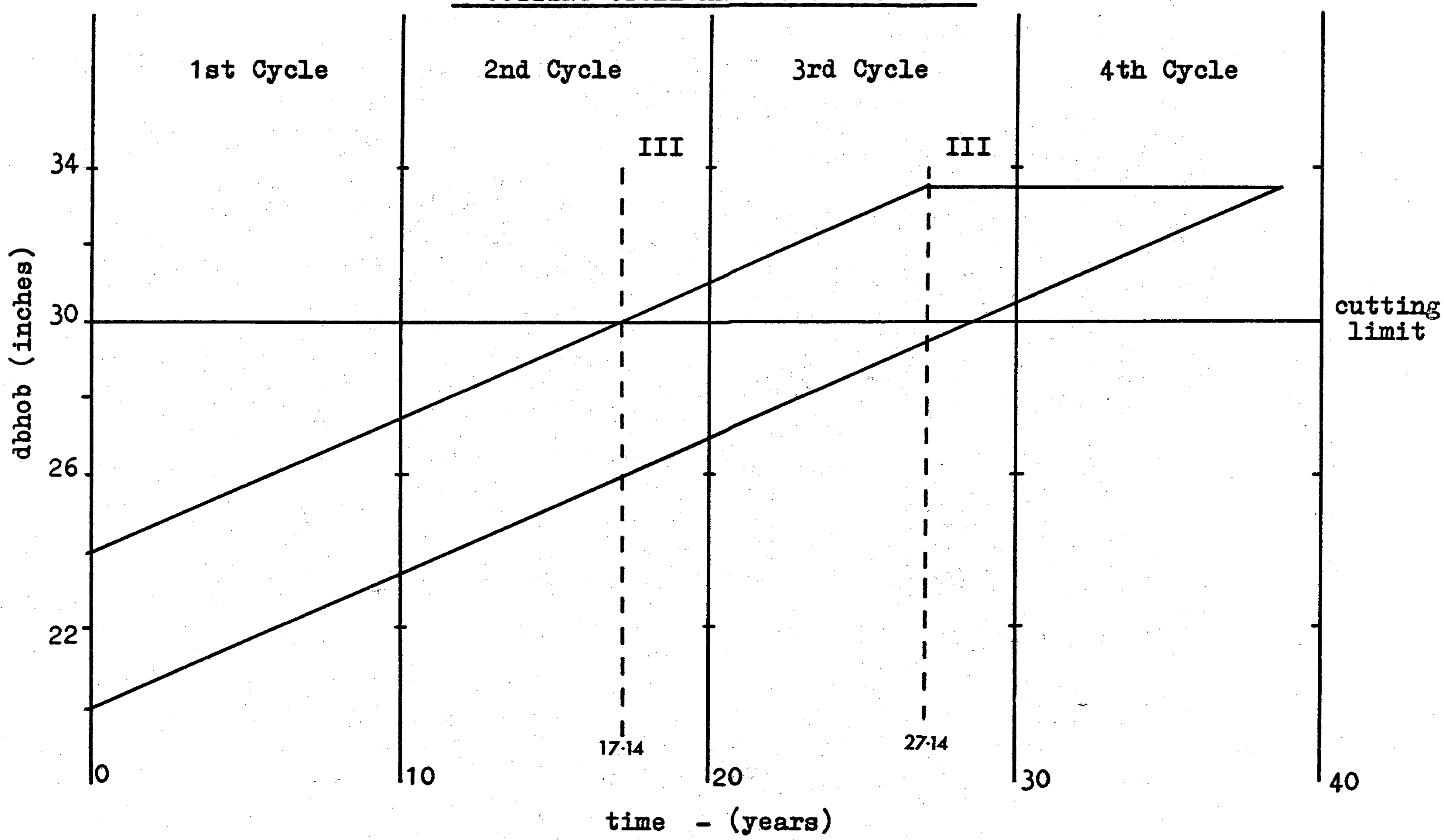


FIGURE 20D

CUTTING CYCLE ANALYSIS EXAMPLE



The difficulty of any method is dealing with the growth which occurs during the cutting cycle. Chapman (1950), encountered the same problem in his derivation of the 'Horizontal Cut Method', from which some of the foundations of cutting cycle analysis may have been drawn. As an illustration, using part of the data of Table 20 consider the trees now in the 28-32 inch class. If the forest were divided into ten annual felling coupes we would expect to find 55 trees of the 28-32 inch class in each coupe, because of the assumption that the growing stock is uniformly distributed. It would be expected that about half of those trees of the 28-32 inch class encountered by the tree marker in the first felling coupe would be larger than the cutting limit of 30 inches dbhob. Those larger would be cut, those smaller would be left behind. As from year to year operations proceed from one coupe to the next, we would expect eventually to come to a coupe in which all 55 trees of the original 28-32 inch class would have had long enough from the time of inventory, just before the first cycle, to grow to be larger than 30 inches. At the time of working this coupe all 55 trees would have been logged. The time taken to reach this coupe is calculated by taking the difference between the cutting limit and the minimum diameter in the class at the start of the cycle and dividing by the diameter growth rate.

Figure 20B illustrates the situation as a continuum, rather than in terms of discrete annual felling coupes. In the period indicated I, in the first cutting cycle portion of this figure, the smallest trees of the original 28-32 inch class grow from 28 to 30 inches dbhob. Because the annual diameter growth is 0.35 inches, the length of period I can be calculated as follows:-

$$\text{Time} = (30-28)/0.35$$
$$= 5.71 \text{ years}$$

Since the order of working is strictly cyclic, in this period operations would have covered 5.71 annual felling coupes. The number of trees from the original 28-32 inch class encountered in this time, but not necessarily cut, can be calculated as follows:-

$$\text{Number encountered} = (5.71/10) \times 550 = 314.05$$

The remaining 235.95 of the original 28-32 inch class will be encountered in period II, and these will be examined later.

Not all of the 314 trees encountered in period I of the first cutting cycle would have been large enough to cut. The next task is therefore to determine the number cut and the number to be left behind to be encountered again during the corresponding period of the second cutting cycle. It was suggested earlier that about half of the 55 trees encountered in the first felling coupe would have been larger than 30 inches dbhob and available for cutting. This is making the assumption that, within a diameter class, the trees are distributed symmetrically about the mid-diameter of the class. The stocking information supplied in Table 19 suggests that the number of trees in a class approximates some function of the inverse of the mid-diameter of the class, which means there are likely to be more trees smaller than, rather than larger than, the mid-diameter of the class. However, provided the classes are not 'too wide', the assumption is probably reasonable for the purpose. On this basis we can calculate the fraction of the original 28-32 inch class larger than 30 inches dbhob at time zero:-

$$\text{Fraction above cutting limit} = \frac{(\text{max. diam.} - \text{cutting limit})}{(\text{max. diam.} - \text{min. diam.})} = (32-30)/(32-28) = 0.5$$

By the end of period I of the first cutting cycle the largest trees of the class will have grown from 32 to 34 inches dbhob. The smallest have grown from 28 to 30 inches dbhob. The fraction available for cutting at time 5.71 is therefore calculated as:-

$$\text{Fraction above cutting limit} = (34-30)/(34-30) = 1.0$$

Because the annual diameter growth is constant, the rate of increase in the proportion available for cutting is linear. The average fraction available for cutting is the arithmetic mean of the fractions at the start and end of the period.

$$\text{Average fraction above cutting limit} = 0.75$$

This fraction may then be applied to the number encountered during the period in order to determine the number cut:-

$$\text{Number cut (period I)} = 0.75 \times 314.05 = 235.54$$

Whilst the number of trees available for cutting may be of some interest, it is usually much more important to know the volume available. As far as the author has been able to observe the method in use, the common assumption is that the tree of mean diameter among those being harvested in a class will be the tree of mean volume. For the volume table supplied this is not true. For a constant height of 50 feet the volume table simplifies to the following equation:-

$$V = -39.18+248.88xS$$

Thus, for a constant height, the tree of mean volume is the tree with mean basal area. If height is calculated as some function of diameter, even this assumption is not true. However, since it is intended to present a radical revision of the whole method in a later section, the calculation here will proceed on the common assumption that the tree of mean diameter is the tree of mean volume.

Referring again to Figure 20B it will be seen that at the start of period I in the first cutting cycle we will be cutting a small number of small trees relative to the end of that period when we will be cutting a larger number of larger trees. The mean diameter of the trees of the original 28-32 inch class available for cutting is therefore not the mean diameter of trees above the cutting limit halfway through the period. Because the annual diameter growth is constant, the true mean may be obtained as the mean of the diameters of those available for cutting at the start and end of period I, weighted according to their numerical representation in the yield. Thus:-

$$\text{Mean dbhob of those cut} = \frac{(0.5 \times 31)+(1.0 \times 32)}{(0.5 + 1.0)}$$

$$= 31.67$$

Consideration of figure 20B will show that this diameter is the diameter at the centre of gravity of the trapezium representing that portion of the original 28-32 inch class which is above the cutting limit during period I of the first cutting cycle. In all the accompanying figures the centre of gravity of the appropriate geometric figure for the trees above the cutting limit can be used to calculate mean diameter.

Because the tree of mean diameter is assumed to be the tree of mean volume the following are the full results obtained for the yield from the original 28-32 inch class in the first 5.71 years of the first cutting cycle:-

Mean diameter	=	31.67
Merchantable height	=	50
Mean volume	=	1322
Number cut	=	235.54
Volume cut	=	311,447 super feet.

Dividing the cutting cycle into two periods was performed to simplify the taking of averages as just described. It is now necessary to consider the yields obtained in period II, from 5.71 years to 10.0 years, the end of the first cycle. In this period, all of the trees of the original 28-32 inch class encountered on the last 4.29 felling coupes will be large enough to cut. Their mean diameter at the start of the period will be 32 inches and at the end of the period will be 33.5 inches. Using the same procedures as before, the following results are obtained for period II:-

Mean diameter	=	32.75
Merchantable height	=	50.0
Mean volume	=	1417
Number encountered	=	235.95
Number cut	=	235.95
Volume cut	=	334,272

Summation of the yields for periods I and II gives the total yield from the original 28-32 inch class during the first cutting cycle. In the same cycle there will also be yields from the original sizes from 32-44 inches and from some of the 24-28 inch class. The calculation of yields from these classes is illustrated in figures 20A-20D, and the results are summarized in Appendix IX.

To calculate a yield for the second cutting cycle it is necessary to reconsider the 78.51 trees left behind from the original 28-32 inch class during period I of the first cutting cycle. The largest trees left behind at any time during this period would have been just under 30 inches. When these are encountered again, ten years later, they will have grown to 33.5 inches. But the diameter of the smallest trees left behind during the first cutting cycle was increasing through the first 5.71 felling coupes. After ten years' growth there is a corresponding gradient in the size of the smallest trees of the original 28-32 class remaining to be cut in the same 5.71 felling coupes of the second cycle. But on all these coupes the minimum diameter is greater than the cutting limit and all 78.51 trees will be cut. Using the same procedures as in period I of the first cycle, the results obtained are:-

Mean diameter	=	32.83
Merchantable height	=	50.0
Mean volume	=	1424
Number cut	=	78.51
Volume cut	=	111,785 super feet.

10.2.2.3 Some complications of cutting cycle analysis

From the preceding worked example, the most striking feature is the time consuming nature of the calculations involved. The computer program, 'FORTIM', was written for the Forestry Commission of New South Wales to speed up the calculation and thus permit the examination of the effects of varying cutting cycle lengths and cutting limits. The program was based on examples supplied by the author and worked in the manner just illustrated. However this program is bound by all the basic assumptions of cutting cycle analysis and encounters the same problems encountered in manual calculation.

To facilitate the working of the preceding example, the problem was simplified in several ways. The first simplification was to assume that diameter growth was constant through all diameter classes. If diameter growth were not constant, but rather some function of diameter itself, the lines used in Figures 10A-10D to represent the progress of diameter would no longer be straight. This would greatly complicate the calculation of weighted mean diameters. This difficulty has sometimes been overcome by ascribing different growth rates to the different diameter classes but maintaining these rates constant for the duration of a cutting cycle. With rapidly changing growth rates and long cutting cycles, projection of diameters under these conditions can lead to quite an unnatural overlapping or dispersion of the diameter ranges of the projected classes, depending upon the nature of the relationship used.

The second simplification in the demonstration example was to specify a constant average merchantable height for all diameter classes. For many eucalypt forests, particularly in trees of sawlog size, this may not be an unreasonable assumption. The difficulty of using varying heights arises when merchantable height is correlated with diameter and is used as a term in the volume table. Under these conditions the tree of average diameter may be quite different from the tree of average volume.

The third simplification is the omission of mortality from the calculation. Clearly, if the stand is to be projected for any length of time, some reduction for mortality or other unmerchantable loss must be made in the smaller sizes. Such mortality expressions are not readily available for eucalypt forest. But if it is found possible to incorporate mortality, either as a continuous function of diameter or as discrete values within diameter classes, the problems of averaging, already discussed for diameter growth, will also be encountered here.

10.2.2.4 The 'CUTAN' program

The 'CUTAN' program written by the author, does not adhere to the idea of attempting to calculate an average volume for the whole of one diameter class for the whole of one cutting cycle, or even for variable periods within a cutting cycle as in the manual calculation. Rather, it divides the forest into a number of equal felling coupes and treats the trees of each original size class on each coupe as a distinct 'projection unit'. Each cutting cycle is divided into a fixed number of 'projection periods' and this number must be constant for all cutting cycles. One felling coupe is selectively logged during each projection period and the same order of working is maintained from one cycle to the next. Thus, if a forest comprises 500 acres and it is specified that there shall be 20 projection periods per cycle, the forest is considered to comprise 20 felling coupes of 25 acres each, for which there will be the same order of working in each cutting cycle. If the cutting cycle length is 10 years, two coupes will be cut each year. If the next cycle is 20 years it will take one year to log each coupe. The determination of current growth rate and mean volume per tree is performed separately for each projection unit and is based on the mean diameter of the trees in the projection unit. If a fairly large number of projection periods is specified, say 20 per cycle, this approach provides a reasonably good means of obtaining averages for a cycle, even when growth rates and volumes are not linearly related to diameter.

CUTAN does follow the assumption that the growing stock, as represented by the aggregate stand table, is uniformly distributed over the forest. If the stand table shows an average stocking of four 24-28 inch trees per acre, as determined by the inventory, each felling coupe of 25 acres is considered to have a stocking of 100 24-28 inch trees at time zero. Every 100 trees on each felling coupe forms one 'projection unit'. Similar projection units are formed for each diameter class. For eight diameter classes and twenty projection periods there would be 160 projection units.

As the analysis proceeds beyond time zero, it is the identity of the projection units that is maintained and the identity of the original diameter classes is lost, at least as far as the growing stock is concerned. Each projection unit has three attributes, namely a maximum and minimum tree diameter and a tree frequency. These are coded DMAX, DMIN and FREQ. Taking the example given above, the projection unit comprising the trees of the 24-28 inch class on the first felling coupe at time zero would have the following attribute values:-

DMAX = 28.0

DMIN = 24.0

FREQ = 100.0

Each attribute must carry the address of the projection unit to which it refers. This address has two components. Firstly, there is an $\underline{I}$ component, which refers to the number of the original size class, the classes being numbered from the original size class with minimum diameter of zero at time zero. Secondly, there is the $\underline{J}$ component which refers to the number of the felling coupe in the order or working. The example used above refers to the seventh original diameter class and the first felling coupe. The attributes of this projection unit are therefore written:-

DMAX(7,1) = 28.0

DMIN(7,1) = 24.0

FREQ(7,1) = 100.0

Actually, at time zero, for any given $\underline{I}$ value the values for all $\underline{J}$ projection units will be the same. This equality will later be disturbed for any unit affected by logging.

Having thus defined the stand at time zero in terms of three attribute arrays, the projection can proceed. Each projection unit is projected individually and for any one unit the procedure is as follows, starting from a base time $\underline{T}$ and a projection period length $\underline{P}$:-

1. Determine the mean projection unit diameter (DMEAN) at time $\underline{T}$, such that:

   DMEAN = 0.5 (DMAX(I,J)+DMIN(I,J))

2. Refer to a table, supplied as data, giving annual diameter growth rates for various diameter classes. Select the growth rate for the class into which DMEAN falls and convert this from an annual increment to an increment for the period $\underline{P}$.

3. Increase DMAX(I,J) and DMIN(I,J) by the amount determined in (2). Increase DMEAN by half this amount to obtain the average diameter halfway through the projection period.

4. On the basis of DMEAN halfway through the period, select a mortality rate from a table of mortality rates by diameter classes, also supplied as data. Calculate the mortality for period $\underline{P}$ and reduce FREQ(I,J) by this amount.

These four steps are repeated for each projection unit at each projection period.

The $\underline{J}$ dimension refers to the number of felling coupes, which is really determined by the specified number of projection periods per cycle. During each projection period logging will take place on one felling coupe only. This means, for example, that during the fifth projection period after the start of a cutting cycle, logging will only take place in those projection units referenced by J = 5. A counter for projection periods (NARRAY) is therefore established. As outlined above, the projection of DMAX and DMIN and the reduction of FREQ for mortality take place for every projection unit at every projection period. The following logging procedure is only applied to those units for which J = NARRAY, the period counter:-

For J = NARRAY:-

1. Determine DMAX(I,J) and DMIN(I,J) for halfway through the projection period. Then calculate DMEAN.

2. Test DMIN (I,J) to see if greater than the cutting limit, CUTLIM. If DMIN(I,J) is greater than CUTLIM, all the trees represented by FREQ(I,J) will be removed in logging at an average diameter of DMEAN. Volume per tree is determined, using a volume table supplied as data, on the basis of DMEAN. Progressive totals of numbers cut and volumes cut are kept by diameter classes, according to the value of DMEAN at time of cutting. These may be printed as often as required.

3. If DMIN(I,J) is not greater than CUTLIM, test to see if DMAX(I,J) is less than CUTLIM. If DMAX(I,J) is less than CUTLIM, no trees of that projection unit will be cut in that cutting cycle and no further action is required.

4. If neither of the conditions of (2) and (3) obtain, CUTLIM falls somewhere between the diameter extremes of the projection unit. In this case, FREQ(I,J) is reduced by the proportion of the diameter range of the unit that is above the minimum cutting limit. Thus:-

$$\text{Number cut} = \frac{\text{FREQ(I,J)} \;.\; (\text{DMAX(I,J)} - \text{CUTLIM})}{(\text{DMAX(I,J)} - \text{DMIN(I,J)})}$$

The diameter class in which the yields are included in this case is selected on the average of DMAX(I,J) and CUTLIM, i.e. the average diameter of those trees above the cutting limit. DMAX(I,J) is then reset to CUTLIM, since the maximum diameter of any tree left behind in logging would be just under the cutting limit.

Only a very unsatisfactory arrangement is made for the replacement of the stand after logging. In using the program provision is made for supplying a table giving the estimated number of seedlings in the smallest diameter class which are likely to regenerate after the removal of one tree from a particular diameter class. Thus, the removal of a tree of 50 inches dbhob may cause the regeneration of 50 seedlings in the 0-4 inch class, whilst the removal of a 16-inch tree may only bring the regeneration of ten seedlings. This provision can only operate when logging has reduced FREQ(I,J) to zero, since the one projection unit can only carry one DMAX and DMIN value. The reason for this somewhat crude approach is the scarcity of suitable expressions for probable regeneration rates under various conditions of irregular forest. For relatively short-term predictions of sawlog yield this may not be a particularly serious disability since regeneration is not likely to be available in sawlog sizes in less than 50 years, at the growth rates currently observed. To determine the yield for a pulpwood market, using smaller sizes, would necessitate some hasty research to re-examine the possibility of providing much better expressions of regeneration rate.

10.2.2.5 Comparison of CUTAN with conventional calculation

Both the CUTAN computer program and the conventional method of manual calculation, (computer coded in the program FORTIM), are bound by the first three assumptions listed in Section 10.2.2.1. These were that there must be a strictly cyclic order of working, that the growing stock is uniformly distributed over the forest, and that the logging prescription is one of strict adherence to a prescribed minimum cutting diameter.

Both CUTAN and FORTIM programs provide the opportunity for rapid testing of various alternatives of cutting limits and cycle lengths, and can also be used for research into the effect of variations in growth rates, mortality rates and other data. CUTAN, however, also attempts to overcome some of the basic limitations of the manual method. Diameter growth rates and mortality rates are reviewed and updated in every projection unit at each projection period rather than at the end of each cutting cycle. Because the yield is calculated individually for projection units as they are logged, the CUTAN program also avoids many of the problems of deriving average volumes from average diameters, as described for the manual method.

The results given below indicate one experimental use of the program CUTAN. The basic data used in Run 1, which is the standard for comparison, are given in Appendix XVI. The stocking, growth rates and mortality rates approximate values for the blackbutt component of an irregular forest on the north coast of New South Wales. The yields quoted are the total volumes cut (s.ft. Hoppus) per acre over each of the ten-year cutting cycles. In each case the cutting limit is 29 inches dbhob in the first cutting cycle and 28 inches dbhob in the subsequent cycles. In Run 2 all diameter growth rates are increased by 0.05 inches per annum. In Run 3 a corresponding decrease is applied. In Runs 4 and 5 the diameter growth rates are as for Run 1 but the average heights are increased and decreased by 5ft respectively. The results are as follows:-

Total Cutting Cycle Yield
(s.ft Hoppus per ac.)

Cutting Cycle	Cutting Limit	Run 1	2	3	4	5
1	29"	2314	2438	2207	2570	2052
2	28"	2208	2525	1899	2408	2003
3	28"	2006	2370	1667	2187	1821
4	28"	2247	2790	1791	2450	2040
Grand Total		8775	10123	7564	9615	7916

Increasing the diameter growth in Run 2 increases the yield by 15.4 per cent of the value in Run 1. Decreasing the diameter growth by the same amount produces a decrease of 13.8 per cent in the yield expectation. Although these major variations in calculated yield are brought about by a variation of approximately 15 per cent in diameter growth, the absolute value of the variation at 0.05 inches dbhob per annum is somewhat finer than the limit of accuracy with which estimates of average diameter growth rate would usually be expressed. Without consideration of any other probable errors in inventory data and in the assumptions of the method itself, I therefore consider that it would be unreasonable to place confidence limits of any less than $\pm$ 15 per cent on yield predictions calculated by cutting cycle analysis. Although the yield estimate variations associated with height variations are somewhat less, I suggest that the variation of 5 ft is about the minimum confidence limit that could be applied to height estimates obtained in management inventory of eucalypt forest. Again this shows the care that must be taken to use the best possible basic data if reasonable yield predictions are to be obtained by the method.

In general, the prediction of yield by the projection of components of the average stand provides some improvements over the adoption of past average total growth as the probable future yield. In the first place there is some attempt to take into account the actual method of working the forest, although operations may not always be strictly cyclic. Secondly, it does at least require the specification of a tree-marking prescription, namely, that all trees over a given diameter will be removed as they are encountered. This prescription could be given greater flexibility. For example, separate stand tables could be drawn up for three species groups sorted on vigour, and separate analyses with different cutting limits could be run for each. Thirdly, the method does give some indication of the sizes of tree to be expected in the yield in terms of average diameter and average volume. Fourthly, some opportunity is provided for studying the yield when the intensity of cutting is varied, although it is here that the user can easily be misled, particularly when long-term projections are quickly run on the computer and clearly printed output is readily available. Although the arithmetical procedure permits the calculation of yields under varying intensities of cut, the principles use in the method make no direct allowance for the real changes in growth rates that will occur if the stand structure is radically altered.

The method therefore remains principally a means of short-term yield prediction, even though it is apparently capable of use for longer term calculation. Any longer term predictive model must consider the effects of changes in stand structure upon the growth rates, if any reliability and flexibility are to be achieved. Moreover, it should always be borne in mind that the average stockings and average growth rates, obtained by combining the observations for a number of sample plots, need not necessarily represent any stand actually existing in the forest. The same average growth rates could be obtained from a forest comprising all fair quality stands and a forest consisting of some very productive stands and some very unproductive stands. But this should not imply that the same pattern of logging and treatment should apply to each.

10.2.3 Plot projection and stand variables

In Section 10.2.1 the discussion concerned the predictio of future forest growth by means of the immediate past average growth, commonly estimated by averaging the past growth of a number of plots. It was suggested that this approach could be refined a little by allocating the growth to various tree status classes. It was made clear, however, that the overall success of the method depended entirely on the extent to which future conditions in the forest were a reflection of past conditions.

With ready availability of computer techniques for fitting regressions to complex data, there is no reason to restrict the growth estimate to a simple averaging of past performances. If it is possible to isolate and measure stand attributes likely to be correlated with the different growth rates of various plots, it should be possible to use regression analysis to give a more reliable growth estimate for a variety of stand conditions. Most regressions obtained for this purpose have been derived for even-aged conifer stands and have been based on combinations and transformations of age, site and stand density. Turner (1966), however, made a detailed study of possible relationships for an irregular eucalypt forest, using data from the Continuous Forest Inventory of Coopernook State Forest in New South Wales. The regressions he considered most suitable for the prediction of basal area growth, volume growth and useful volume growth are listed in Appendix X. These equations were selected after a comprehensive study of various combinations of twenty independent variables. In the equations for basal area growth and volume growth, the three independent variables selected are generally considered to exhibit a strong degree of mutual independence. On this ground, such equations could be expected to be fairly reliable over a range of values for the combination of independent variables. When tested against the actual increments observed in the next remeasurement of the Coopernook C.F.I., the regressions gave fairly reliable predictions of average forest growth except for basal area ingrowth. The error in the prediction of the growth of individual plots, however, was much higher (between 60 and 100 per cent).

Another example of stand projection for uneven-aged forest stands is given by Moser and Hall (1969). Using the data for a 49-acre, uneven-aged stand of mixed northern hardwoods in Wisconsin, they were able to obtain a satisfactory non-linear least squares fit to the relationship:-

$$V = b.\ B^{q}$$

where:

V = total stand volume

B = stand basal area.

They also used calculus techniques to derive a prediction for basal area growth rate as a function of current basal area. These equations were welded to give a prediction of volume growth rate. Because of inadequacies in their data, they were unable to check on the accuracy of their volume predictions. Using the chi-square test of Freese (1960) however, they were able to show from their observations over two 6-year periods that their predictions would achieve a satisfactory level of reliability in estimating basal area growth within 10 per cent of the true value. But their observations were based on 40 plots in only 49 acres and it could well be expected that such relationships, based solely on stand basal area, would prove less reliable when derived from a less intensive sample in a more variable population. Moser and Hall (op. cit.) were using the relationship:-

$$dB/dt = -0.46569B^{1.0125} + 0.49818B$$

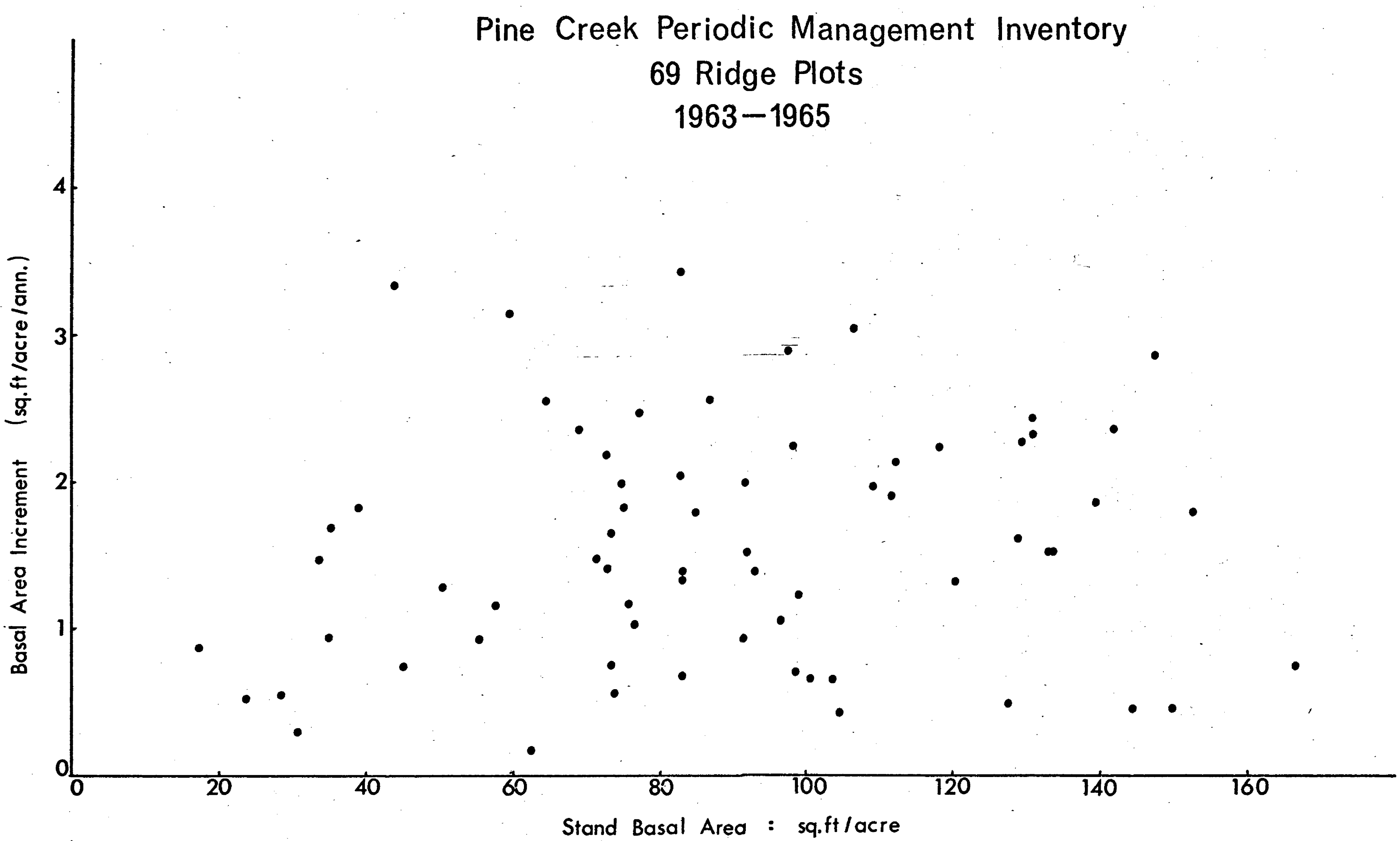
where B = stand basal area.

From Figure 21 it can be seen that no such simple relationship holds for basal area growth rate in the 69 plots of the Ridge stratum of the Pine Creek inventory. Clearly, additional variables, such as those used by Turner, B.J. (1966) would be needed to obtain reliable predictions of the growth of individual stands.

Attempts to derive satisfactory predictions are important since, inevitably, forest management must divide the forest into some form of 'stand' for administrative purposes. These administrative units may be of various sizes and may be given various names but a commonly used unit is the compartment, which can be defined and illustrated on a map and which is delineated in the field by roads, fire-breaks and other semi-permanent features. Compartments are the general units used in the definition of an order of working for various operations such as logging, silvicultural treatment or control-burning.

Smith (1962), however, defines a 'stand' for silvicultural purposes as 'a contiguous group of trees sufficiently uniform in species composition, arrangement of age classes and condition to be a homogeneous and distinguishable unit'. A stand, defined in this way, has a definite silvicultural significance. Because of homogeneity in composition, age and condition, a stand could reasonably be expected to exhibit a fairly uniform growth rate throughout.

Figure 21


Pine Creek Periodic Management Inventory
69 Ridge Plots
1963—1965
Basal Area Increment (sq.ft/acre/ann.)
0
1
2
3
4
0
20
40
60
80
100
120
140
160
Stand Basal Area : sq.ft/acre

In a plantation situation the boundaries of the stand, (the silvicultural unit,) and the compartment, (the administrative unit,) might conveniently coincide. Most plantation compartments would be uniform with respect to species composition and age, and fairly uniform with respect to condition. It has been suggested above that the growth of the forest can be usefully predicted by the projection of the growth of the individual stands which comprise it. In the plantation situation this could involve the projection of compartment growth. Gibson et al. (1968), however, recognise that reliability of prediction requires a fairly high level of uniformity within projected stands. His computer program, 'FORSIM', for the simulation of plantation growth, therefore permits the subdivision of compartments to homogeneous units called 'Sections' if necessary. For growth projection these become the stands of the forest.

In this context it is expected that growth within stands will be fairly uniform, that similar stands will have similar growth rates and that differing stands will have different growth rates. As a basis for predicting growth it is therefore necessary to use the inventory sample to describe the forest stands in terms of attributes correlated with growth and incorporated in the prediction regressions. The extent to which the attributes of a sampling unit will be representative of the stand depends largely upon the homogeneity of the stand.

In the plantation situation stands may be quite large and individual sampling units may be representative of quite large areas of the stand around them. In general, forest operations can only be planned down to the level of the administrative unit, whether compartment or section. For a plantation the possible effects of any operation on future growth can be predicted by considering the effects on the sampling unit representing the stand, which is the administrative unit.

But for irregular forest the problem is by no means as simple. Here, the boundaries of the silvicultural unit and the administrative unit no longer coincide. Because of the long history of repeated selective logging the forest has developed an irregular, grouped condition of stocking (Section 2.3.3). In many areas, particularly those where heavy logging and fire have not promoted a more general regrowth of intolerant species, the forest is now composed of numerous, small patches of regrowth, scattered through a matrix of remnants of the stand before logging. Each patch constitutes a small stand and the one compartment may comprise stands belonging to a series of age classes, depending upon the frequency of previous logging. Such a structure poses several problems for the prediction of growth and yield.

Firstly, when the minimum unit for definition of a forest operation is the compartment, which is a composite of various different stands, the probable effect of any operation on the compartment as a whole need not be well reflected by the effect on a single sampling unit, which may occupy only one of the several types of stand. It is therefore scarcely legitimate to devise an order of working compartments on the basis of attributes of individual sampling plots, when these attributes reflect a particular stand rather than the compartment as a whole. One solution would be to map the small stands and sample and manage them individually. The economics of management in eucalypt forest do not permit this. The practical solutions apparently available are either to increase the number of plots to obtain a representative sample of the stands within a compartment, or to increase the size of the sampling units so that they become more representative. As much of the time spent in eucalypt management inventory is spent in travelling to plots and in locating and establishing them, (Appendix IV), the first of these alternatives is likely to be rather costly. The second alternative, of increasing plot size, increases difficulty of obtaining reliable predictions of plot growth, since the plot may embrace several different stands. Under these conditions the 'stand parameters' used in growth regressions tend to lose their biological significance and the correlation with growth appears more casual than causal. This is perhaps part of the problem found by Turner, B.J. (1966), (mentioned earlier in this section) in obtaining reliable growth predictions for individual plots.

The projection of the growth of irregular forests by projecting the growth of individual plots, or stands, may be summarized as follows. Individual sampling units are not generally representative of the administrative units of the forest, since these may contain numerous different stands. This means that the predicted growth of the individual plots does not form a satisfactory basis for determining an order of working. Moreover, although the growth relationships obtained may indicate desirable <u>stand</u> characteristics to aim for, they are not likely to give a clear indication of the <u>trees</u> to be harvested in logging to attain these stand characteristics. On the other hand, the aggregate growth of a number of plots projected <u>individually</u> may be a fairly good prediction of the forest growth as a whole, since the plots would be expected to be a reasonable representation of the distribution of the <u>stands</u>, which are the growing units of the forest. If an attempt is made to enlarge the size of the plots so that they are better representatives of the administrative units, through embracing several stands, the use of stand parameters for plot projection may not give results of sufficient reliability. A possible alternative is to project the growth of individual trees within plots which attempt to represent the administrative units.

10.2.4 Tree growth projection

As in all other methods of projecting forest growth, it is necessary to have some estimate of the current condition of the forest as a base. This estimate is obtained by means of an inventory using sampling units.

In the previous section it was suggested that the sampling units are likely to be too small to be representative of the administrative units in which they are placed. In this section it is still considered necessary to use sampling units, or plots, to estimate the forest condition but, for projection of growth, the sampling units should be described by the attributes of the individual trees they comprise. This approach can have two principal advantages. Firstly, if the size of the sampling unit is increased to make it more representative of the administrative unit, the projection of individual trees may prove more reliable than the use of stand attributes, since the plot may embrace several stands. Secondly, the use of individual tree projections may permit a closer bonding between the prediction of yield and the prescription for marking trees to be harvested.

The arguments presented in Section 7.4 and the data illustrated in Figures 10-19 suggest that information is available for a reasonably reliable prediction of individual tree growth in irregular eucalypt forest. The sample of data illustrated indicates that, within species groups, diameter development is best predicted by classification into crown quality or dominance classes. Although there is still some variability about the growth predictions within dominance or crown classes, at least one worker in the U.S.A. (Trimble, 1969) has found that the objective determination of various crown parameters and of competing basal area does little to reduce this variability. Predictions of tree diameter growth based on crown classes are probably about as good as any available without further extensive research and they are probably reasonably satisfactory, at least in the short term.

The use of such relationships for long term predictions however, presents one very important problem. The growth predictions can only be reliable as long as the trees maintain their crown class. The maintenance of crown class must inevitably depend upon the condition of the stand as it reflects surrounding competition. Clearly, if growth of the individual trees of an existing stand were projected for longer periods without any provision for suppression and mortality, or for logging and regeneration, the stand would eventually appear to develop an unrealistically high level of stocking. The time it would take to generate such an unrealistic condition would depend upon the growth rates assumed and the initial stocking at the start of the growth projection. To make effective long-term predictions using a tree-growth model it would therefore be necessary either to incorporate some provision for a gradual reduction in crown quality in some trees and, perhaps, to provide for mortality, or to ensure that a theoretical logging or silvicultural treatment operation maintained the projected growth rates and stand stocking at realistic levels.

10.2.5 Review of proposed methods

The simplest of the four general approaches to growth prediction and yield calculation discussed above, is to set the level of cut at the average total growth of the forest observed in the immediate past. An estimate of the past total growth can be obtained with a fairly high level of precision by Continuous Forest Inventory systems using sampling with permanent units or with partial replacement of permanent units. Estimates with considerably lower precision, but possibly lower cost and lower risk of sampling bias, may be obtained by repeated samples using temporary units. The successful application of this approach requires no estimate of the current level of growing stock per se, but depends entirely on the reliability of the growth estimate. The determination of allowable cut in this way provides a minimum of information of administrative assistance to the forest manager. Of necessity, the prediction of yield can only be reliable in the short term since it is based on the premise that conditions in the future will closely reflect the conditions of the immediate past when the growth observation was made. This, in turn, demands that future operations should closely resemble past operations in logging and treatment. Admittedly, some variation is possible since performance can again be reviewed at the next inventory measurement, but no firm basis is provided for a planned long-term optimisation of yield. Moreover, no indication of a useful order of working is given, nor any details of the sizes and qualities of trees likely to be harvested. The forest manager is therefore only really provided with information on the maximum volume he may cut if the cut is to equal growth. The author therefore strongly questions the value of a general management inventory for this purpose if the forest has previously been managed. An estimate of the likely quantity and quality of the yield could almost certainly be made just as adequately from past experience and a programme for planned optimisation of logging and silvicultural procedures could probably be based more satisfactorily on experiments established specifically for that purpose rather than on the observation of plots primarily intended to sample the current growing stock.

The second approach described is that of stand table projection. This approach was discussed at some length since it has been recently applied to the prediction of yield from irregular forests in both New South Wales and Queensland. Its most notable feature is that it attempts to rationalise the calculation of yield, having regard to the process of selective logging and the prescription for marking trees to be cut. Cutting cycle analysis is a method of stand table projection but in its Australian application it involves the following assumptions which seldom obtain in real practice:-

(a) Strictly cyclic order of working.
(b) Uniform stocking over the whole forest.
(c) Strict adherence to a prescribed minimum cutting diameter.
(d) Constant diameter growth rate within a diameter class over a cycle.

(e) Constant mortality rate within a diameter class over a cycle.

The computer program, CUTAN, developed by the author, not only speeds up the process of calculation but serves to overcome assumptions (d) and (e) and, to some extent, assumption (c). The assumptions of uniform stocking and strictly cyclic working are maintained, despite the expectation that they will be unrealistic. Moreover, the stand-table, from which the growth is projected, is usually derived by averaging the stocking figures of a number of sample plots. In fact, the average stocking derived in this way may exist in none of the plots. Yet another problem is that, although the arithmetical procedure allows the calculation of yield over long periods, the method has no inbuilt procedure for adjusting the growth rates and mortality rates according to the levels of stocking generated in the projection. The reliability of the growth rates used therefore depends, as it did in the previous approach, upon the maintenance of the conditions under which the average growth rates were derived. For this reason the method remains applicable principally to short-term yield regulation, perhaps for one cutting cycle. For this purpose it is probably unduly complex. Considering the many fundamental assumptions involved, just as good an estimate of likely short-term yield, when there will be no radical revision of logging procedures, could probably be made from an examination of the present estimates of growing stock and the yield results from previous harvesting.

The third suggested approach was to relate the allowable cut to the growth of the forest estimated by projecting the growth of individual stands or sampling units. This type of approach is better than either of the previous two methods in gaining long-term estimates of growth since it provides for the need to maintain feasible stand structures. It is also more realistic than stand-table projection since it employs the projection of actual stands or plots rather than the projection of some theoretical average stand table according to the average growth rates of various actual stands. The projection of plot growth is performed by means of regressions based on variables describing plot conditions. In order to use these regressions the forest manager must specify the way in which harvesting will affect the plot parameters. The yield must therefore be capable of description in terms of plot parameters. Moreover, the order in which the harvesting operation is applied to the various plots in the course of the simulation of growth will undoubtedly affect the yield. This presents a real problem for irregular forest since the order of working is usually specified in terms of administrative units, generally termed compartments. Because the structure of the forest is extremely irregular, being made up of very many small groups or stands resulting from different periods of logging and treatment, no one small plot is likely to be representative of a large administrative unit, although the total sample of plots may be representative of the general range of stands in the forest as a whole. Whilst it may be possible to develop an optimum order of working for the plots for the purpose of simulation, it does not necessarily follow that the same order of working the compartments in which they occur will also be optimum. Furthermore, although for projection purposes it may be sufficient to define the yield in terms of plot parameters, i.e. as so much of the plot basal area or volume, this is generally inadequate information for the preparation of a cutting prescription. Even a fairly small plot in an irregular eucalypt forest is likely to contain trees which vary greatly in species, size, quality and vigour. The independent terms of the plot projection regressions will give little indication of which trees to cut if they are solely plot attributes. The forest manager is therefore left with the two problems of laying down an order of working and of defining a cutting prescription.

The fourth approach, suggested, attempts to overcome the second of these problems by projecting the growth of individual trees within the plots. Section 7.4 discusses the use of crown classifications in predictions of individual tree growth but the reliability of these predictions, such as it is, depends upon the ability of the trees to maintain their crown classifications. This, in turn, is dependent on the maintenance of an appropriate stand structure. Simulation of forest growth by individual tree projections is not likely to be realistic unless it incorporates a parallel review of stand structure.

Attempts to simulate the growth and yield of even-aged stands appear to be concentrating on a stand projection approach but with a parallel review of probable tree characteristics. Typical is the current team effort to develop such a model for the Pinus radiata plantations of the Forestry Commission of New South Wales. Here, the regressions for projecting stand growth are based on stand basal area, mean dominant height and age. But because the plots, which are the projection units, are in fact true stands in the silvicultural sense, being reasonably homogeneous in species, age and stocking, it is possible to provide probability functions based on stand attributes to predict the likely size-class distributions at any time. Similar functions can be used to simulate a particular type of thinning operation. Furthermore, because of the comparative uniformity of plantation conditions, one or two fairly small sampling plots can be expected to be sufficiently typical of quite large administrative units of forest. The plot attributes can therefore be used to determine an order of working in the compartments or sections.

An approach similar to the one just described for plantations is the one most likely to succeed in the long term in combining growth prediction and yield regulation in irregular forest, but certain qualifications must be made. Firstly it must be expected that regressions for plot projection in irregular forest will be less reliable than those for plantations because individual plots are quite likely to embrace more than one silvicultural stand.

Plot parameters will therefore not be as good predictors of growth as the true stand parameters which are estimated by sampling units in plantations. Secondly, it will not be possible to project plot growth and then reconstitute the individual trees of the plot by means of mathematical functions, since tree sizes, species, quality etc. will not bear a constant relationship to plot parameters. To reconstitute the individual trees in the stand it will be necessary to hold in memory the details of all their attributes as well as the plot attributes. After projecting the plot growth by means of the plot attributes, the effects of this growth may then be distributed amongst the various individual trees by updating their attributes. The quantity of the yield may be specified in terms of plot attributes and the trees to be cut in terms of tree attributes. The third and most difficult problem is that of determining the order of working when, under inventory procedures commonly in use, individual sampling units are unlikely to be representative of larger administrative units in irregular forest. This problem remains largely unresolved but is considered in the following section.

10.3 Local yield and the order of working

Previous discussion in this chapter has stressed that in a variable forest the order of working will affect the yield obtained. Clearly, if unproductive areas are logged first, treated and brought into production, growth, and perhaps yield, will be increased more rapidly than if already productive areas are given higher priority. If the yield obtained is affected by the order of working, it is also essential that the method of predicting yield should take the order of working into account. Yet it has also been suggested in previous sections that many present methods of inventory in irregular forest do not give reliable information of stocking on a compartment basis and are therefore not well suited to determining an optimum order of working.

A major contribution to the solving of this problem is made by Grosenbaugh (1955). His paper is based on the premise that there is a need to achieve silvicultural flexibility on a tree and density basis without reference to stands, when stands are distinguished by differences in age or size distribution, differences in quality, differences in density or stocking and differences in composition or species. Grosenbaugh argues against the definition of stands within administrative units, using the following reasoning:

> Present stand boundaries tend to disappear rapidly after cutting, girdling, burning or any treatment that favours reproduction over large areas; hence, delineating stands may contribute little to the future management of an area. Furthermore, it is administratively intolerable to keep track of a hodge-podge of small stands; they are too small for individual timber sales, prescribed burns, access roads, or deadening operations. Finally, maintaining the identity of individual stands or stand-classes greatly complicates inventory without improving sampling precision: there is usually high volume variation within stand classes and poor stand-area determination.

From this basis Grosenbaugh argues a need to recognise only one common type of area unit, called a record-unit, for all management purposes. The one type of unit would be used for mapping, sampling design and preparation of plans for order of working in logging, silvicultural treatment, control-burning etc. The record-units should be defined as convenient and permanent operating areas whose boundaries will be readily identifiable, now and in the future, both on the ground and in aerial photography. Silvicultural considerations should influence boundaries only when it is obvious that the same kind of silviculture should not be applied to adjoining areas. The compartments usually defined on maps of eucalypt forest would certainly fit these prescriptions, whether they were bounded by roads or by water courses. Subdivision of compartments into working-circle components on the basis of species type, as at Pine Creek, offers somewhat less agreement with the definition of a record-unit. The boundaries of such areas could hardly be described as permanent, since silviculture can influence species composition to some extent, and there may also be problems of identification of boundaries both in the field and on photographs. On the grounds that the authors of the Pine Creek Management Plan accepted the feasibility of applying different silvicultural strategies to two working circles within a compartment, the recognition of two record-units within a compartment may just be acceptable in this example. But Grosenbaugh's definitions do not accept the usefulness of any further stratification or typing within the administrative record-unit.

Grosenbaugh then proceeded to define various 'tree classes' according to marketing and silvicultural potential. These definitions and their novel titles are reproduced for convenient reference as Appendix XIII. The next task attempted was to define a rapid method of inventory to obtain a reliable assessment of each record-unit in terms of the tree classes. It was suggested that these estimates be expressed in terms of basal area, or in terms of volume through a relation to basal area, thus permitting the use of rapid angle-count sampling for inventory. Although the assignment to the various classes would be largely subjective, the silvicultural basis to their definition would be helpful in selecting an order of working and allowable cut in the record-units according to the indicated desirability and magnitude of the following tasks:

1. Salvaging static, decreasing or threatened values.

2. Providing adequate growing space for valuable or potentially valuable trees by removing less valuable ones.

3. Regenerating stands not adequately utilising growing space.

Cowley (1968a) describes the modification of this diagnostic survey technique (Grosenbaugh, 1955) for use in Wombat Forest, an irregular eucalypt forest in Victoria. Although different management classes (tree classes) were used here, they were still based on silvicultural and marketing potential as indicated by crown quality, crown competition and stem quality. Considerable attempt was made to obtain objective definitions of these features. Under this Victorian scheme the record-units are defined as compartments and it is envisaged that at least 20 sampling points would be required in each compartment. A systematic sampling system is advocated, with the assessor establishing the sampling points in the field by pacing along a compass line. Using an optical wedge with basal area factor of 10, an angle count is recorded for each management class at every sampling point. Merchantable log lengths, allowing for defect, may also be recorded for calculating volume. Maximum slope on the plot is recorded, together with stand height, being the average height of the three trees of largest diameter within one chain of the observer.

At the conclusion of the inventory, compartment stocking in each management class is obtained by averaging all the sampling point values in the compartment. The sections are then arranged in order of working according to general priorities similar to those suggested by Grosenbaugh (1955) but always with recognition of the need to maintain a stable and balanced supply to the various accepted markets. The actual schedule of priorities for selection of trees to be cut is specified in terms of management classes. The intensity of cutting is constrained by the need to balance pulpwood and sawlogs, by the need to obtain certain minimum yields for economic harvesting, and by specifying minimum levels of total basal area to be retained according to different stand height classes. Since volumes are related to basal areas, the likely yield can be predicted from the basal area that will be removed in reducing the compartment stockings to the agreed basal area limits.

The Victorian diagnostic survey technique, just described, is intended primarily to sample the logging areas for the next one, two or possibly three years. From the point of view of achieving the fastest increase in productivity, the order of working within such an area would be unimportant. The great detail obtained, however, would be invaluable both in regulating operations during the period to ensure stable yield and also in prescribing the most suitable level of cutting and predicting the probable yield. Moreover, it is also envisaged that by using a common record-unit for inventory, yield regulation and other activities, and by requiring that these units be defined by clear, permanent boundaries, it should be possible to maintain a continuing information recording system to supplement any future inventory data.

The effective implementation of such a scheme of diagnostic survey would depend upon the availability of certain other items of information. The most urgently required of these is the knowledge that other logging areas could maintain stability of utilisation by providing a comparable yield for at least the next ten years. This presupposes some other form of inventory to assess the stocking of the remainder of the forest. Such an inventory need only achieve a considerably lower order of precision, although the greater the local precision the greater the ease of determining a good order of working in terms of annual logging areas. For this purpose alone the sample need not be permanent, although for several other reasons (Section 5.3) permanent plots may be considered desirable. In fact, Wombat Forest is served by a C.F.I. With time, the detailed records built up with diagnostic surveys and routine yield recording would tend to obviate the need for supplementary stocking information. The second type of information which is assumed to be available concerns the optimum cutting strategies, the levels of basal area to be retained and the likely growth following cutting. Such information is essential to longer term planning. Methods of obtaining this type of information were discussed in Chapter 5. Some information of this type may be obtainable from C.F.I. systems but for determination of reliable growth regressions some form of purposive sampling may prove more efficient (Section 5.5).

The above Victorian work appears to be the only major effort in Australia to obtain information with a level of local reliability for the intensive management of irregular forests. It is useful to consider the possible cost involved. Cowley (1968a) estimates that about 20 points could be assessed by one man in one day using the Victorian diagnostic survey technique. He also estimated that about twenty points per record unit would be necessary to give sufficient reliability of estimate. As an example, these data could be applied to Pine Creek Forest, comprising approximately 8600 acres in 43 compartments of average area 200 acres. Assuming no subdivision of compartments into working circles, the total number of points to be assessed would be 860, requiring 43 man-days of labour. The Victorian estimates of time requirement are based on local conditions of scrub density, however, and for most situations in northern New South Wales or Queensland it would perhaps be more realistic to reduce the estimate of the speed of assessment to 10 plots per man per day. On this basis, 86 man-days would be required to assess 8600 acres in 43 compartments. Using systematic sampling, the twenty points assessed in 200-acre compartments would need to be established on a 10 chain square grid. At an average cost of $15 per man-day, the complete diagnostic survey would cost $1290 but the complete 8600 acres would not be assessed at any one occasion. The work would more likely be divided into four sections, costing approximately $320 on each occasion.

The recent remeasurement of the Periodic Management Inventory, comprising 114 permanent plots in the same area, was completed in 80 man-days, thus incurring a comparable total cost. Although this cost would also be incurred only once in the course of a ten-year cutting cycle further continuing costs would be incurred in the processing of data, in the maintenance of the plots and the recording of removals during logging and silvicultural treatment.

A combined inventory system involving C.F.I. and diagnostic sampling could therefore be expected to cost in the vicinity of $3500 over ten years. In the year 1967/68, which appears typical of recent years, revenue in Pine Creek from all timber sales and lease rentals was $32,000. Expenditure in the same period was $15,000. Nett revenue over a ten-year period would therefore be expected to be of the order of $170,000. The additional cost of approximately $3,500 for inventory would represent a reduction of only 2 per cent in nett revenue. On the basis of these cost estimates the author considers that much wider investigation and implementation of diagnostic survey techniques would seem feasible for other states besides Victoria where they have been developed.

CHAPTER 11

DEFECT AND TREE VALUES IN NEW SOUTH WALES

11.1 The mensurational problem

Some aspects of wood properties and bole quality in eucalypts were discussed briefly in Section 2.2.2. Problems of assessing commercial quality were discussed in somewhat greater detail in Section 7.3. An attempt will be made here to summarize briefly the discussion of these sections. For the immediate purposes of the forest manager the problem appears to resolve into two principal questions, namely:

1. Is any part of the tree suitable for a particular purpose? Is the tree merchantable?
2. If the tree is merchantable, what proportion of it is saleable?

The factors which determine merchantability are of three types:

1. Size of tree.
2. Location in respect to mill and market.
3. General bole quality.

Minimum standards for acceptability for a given type of utilisation are defined not by a simple minimum standard for each type of factor but by an interaction of the three. It will later be shown how the stumpage appraisal system employed by the New South Wales Forestry Commission acts to integrate these three and determine acceptability when the tree is measured for sale as a sawlog.

Defects in eucalypts are of two types, external and internal. External defects include features such as bends, sweeps and visible fire and logging damage. Even though it may not be easy to define standards for accepting bends and sweeps, and although standards may vary from one product to another, at least the defect is visible and can be readily assessed in the field. Internal defect, which occupies most of the discussion in this chapter, presents a more difficult problem of assessment and is probably more significant in causing timber wastage. Internal defects are of four principal types:

(a) Termite damage.

(b) Fungal decay.

(c) Gum-vein formation.

(d) Mechanical failure.

An anonymous worker writing for Rural Research in CSIRO, (Anon, 1968), has summarized most of the findings of the principal research into Australian termites, making particular reference to the various works by T. Greaves. Most damage to commercially important trees is done by three species. *Porotermes adamsoni*, the alpine termite, is a large species and causes serious economic loss, particularly in the higher country of south-eastern Australia. Trees attacked by it are often completely useless for sawing, although their worthlessness may not be evident until after felling. Characteristically the species eats its way up the tree following the growth rings, which are often fairly prominent in this high country area. The galleries therefore may extend the full length of the trunk from centre to sapwood and, although the actual volume of wood eaten is small, the log is weakened throughout and no merchantable timber can be cut from it. *Coptotermes acinaciformis* and *Coptotermes frenchi* occupy the subalpine and low altitutde forests of the coasts and the inland. Although *C. acinaciformis* usually confines its activities to the central part of the tree, it undoubtedly causes greater economic loss than any other species. If the tree is large enough, sound timber may be milled from around the 'pipe' created by the termites because this species does not usually form galleries in the growth rings. Colony-founding pairs of *C. acinaciformis* cannot force an entry into sound wood but must find access through decayed wood, which usually forms around fire scars, wounds or cracks. Established colonies, however, can in some circumstances construct underground tracks and invade other trees at a considerable distance from the parent colony. Discussion of any restrictions on the development of a colony after establishment do not seem to appear in the literature. From a general reading of the literature the author would expect that temperature changes towards the outside of a tree, together with greater durability of the most recently formed wood, may restrict the proximity to which the colony is likely to approach the sapwood. Infested trees are not always easy to recognise, except that long-established colonies of C. acinaciformis may sometimes be detected by a ring of 'aeration galleries' at the bole surface. Rudman (1964) discusses the way in which some trees may be resistant to termite attack through the production of termite repellant extractives.

Although the losses due to fungal decay are probably less extensive than those due to termites (Anon, 1968) they are none the less very considerable. In general the fungi capable of causing decay in living trees belong to the Basidiomycetes group. Those active in eucalypts appear not to invade from the root system but from injuries above ground level. A similar finding in North American hardwoods is reported in a comprehensive study by Shigo and Larson (1969). Among the points of entry studied by these workers are branch stubs, stem stubs, logging wounds, insect galleries, animal damage, fire wounds, seams and frost cracks. Doubtless the same sorts of damage provide entry points for decay causing fungi in eucalypts. Jacobs (1955) describes the very successful manner in which eucalypts can shed branches cleanly up to about an inch in diameter. Successful occlusion of branch stubs can only take place if they do not become centres for fungal infection. In the eucalypts a layer of kino may be secreted over the branch stubs thus helping to protect them from fungal attack. If the branch is large, or if it has been damaged and is not being shed in the course of the normal growth process of the tree, it may not be properly protected against fungal attack. Under some circumstances branch occlusions may be sources of fungal attack. Fire wounds are also likely to be points of entry for decay causing organisms. Although eucalypts in general have evolved in an environment where fire was common, and have therefore developed with growth habits mitigating the effects of fire, there are still many fires which are sufficiently intense to break these protective barriers and permit entry of fungi. In the course of some pilot studies on problems of assessing defect the author also observed pockets of rot associated with larval galleries in *E. punctata* and *E. sieberi*. Although no extensive investigation was carried out it seemed probable that these small pockets of rot in the centre of the trees could continue to expand into much larger rot pockets long after the insect which introduced them had left.

The mensurationist is therefore faced with extremely difficult problems in trying to relate internal defect to external symptoms. The decay causing organisms may gain an entry in several different ways such as poor branch occlusion, fire damage, logging damage or insect attack. But not in every case will these kinds of damage be indicators of actual fungal attack, or of fungal attack that has been established long enough to have caused fungal decay of commercial significance. Furthermore, because the central column of heartwood in the bole serves principally in a support function for the crown, the presence of even quite extensive areas of decay are not likely to be reflected in other external symptoms such as the health of the crown or the quality of the bark. The decay causing fungi are not parasitic upon the vital growing tissues of the tree.

The task of predicting the probable rate of increase in decayed wood volume in a tree is even more difficult. It is worthwhile considering the processes that may be involved. Rudman (1964) in a study of jarrah (E. marginata) observed that after the juvenile or immature wood stage was passed, most trees continued to produce decay resistant wood throughout their life. But with the ageing of the heartwood this initial decay resistance decreased, apparently due to the polymerisation of the polyphenol extractives which were the active fungitoxins. Nelson and Heather (1971) observed the same pattern of durability in flooded gum (E. grandis). Under these circumstances rapid tree growth in early years would lead to a large central column of heartwood which was decay susceptible because it was formed in the early life of the tree. Rapid growth in later years, however, would increase the width of decay resistant wood since there would have been less time for the loss of durability through the polyphenol polymerisation that is associated with age. The probability of decay occurrence and, more significantly, the relative rate of decay spread could be expected to be related in a fairly complex way to tree vigour. The actual rates of spread would be further dependent upon the durability of the tree species and upon the vigour of the species of fungus causing the rot.

Shigo and Sharon (1970) made a detailed study of the ways in which decay-causing Hymenomycete fungi are able to spread in sugar maple (Acer saccharum). They found that the spread of these fungi was always preceded by a colonisation of the wood by bacteria and nonhymenomycetous fungi, and concluded that wood must be altered in very specific ways before heart-rot fungi can cause decay. Shigo and Larson (1969) take a step further in claiming that a similar pattern of succession is the general rule for the establishment of decay in many North American hardwoods. The first phase is one of discoloration of tissues after the tree is damaged. The discoloration appears to be due to chemical changes in the wood. Although it may spread through all the tissues present at the time of injury, discoloration does not affect new wood formed after the injury. In the second phase bacteria and nonhymenomycetous fungi invade the discolored tissues. In the third phase, Hymenomycetes may invade and cause decay in those cells altered by the previous invasion of the pioneer colonising organisms. Shigo and Larson (op. cit.) claim that the spread of discoloration and subsequent decay can only continue as long as the wound area remains open, and that the process is confined to the wood present at the time of the injury. Provided no further injury occurs the maximum volume of defect is therefore constrained to the discolored zone.

Studies similar to those described for North American hardwoods have not been made for eucalypts in Australia. It is possible that the eucalypts may present slightly different problems since they do form true heartwood. But it seems that in attempting to assess the extent and the rate of growth of fungal defect the mensurationist may be faced with the following types of problem:

(1) Some form of injury must provide a point of entry for a decay-causing fungus. The types of injury which can lead to infection are numerous but a suitable inoculum must also be present. Thus, not all injuries will lead to decay.

(2) The possibility of infection and the subsequent rate of spread will also depend strongly upon the durability of the wood exposed to infection. This in turn will depend upon the species of tree and the age of the wood exposed.

(3) The extent of decay may be governed by the rate of spread of precursors to decay-causing fungi in relation to the rate at which the injury is healed. A maximum limit to the spread of infection may be imposed by the volume of wood present at the time of an injury, provided no later injury permits secondary infection of wood formed later.

The third type of commonly occurring defect listed above is described as gum vein formation. Eucalypts usually produce layers of 'gum' or kino in response to various types of injury and particularly in response to fire. Jacobs (1955) discusses the formation of gum veins in various situations. However, in most cases the gum veins as such, are not a sufficiently serious form of defect to cause loss of merchantable volume.

The fourth type of internal defect which causes loss of merchantable volume can perhaps be described as mechanical failure and is particularly serious in some species notably tallowwood, bloodwood and spotted gum. This type of defect causes extreme difficulty in the measurement of logs for sale. When first felled the ends of the log may appear quite sound and if measured at the stump or soon after felling it may be sold accordingly. But when logs are allowed to dry in the mill yard they may open up in a series of concentric rings. Sometimes the problem does not become apparent until the logs are sawn and the boards that are cut simply fall apart. The origin of this very serious type of defect does not seem to have been traced. There does not appear to be any clear external evidence of its occurrence. The only bases for predicting its occurence are that rings only seem to form in the three species mentioned, they are generally in larger trees and they may be more prevalent in some localities than others.

The discussion of this section has been directed towards defining the mensurational problem and may be summed up in the following way. Defect may be external or internal. Although external defects are visible and are therefore open to assessment, the standards to be applied in their assessment will vary from one intended use to another. Internal defects are much more difficult to assess. They may be of several different kinds, again differing in economic importance depending upon the use intended. Very often there are no external symptoms of internal defect, but even when some association with external symptoms is observed, the association is likely to be inconsistent, particularly in quantitative terms. The prediction of defect volume and rates of change in defect volume in standing trees is therefore almost certain to be extremely difficult. The cost of research to establish techniques of assessment is likely to be extremely high and, from the problems outlined above, there appears to be no real guarantee that reliable results would be obtained at the conclusion of such a project.

I have therefore begun a study on the possible immediate management significance of an inability to assess defect in the standing tree. The arguments presented in the following sections are directed towards the need for short-term yield regulation information and do not consider the long-term benefits of a research program aimed at an eventual control of defect occurrence. In this study I have worked with the New South Wales Forestry Commission hardwood stumpage appraisal for several reasons. First, I was familiar with the system and had ready access to appropriate data. Secondly I wanted a pricing system which was actually in use so that there can be no argument over realism. Thirdly, and most importantly, the system is very complex in its consideration of various types of costs, and is therefore sensitive to many different types of real sale situations. The next section will be devoted to an explanation of the system since it is vital to what follows.

11.2 The NSW hardwood stumpage appraisal system for sawlogs

The earliest exposition of the basis of the hardwood stumpage appraisal system now used by the Forestry Commission of New South Wales is given by Cooke (1952). Although there have been many variations and elaborations to the system since then, many of the same principles still apply. The basic philosophy is one of attempting to achieve a stumpage equation allowing sawmillers to compete equally at their principal markets regardless of the difficulties of their particular supply areas and regardless of the prevailing log quality. A type of residual stumpage determination is the form through which the equation is achieved.

The sale volume of a hardwood sawlog is determined in the following way. The length of the log is measured to the nearest foot. The bark is then removed at the mid-point of the log and the centre girth under bark is measured in inches using a girth tape, or occasionally using calipers. The gross volume is calculated in units of superficial feet Hoppus using the following formula:-

$$\text{Gross volume} = (\text{C.G.}/4)^2 \times L/12 \text{ s.ft Hoppus}$$

where:

C.G. = centre girth (inches)

L = length (feet)

An allowance for internal defect is made by measuring the average 'pipe' diameter at each end of the log and taking the mean. Sometimes this is a fairly simple procedure, for example for a well-defined central area of rot or for a colony of the termite C. acinaciformis. For other defects, such as the loose 'rings' described earlier, it may be more difficult to define the diameter of a 'pipe' of defect. But with experience it seems to have been possible to reach reasonable levels of agreement between the sawmillers and the Forestry Commission measuring officers. The volume of defect is calculated by the following formula:

$$\text{Defect volume} = P^2.L/12 \text{ s.ft true}$$

where:

P = average pipe diameter (inches)

L = log length (feet)

The defect volume, in true measure, is subtracted from the gross volume, in Hoppus measure, to give a quantity which is generally termed the Nett Hoppus Volume. This cumbersome Hoppus measure/true measure combination serves no useful purpose in modern times and will undoubtedly be removed with proposed conversion to metric units. Nevertheless it is an integral part of the pricing system and will have to be used in the following discussion. Figure 22 illustrates the pattern of relationships between gross volume and nett volume in true measure and Hoppus measure.

The stumpage appraisal system calculates the residual value of a tree of standard size and standard species after deducting the probable logging, conversion and transport costs from its value as the sawn product at a principal market. All the calculations are based on units of 100 super feet. The appraisal begins by fixing the price of 100 s.ft sawn, free on rail, at the principal market, usually Sydney. From this are deducted the cost of rail freight and the cost of haulage of the sawn timber from the sawmill to the railhead. At this point the sawmiller is allowed a fixed manufacturing margin for 100 s.ft true volume of the sawnwood. An allowance is then made for the loss of recovery in sawing. On the basis of mill studies Cooke (1952) argued that the recovery from nett Hoppus would be constant for the standard size and this principle is still applied in the system. Figure 23 shows that the nett Hoppus volume is a fairly stable percentage of true nett volume up to 40 per cent defect (Hoppus basis). Beyond this defect percentage nett Hoppus volume decreases fairly rapidly as a proportion of true nett volume and the use of a fixed recovery expectation would tend to favour the sawmiller provided there were no corresponding losses of recovery because of difficulties of sawing at high defect levels. The residual value of the sound wood at this stage is the Mill Door Log Value, (M.D.L.V.). This is an important quantity in the ultimate determination of price.

In getting the tree from stump to mill door several costs are involved. The system recognises costs in felling, snigging and log haulage. Felling is set at a fixed cost for all trees. Snigging and log haulage, however, are appraised on a compartment basis. The snigging rates are

FIGURE 22

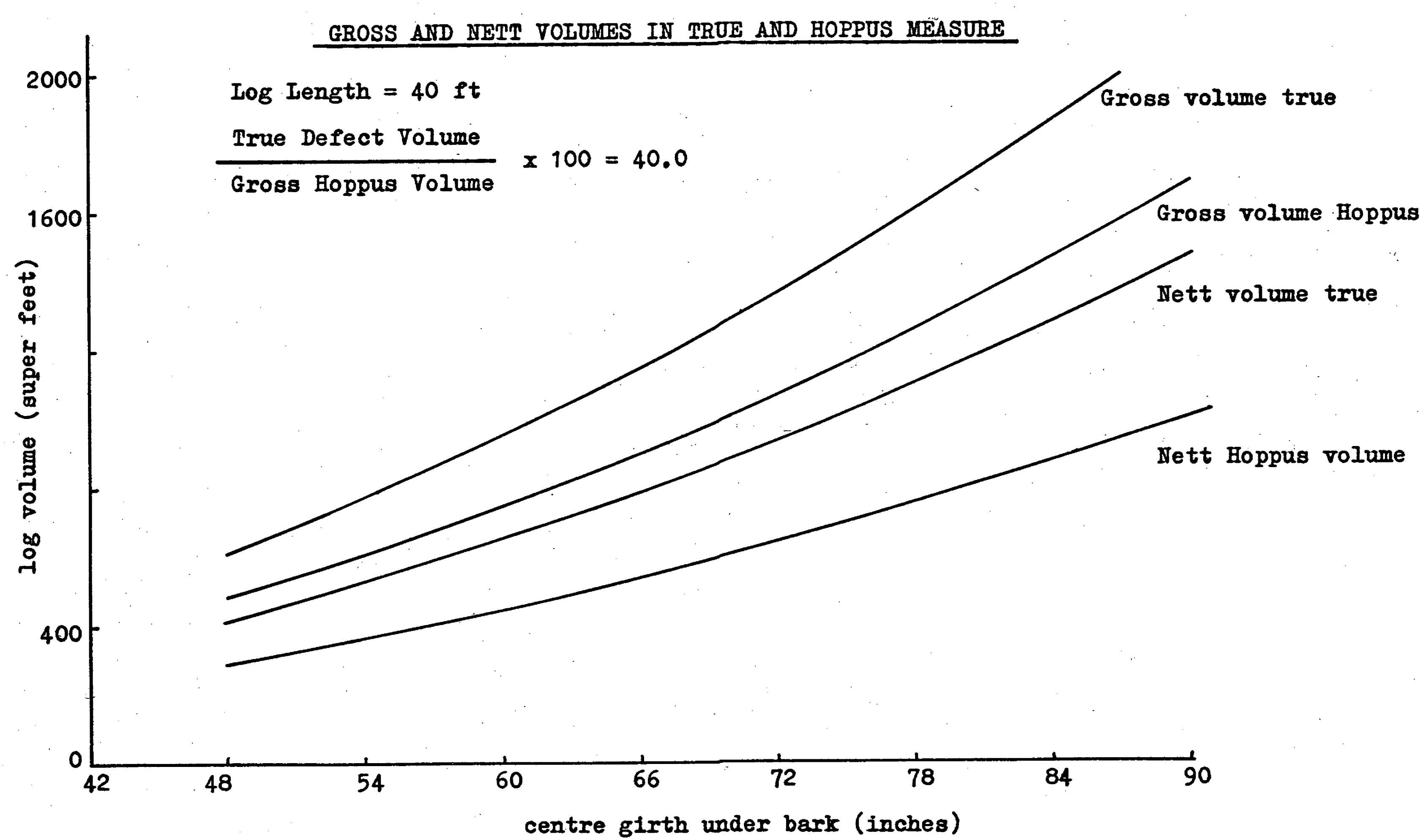
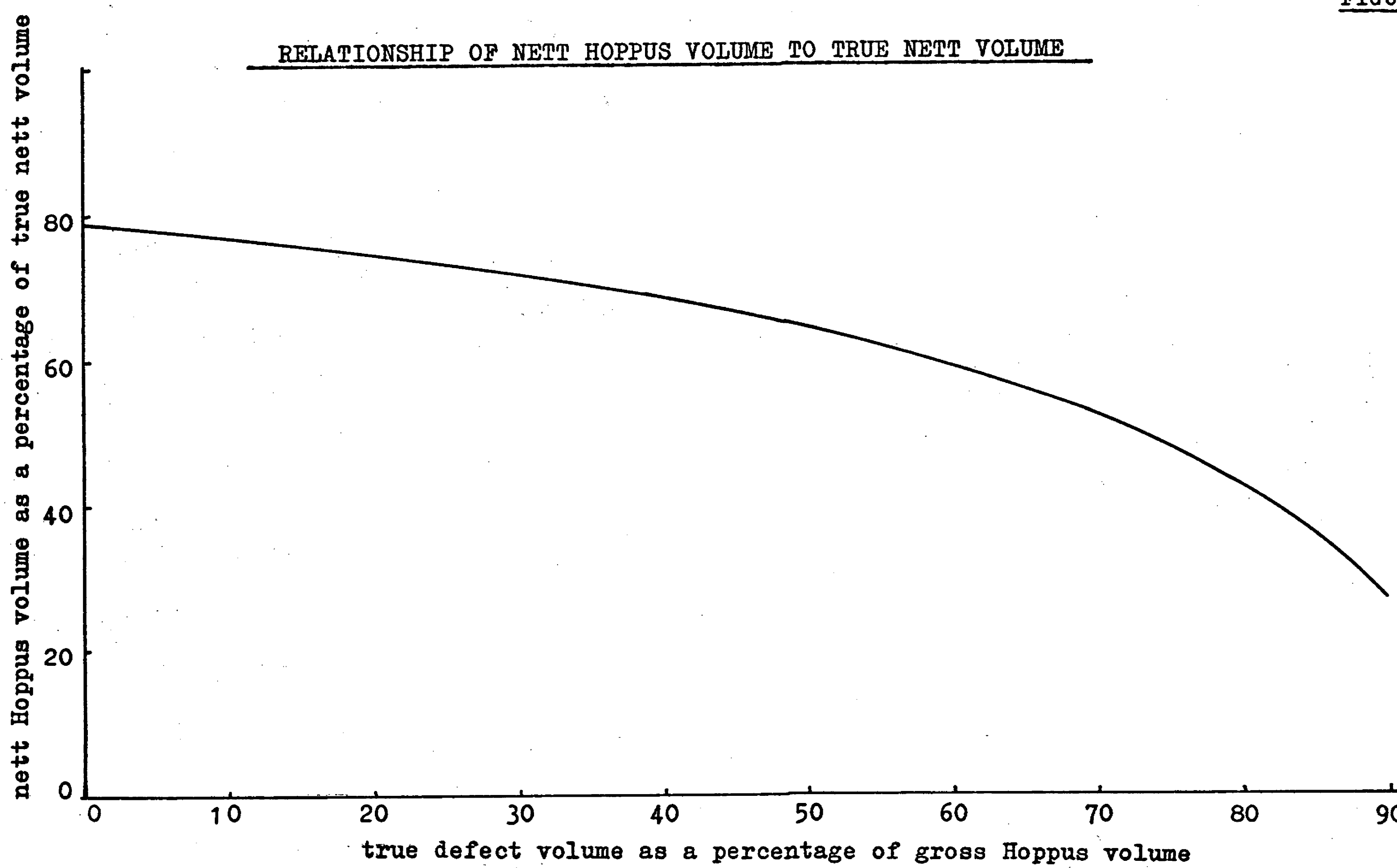

GROSS AND NETT VOLUMES IN TRUE AND HOPPUS MEASURE
Log Length = 40 ft
True Defect Volume / Gross Hoppus Volume x 100 = 40.0
Gross volume true
Gross volume Hoppus
Nett volume true
Nett Hoppus volume
log volume (super feet)
2000
1600
400
0
42
48
54
60
66
72
78
84
90
centre girth under bark (inches)

FIGURE 23

RELATIONSHIP OF NETT HOPPUS VOLUME TO TRUE NETT VOLUME



based on a study of crawler tractor performance made by Grugeon (1961) and take into consideration such factors as average snig distance, slope, the nature of the terrain and the average yield per acre. Log haulage costs are based on the average distance of haul by various road standard classes. When these costs per 100 s.ft are deducted from the mill door log value, the residual value is termed the Base Rate. The base rate is in fact the estimated standing unit value of a sound tree of standard size and standard species. A typical appraisal for the north coast of New South Wales is given as Appendix XIV.

The system is even more complex than this, however, because it also makes allowance for changes in expected recovery with different log sizes and species and for different market prices obtained for some species groups. Since both these variations affect only the nett volume they are applied as a flat margin to the nett volume only. As the margins affect the consideration of profitability, to be discussed later, they are listed in Appendix XV.

The price of each log is calculated individually using the calculated mill door log value and the base rate for the compartment together with the nett margin for the particular log according to its centre girth and species. The price formula used is as follows:

Formula A

$$\text{Price} = GV.BR - DV(MDLV) + (NV.MAR)$$

Formula B

$$\begin{aligned}\text{Price} &= (NV.BR) - (DV.LC) + (NV.MAR)\\ &= (GV.BR) - (DV.BR) - (DV.LC) + (NV.MAR)\\ &= (GV.BR) - DV(BR + LC) + (NV.MAR)\\ &= (GV.BR) - DV(MDLV) + (NV.MAR)\end{aligned}$$

where:

GV = Gross Hoppus volume of log

MV = Nett Hoppus volume of log

DV = True defect volume

BR = Base rate

MDLV = Mill door log value

MAR = Nett stumpage margin

LC = Logging cost from stump to mill.

As shown by the illustrated working the two formulae are fundamentally the same. Formula B shows the rationale behind the approach. The sawmiller is charged the residual value of the nett volume as it stands in the forest, since it is only the nett volume that he converts and markets. The charge for the nett volume is loaded with a stumpage margin according to size and species. But in obtaining the nett volume he must also pay for felling, snigging and hauling the defect volume which is only removed during sawing at the mill. He is therefore given allowance for these costs.

Formula A is the one more commonly applied and demonstrates the economic implications of the method a little more simply. Since logging costs are subtracted from the mill door log value to obtain the base rate, the mill door log value will always exceed the base rate. It is therefore clear from Formula A that unless the nett margin is very high there will be a percentage of defect that would render the log effectively worthless. Beyond this percentage defect the log would take on a negative value, indicating that the sawmiller would need to be subsidised to remove it profitably. The margins are seldom large and are in fact negative for smaller logs and poorer species. Consider a Group C species log of 60 inches centre girth and 40 ft length in an area with mill door log value of \$3.63 and base rate of \$2.41 per 100 s.ft. The margin to be applied for such a log would be -\$0.70 per 100 s.ft nett. At 40 per cent defect the log is worth \$4.04 or 54 cents per 100 s.ft gross. At 56.7 per cent defect the log is worth \$0.375, or 5 cents per 100 s.ft gross. At 58.4 per cent defect the log is theoretically worthless. The Forestry Commission has set a policy of selling logs for no less than a <u>minimum rate</u> of 5 cents per 100 s.ft of gross volume. If the log contains more defect than the percentage at minimum rate, i.e. more than 56.7 per cent in this example, the log is said to be optional and the Commission does not usually enforce its sale. If the sawmiller is a particularly efficient operator or if he is prepared to accept a lower profit margin than the Commission allows in the manufacturing margin of the stumpage appraisal, he may elect to take the optional log and be charged 5 cents per 100 super feet gross volume. Many optional logs are sold in this way, particularly in areas of rapidly dwindling supply.

11.3 Price, defect and merchantability

The previous section has shown the way in which mill door log value, base rate and stumpage margin act together to determine the percentage defect at which a sawlog is worth only the minimum royalty rate in the NSW stumpage appraisal system. Technically any log with a greater proportion of defect should be uneconomical to harvest and should therefore be unmerchantable, but in reality many such 'optional' logs are sold at a set minimum royalty rate per unit of gross volume. Optional logs, however, are not usually included in the sawmiller's prescribed annual volume 'quota' fixed by the Forestry Commission. In attempting to relate quota to the probable growth of the forest it is essential to know what proportion of the volume is 'in-quota'.

In this section I will develop a technique which abandons the traditional approach of assessing the merchantability of individual trees according to fixed, and often subjective, standards. Instead I will show how an assessment of average percentage defect through the stand obtained by inventory can be integrated with the comprehensive stumpage appraisal system already in use to provide estimates of the current merchantable gross and nett volumes of the stand, together with standing values. Within the constraints of the present sawlog marketing system, these volumes and values can be objectively adjusted to allow for the effects of any changes in royalty rates. Some of the limitations of the approach will be discussed later but at the outset it must be made clear that the detailed estimates which follow refer only to the trees which are not optional, the 'in-quota' trees, and do not aim to predict the sawmiller's likely willingness to accept optional logs if offered for sale by the Commission.

The worked example illustrated in Tables 21-26 is based on the estimates of the growing stock in the Ridge Stratum of Pine Creek S.F. in 1969. The C.F.I. data were processed to give summaries of standing gross volumes by dbhob classes, regardless of any assessment of merchantability. In the calculation of volumes merchantable heights were used for the trees considered merchantable. For the trees considered unmerchantable, bole height was used, according to the definition given in Section 7.2.2. In the 'merchantable' trees there appeared to be little difference between bole height and merchantable height in most cases and the standards of assessment can therefore be considered to be fairly uniform throughout. The volume table used was supplied by the New South Wales Forestry Commission and is as follows:

$$V = 0.7583-0.3592H-0.00879H^2+B(-18.9745+6.532H-0.0235H^2$$

where:

V = gross volume (s.ft Hoppus)

H = merchantable height (ft)

B = basal area over bark (sq.ft)

For sale purposes, however, the price is not directly related to dbhob but to the under bark centre girth of the logs. On the basis of detailed observations of 150 trees felled in the course of logging at Pine Creek the following relationship was devised:

$$C.G. = -0.7769+1.8656D+194.7831/(0.5(H+S))$$

where:

C.G. = under bark centre girth of log (inches)

D = dbhob (inches)

H = merchantable height (feet)

S = stump height (feet).

The author acknowledges that this relationship should vary from one species to another and from one bark condition to another (Section 7.2.1) but in the absence of more detailed data the above equation seemed reasonable for the purpose. By assuming an average merchantable height of 40 ft and an average stump height of 2 ft the relationship can be used to find the dbhob values corresponding to any given centre-girth value. Appendix XV indicates the centre-girth limits corresponding to the four stumpage margin classes of large, medium, intermediate and small. The equivalent dbhob values obtained by using the above equation are shown below:

Margin Class	Large	Medium	Intermediate	Small
Centre Girth	8'+	5'6"-7'11"	4'-5'5"	4'-
DBHOB (ins)	47+	31-47	21-31	21-

From these figures the distribution of volume by dbhob classes was converted to a distribution by the centre girth classes of the appraisal system. The results are given in Table 21.

From this point the exercise becomes somewhat more theoretical since it involves the use of a hypothetical distribution of defect in the stand, as set out in Table 22. No comprehensive survey of defect distribution in standing trees at Pine Creek has ever been carried out. From the great detail provided by a computerized accounting system for hardwood sales it is possible to obtain an estimate of the defect being taken in current sales, but inevitably this level of defect is strongly influenced by the prevailing tree-marking practice. The estimate obtained in this way could certainly not be taken as being representative of the forest as a whole. A proper estimate could only be obtained by felling a sample selected by a suitable objective procedure. But for the demonstration of the different levels of volumes and values that could be associated with price differences the distribution shown in Table 22 seems adequate although it is no more than a guess based on my own general observation. The trees of more than 80 per cent defect, expected to comprise 15 per cent of the total gross volume, would include any trees rendered completely useless for sawing by such external defects as very bad stem form or severe fire damage.

The pattern of defect distribution suggested in Table 22 has been applied to the data of Table 21 to derive Tables 23A and 23B setting out volumes within percentage defect classes according to log size and species groups. It was assumed that the distribution of percentage defect, as opposed to absolute defect volumes, is constant over all sizes and species. Again, in the absence of definite information to the contrary, this is a convenient working assumption although it may well be disproved by furthe investigation. The nett volumes in Table 23B were obtained by subtracting the defect volume corresponding to the average percentage of a defect class from the gross volume in the same class. Thus the gross volume in the 20-29 per cent defect class for Group A Medium logs is 31.7 s.ft per acre. The defect volume corresponding to 24.5 per cent defect, at the mid-point of the class, is 7.8 s.ft. By subtraction the nett volume is 23.9 s.ft per acre.

As shown in Section 12.2 the percentage defect at which a log is worth only the minimum rate depends upon the prevailing mill door log value, the base rate and upon which of the twenty possible stumpage margins is applicable. Table 24A sets out the percentage defect at a minimum rate of 5 cents per 100 s.ft gross for each of the twenty stumpage margins under three different appraisals. Appraisal A, with mill door log value of $3.63 and base rate of $2.41 would be applicable to several parts of Pine Creek S.F. The derivation of this appraisal is set out in Appendix XIV. In brief, the sawmill site is located 4 miles from a suitable railhead, which is in turn 365 miles from the principal market. The log haul to mill is 5 miles along fair quality road and the ground conditions are such that a 50-60 H.P. crawler tractor should be able to snig 12,000 s.ft per day. Appraisal B resembles Appraisal A but an increase in the key-market price from $15.46 to $15.66 has produced an increase of $0.13 in both the mill door log value and the base rate. Again, Appraisal C is similar except that logging costs have been reduced by 20 cents from $1.22 to $1.02. This increases the base rate to $2.61 but does not affect the mill door log value. (At $1.02 the logging costs would be about the lowest possible since just felling and loading on to a truck cost $0.55).

Table 24B sets out the minimum rate percentages of defect for two further appraisals and repeats Appraisal A for convenient comparison. In Appraisal D logging costs are retained at a value of $1.22 per 100 s.ft but the mill door log value is increased to $4.03 through a reduction of $0.60 in the rail freight cost for a mill located 140 miles closer to the key-market. In the final case, Appraisal E, the mill site is considered to be the same but the logging costs are increased from $1.22 to $1.72, a difference that would exist if the forest were located a further 17 miles from the mill or if the country were steeper and the daily snig volumes lower.

Table 25 shows the estimated volumes of 'in-quota' (not 'optional') logs obtained by comparing the minimum-rate defect percentages of Table 24 with the gross and nett volumes of Table 23. For each log size and species group the in-quota volume is obtained by adding the volumes for all classes of lower defect than the minimum rate percentage, together with a proportion of the volume for the defect class into which the minimum rate percentage falls. For example minimum rate percentage for a medium blackbutt under appraisal A would be 66.8 and the gross volume in 60-69 per cent defect class is 139.2. The proportion above minimum rate percentage is calculated as (7.8/10).139.2, which is 108.6 s.ft. This volume is added to the volume in the classes of less defect for the same size and species to give the gross in-quota volume of 1013.4 s.ft for medium blackbutt under Appraisal A, as shown in Table 25. The various values were calculated from the gross and nett volumes by applying the price formula given in the previous Section, using the appropriate mill door log value, base rate and stumpage margin.

The detailed results for all five appraisals illustrated in Table 25 are summarized in Table 26. The differences between appraisals are further highlighted by the statement of average unit values given in Table 27. The above exercise serves two important purposes. The primary aim was to develop a means of assessing the average merchantable volume of the forest using standards not limited by the inflexibility of purely subjective estimates. A secondary, but no less important, result has been the illustration of fairly typical current average standing values for the forests with which this thesis is concerned.

The value of the approach as a technique for assessing merchantable volumes lies in its objectivity and its flexibility under conditions of changing prices. The average distribution of percentage defect by size and species groups would need to be established by felling a suitable sample of trees and examining them on the ground. Provided there were no great changes in this pattern of defect with time both in-quota gross volumes and nett volumes could be predicted from inventory plots estimating simply gross volumes on all classes of tree without regard to subjective assessments of merchantability. The usefulness of flexibility in a situation of possible change in prices is indicated in Table 26 in the difference between

Appraisals A and B where a simple increase of $0.20, or 1.3 per cent, in the key-market price brings an increase of 3.5 per cent in the in-quota gross volume, and 2.4 per cent in the in-quota nett volume. It is from this standing volume that the prescribed quota yield must be obtained.

However the method does suffer from several limitations First, the results obtained will only be applicable within the context of the established appraisal system, i.e. they will not be correct in the event of a change in intended end use. But the same limitation would apply to subjective estimates of merchantability if there were an expected change, say from sawmilling to pulping. The second problem is that by working only with stand averages, without identification of the defect in individual trees it is not easy to relate expected yield to standing in-quota volume except in the case of clear-felling or perhaps when all trees above a certain diameter limit are to be cut. If the logging is to be more of a selection type, the actual yield obtained will depend on both the size and the defect of the trees marked for removal. But at present in New South Wales no technique has been developed for relating predicted yields to a satisfactory tree marking prescription based on assessments of individual trees. Furthermore, all individual tree assessments presently made in inventories in New South Wales are limited by the inflexibility of subjective estimates when merchantability standards change, and by the fact that only gross volume estimates are obtained. At least by the method described above the forest manager is given an estimate of the maximum current gross <u>and nett</u> volumes from which his harvest can be drawn. The third problem is that the rate of change in merchantable volume must be estimated from independent samples, since trees once felled and measured for defect can scarcely be remeasured later for defect growth. When the sample estimates are independent not only may the estimates of change in defect levels lack precision but also it may be difficult to isolate the change into its several components. This problem is discussed in more general terms in Section 5.3. From independent samples of felled trees it is possible to estimate the total change in average defect due both to actual changes within trees and to the effects of differential selection for harvest and silvicultural treatment. This differential selection may have considerable effect since it is the author's experience that tree markers for selection logging in NSW often attempt to select trees to be felled according to their internal defect. Each tree is sounded with an axe. If it sounds particularly bad, it is not felled as a log but may be removed later in the course of silvicultural treatment. If it sounds particularly good it is left to grow on. Unless the need to create efficient regeneration openings is particularly pressing only the trees in the middle range of defect get taken. To isolate the component of defect change due to actual defect growth it would be necessary to have a means of assessing defect in standing trees so that dependent estimates could be made in the growing tree. McGrath (1965a) considers that such a technique is essential to efficient management. The author is inclined to question this assumption and the problem is discussed further in the following Section.

As mentioned earlier the method used to estimate merchantable volumes has given the added secondary benefit of providing estimates of approximate average standing values for irregular forest in New South Wales. These estimates are summarized in Tables 26 and 27. The basic study has been carried out on the estimated growing stock of the Pine Creek S.F. and at a mill door log value of $3.63 and base rate of $2.41 the in-quota volume is valued at $50.14 per acre. By increasing the key-market price by $0.20 (Appraisal B) or 1.3 per cent, the standing value increases by 10.7 per cent to $55.50 per acre. This increase is due not only to the average stumpage increase from $1.26 to $1.36 per 100 s.ft nett (7.9 per cent) but to an increase of 97 s.ft per acre (2.4 per cent) in the nett in-quota volume because of the increase in the percentage defect at minimum rate. The difference between the assessments under Appraisals A and C illustrates the very great benefits that can be obtained by a decrease in logging costs through improved access. Although assessments are seldom calculated in such detail, officers of the New South Wales Forestry Commission are well aware of the principles involved when they are arguing a financial case for new road construction. By a decrease of $0.20 in the logging cost the in-quota nett volume is increased by 9 per cent and the standing value is increased by 27.7 per cent from $50.14 to $64.05 per acre. The comparison with Appraisal D is a little different since there is no reduction in logging cost but only an increase in the mill door log value due to a $0.60 reduction in charges for rail freight to market. The increase in percentage defect at minimum rate is not as great as for Appraisal C but the increase in the average royalty of acceptable trees increases the standing value by 33.8 per cent to $67.07 per acre. Finally, Appraisal E illustrates the opposite of Appraisal C, showing the very great decrease in standing values and economic volumes when the forest is only a little less accessible than Pine Creek. The increase of $0.50 from the logging cost of Appraisal A to Appraisal E could be effected by a further 17 miles of log haulage on B class roads, by a reduction of 6000 s.ft in the daily snig volume used in the appraisal, or by some combination of the two. The difference of 29 per cent in the assessed nett in-quota volumes between Appraisals A and E shows the need for a flexible system such as the one described if estimates of merchantable volumes are to be comparable from one area to another. The true merchantability of the tree does not depend simply upon whether it looks as though it could be sawn, but upon whether it can be economically harvested and transported to the mill to be sawn.

The standing value of Pine Creek Forest at only $50.14 per acre seemed to the author to be a surprisingly low figure. It must be remembered, however, that this is only the value of existing sawlog trees, which are the economically saleable trees larger than 16 inches dbhob. Table 21 shows the C.F.I. estimate of total gross volume of all trees larger than 16 inches dbhob as being 10,036 s.ft Hoppus per acre. Starting from the hypothetical distribution of defect given in Table 22, the estimate of merchantable volume under Appraisal A is 6,342 s.ft gross or 3,985 s.ft nett per acre. Even were Table 22 considered to be incorrect it seems unreasonable to expect that any more than a maximum of 8,000 s.ft gross or 6,000 s.ft nett would be saleable from a total volume of 10,000 s.ft. On this basis the maximum possible value is probably in the vicinity of $75 per acre but without evidence to the contrary the author is inclined to believe that the calculated figure of $50 is more likely. Again it should be stressed, however, that the value estimate may vary markedly from one appraisal to another. To the calculated sawlog value could be added some further value in round timbers of less than 16 inches dbhob. The availability of a pulpwood market could further increase existing values by providing a sale potential for small and defective trees. But even were an industry established it remains to be seen that the yields per acre from selection logging would be sufficient to make pulpwood logging economical.

At a value of $50.14 per acre and with a total area of approximately 8,800 acres the total standing value of the forest is estimated to be $441,232. In the financial year 1966/67 the total gross revenue from the forest was $40,530 with a total expenditure of $16,619. The latter figure involves actual expenditure only. It does include a re-investment of $1,340 in reforestation but makes no provision for contingencies such as the need for periodic inventory. Using these figures, however, a nett income of $23,911 is obtained which when capitalised at 5 per cent interest gives a productive valuation of $478,220, or just

TABLE 21

DISTRIBUTION OF GROSS VOLUMES BY LOG SIZES

Pine Creek S.F. - Ridge Stratum

(1969)

Gross Volume Per Acre

(s.ft Hoppus)

(Trees Greater than 16 inches dbhob only)

	Species Group					
Girth Class	A	Bbt	B	C	D	Total
Large	-	-	-	-	-	-
Medium	264	1392	196	178	251	2281
Intermediate	790	1835	371	273	721	3990
Small	886	1302	582	429	566	3765
Total	1940	4529	1149	880	1538	10036

TABLE 22

PERCENTAGE REPRESENTATION OF DEFECT CLASSES

(Hypothetical)

Percentage Defect Class	Percentage Representation in Gross Volume
Less than 20	8
20-29	12
30-39	15
40-49	15
50-59	15
60-69	10
70-79	10
More than 80	15

TABLE 23A

DISTRIBUTION OF VOLUME BY SIZE AND SPECIES CLASSES

Pine Creek S.F. - Ridge Stratum

(1969)

Gross Volume Per Acre

(s.ft Hoppus)

Percentage Defect Class

Sp.	Size	-20	20-29	30-39	40-49	50-59	60-69	70-79	80+
A	Med.	21.1	31.7	39.6	39.6	39.6	26.4	26.4	39.6
	Int.	63.2	94.8	118.5	118.5	118.5	79.0	79.0	118.5
	Small	70.9	106.3	132.9	132.9	132.9	88.6	88.6	132.9
Bbt	Med.	111.4	167.0	208.8	208.8	208.8	139.2	139.2	208.8
	Int.	146.8	220.0	275.3	275.3	275.3	183.5	183.5	275.3
	Small	104.2	156.2	195.3	195.3	195.3	130.2	130.2	195.3
B	Med.	15.7	23.5	29.4	29.4	29.4	19.6	19.6	29.4
	Int.	29.7	44.3	55.7	55.7	55.7	37.1	37.1	55.7
	Small	46.6	69.8	87.3	87.3	87.3	58.2	58.2	87.3
C	Med.	14.2	21.4	26.7	26.7	26.7	17.8	17.8	26.7
	Int.	21.8	32.6	41.0	41.0	41.0	27.3	27.3	41.0
	Small	34.3	51.3	64.4	64.4	64.4	42.9	42.9	64.4
D	Med.	20.1	29.9	37.7	37.7	37.7	25.1	25.1	37.7
	Int.	57.7	86.3	108.2	108.2	108.2	72.1	72.1	108.2
	Small	45.3	67.9	84.9	84.9	84.9	56.6	56.6	84.9

TABLE 23B

DISTRIBUTION OF VOLUME BY SIZE AND SPECIES CLASSES

Pine Creek S.F. - Ridge Stratum

(1969)

Nett Volume Per Acre

(s.ft Hoppus)

Percentage Defect Class

Sp.	Size	-20	20-29	30-39	40-49	50-59	60-69	70-79	80+
A	Med.	17.9	23.9	25.9	22.0	18.0	9.4	6.7	6.1
	Int.	53.7	71.6	77.6	65.8	53.9	28.0	20.1	18.4
	Small	60.3	80.3	87.0	73.8	60.5	31.5	22.6	20.6
Bbt	Med.	94.7	126.1	136.8	115.9	95.0	49.4	35.5	32.4
	Int.	124.8	166.1	180.3	152.8	125.3	65.1	46.8	42.7
	Small	88.6	117.9	127.9	108.4	88.9	46.2	33.2	30.3
B	Med.	13.4	17.7	19.3	16.3	13.4	7.0	5.0	4.6
	Int.	25.3	33.4	36.5	30.9	25.3	13.2	9.5	8.6
	Small	39.6	52.7	57.2	48.5	39.7	20.7	14.8	13.5
C	Med.	12.1	16.2	17.5	14.8	12.1	6.3	4.5	4.1
	Int.	18.5	24.6	26.9	22.8	18.7	9.7	7.0	6.4
	Small	29.2	38.7	42.2	35.7	29.3	15.2	10.9	10.0
D	Med.	17.1	22.6	24.7	20.9	17.2	8.9	6.4	5.8
	Int.	49.1	65.2	70.9	60.1	49.2	25.6	18.4	16.8
	Small	38.5	51.3	55.6	47.1	38.6	20.1	14.4	13.2

TABLE 24A

PERCENTAGE DEFECT AT MINIMUM RATE

	Appraisal A					Appraisal B					Appraisal C				
	MDLV $3.63		Base Rate $2.41			MDLV $3.76		Base Rate $2.54			MDLV $3.63		Base Rate $2.61		
Species	A	Bbt	B	C	D	A	Bbt	B	C	D	A	Bbt	B	C	D
Large	73.7	70.7	69.2	65.0	61.9	74.4	71.5	70.2	66.2	63.3	77.8	75.3	74.1	70.5	67.9
Medium	70.0	66.8	65.0	60.7	58.1	70.9	67.9	66.2	62.2	59.8	74.7	72.1	70.5	66.9	64.7
Intermediate	66.0	63.0	60.7	56.7	53.5	67.1	64.3	62.2	58.5	55.6	71.3	68.8	66.9	63.5	60.8
Small	53.5	53.5	53.5	47.7	47.7	55.6	55.6	55.6	50.4	50.4	60.8	60.8	60.8	56.0	56.0

TABLE 24B

PERCENTAGE DEFECT AT MINIMUM RATE

	Appraisal A					Appraisal D					Appraisal E				
	MDLV $3.63		Base Rate $2.41			MDLV $4.03		Base Rate $2.81			MDLV $3.63		Base Rate $1.91		
Species	A	Bbt	B	C	D	A	Bbt	B	C	D	A	Bbt	B	C	D
Large	73.7	70.7	69.2	65.0	61.9	75.7	73.2	72.0	68.5	66.0	63.4	59.1	57.1	51.2	46.8
Medium	70.0	66.8	65.0	60.7	58.1	72.6	70.0	68.5	65.0	63.0	58.2	53.8	51.2	45.2	41.6
Intermediate	66.0	63.0	60.7	56.7	53.5	69.2	66.8	65.0	61.9	59.4	52.5	48.4	45.2	39.6	35.2
Small	53.5	53.5	53.5	47.7	47.7	59.4	59.4	59.4	51.1	51.1	35.2	35.2	35.2	27.2	27.2

TABLE 25A

APPRAISAL A - M.D.L.V. $3.63 B.R. $2.41

Volume (s.ft) and Value ($) Per Acre

Trees Above Minimum Rate

	Medium			Intermediate			Small		
Sp.	Gross	Nett	Value	Gross	Nett	Value	Gross	Nett	Value
A	200.6	117.8	2.54	568.8	342.2	5.82	502.8	328.6	2.84
Bbt	1013.4	607.0	10.88	1266.2	775.3	11.15	738.9	482.8	4.17
B	139.2	84.3	1.36	247.5	153.6	1.94	330.3	215.9	1.86
C	118.7	73.8	0.94	168.1	107.2	1.09	206.1	141.2	0.92
D	159.8	101.0	1.11	409.2	267.4	2.31	272.0	186.4	1.21
Total	1631.7	983.9	16.83	2659.8	1645.7	22.31	2050.1	1354.9	11.00

TABLE 25B

APPRAISAL B - M.D.L.V. $3.76 B.R. $2.54

Volume (s.ft) and Value ($) Per Acre

Trees Above Minimum Rate

	Medium			Intermediate			Small		
Sp.	Gross	Nett	Value	Gross	Nett	Value	Gross	Nett	Value
A	203.0	118.4	2.69	577.5	345.3	6.28	530.7	341.3	3.29
Bbt	1028.7	612.5	11.70	1290.1	783.8	12.16	779.9	501.5	4.83
B	141.5	85.1	1.47	253.1	155.6	2.14	348.6	224.2	2.16
C	121.4	74.7	1.03	175.5	110.6	1.24	223.5	149.9	1.11
D	165.2	103.2	1.25	431.9	277.8	2.68	294.9	197.9	1.47
Total	1659.8	993.9	18.14	2728.1	1673.1	24.50	2177.6	1414.8	12.86

TABLE 25C

APPRAISAL C - M.D.L.V. $3.63 B.R. $2.61

Volume (s.ft) and Value ($) Per Acre

Trees Above Minimum Rate

	Medium			Intermediate			Small		
Sp.	Gross	Nett	Value	Gross	Nett	Value	Gross	Nett	Value
A	213.1	120.9	2.94	610.7	355.2	7.02	591.9	367.6	4.00
Bbt	1087.2	628.9	13.00	1372.6	813.1	13.89	869.7	540.0	5.87
B	149.9	87.9	1.66	270.5	161.8	2.47	388.8	241.4	2.62
C	129.8	77.7	1.19	189.8	115.9	1.46	259.6	166.3	1.39
D	177.5	107.6	1.45	481.7	299.1	3.25	342.4	219.5	1.84
Total	1757.5	1023.0	20.24	2925.3	1745.1	28.09	2452.4	1534.8	15.72

TABLE 25D

APPRAISAL D - M.D.L.V. $4.03 B.R. $2.81

Volume (s.ft) and Value ($) Per Acre

Trees Above Minimum Rate

	Medium			Intermediate			Small		
Sp.	Gross	Nett	Value	Gross	Nett	Value	Gross	Nett	Value
A	207.5	119.5	3.00	594.1	351.0	7.25	579.4	363.2	4.30
Bbt	1057.9	621.5	13.38	1335.9	800.1	14.35	851.5	533.6	6.31
B	146.0	86.8	1.72	263.5	159.3	2.57	380.6	238.5	2.82
C	126.4	76.5	1.23	185.4	114.3	1.54	253.8	163.7	1.54
D	173.2	106.1	1.53	471.6	295.5	3.50	334.8	216.1	2.03
Total	1711.0	1010.4	20.86	2850.5	170.2	29.21	2400.1	1515.1	17.00

TABLE 25E

APPRAISAL E - M.D.L.V. $3.63 B.R. $1.91

Volume (s.ft) and Value ($) Per Acre

Trees Above Minimum Rate

	Medium			Intermediate			Small		
Sp.	Gross	Nett	Value	Gross	Nett	Value	Gross	Nett	Value
A	168.4	106.3	1.60	436.5	287.6	3.22	259.6	194.5	0.84
Bbt	796.2	519.1	6.19	900.9	614.8	5.59	381.5	285.8	1.24
B	104.5	69.7	0.73	164.2	114.4	0.87	170.5	127.8	0.56
C	78.9	55.0	0.42	97.9	71.4	0.41	76.4	60.9	0.17
D	97.5	69.8	0.44	211.1	158.3	0.69	101.0	80.6	0.22
Total	1245.5	819.9	9.38	1810.6	1246.5	10.78	989.0	749.6	3.03

TABLE 26

SUMMARY OF STANDING VOLUMES AND VALUES

Growing Stock of Pine Ck. S.F. Ridge Stratum

Trees of Less Defect Than Minimum Rate Percentage

	Appraisal MDLV	Appraisal Base Rate	Gross Volume (s.ft H/acre)	Nett Volume (s.ft H/acre)	Value ($/acre)
A	3.63	2.41	6342	3985	50.14
B	3.76	2.54	6566	4082	55.50
C	3.63	2.61	7135	4303	64.05
D	4.03	2.81	6962	4246	67.07
E	3.63	1.91	4045	2816	23.19

TABLE 27

SUMMARY OF STANDING UNIT VALUES

(Volumes and Values as in Table 25)

	Appraisal MDLV	Appraisal Base Rate	Value/100s.ft gross ($)	Value/100s.ft nett ($)
A	3.63	2.41	0.79	1.26
B	3.76	2.54	0.84	1.36
C	3.63	2.61	0.90	1.49
D	4.03	2.81	0.96	1.58
E	3.63	1.91	0.57	0.82

a little more than the estimated standing value. The inference is that current capital fixed in the standing trees is in fact earning nearly 5 per cent interest. During the period 1966/67, for which the above net income was quoted, the yield was just over 1.5 million super feet. Detailed records of forest yields have been kept since the first management plan was written for the forest in 1920. A brief summary of these is given as Table 28.

TABLE 28

Average Yield from Pine Creek S.F.

(s.ft Hoppus)

Period	Total Yield	Annual Yield	Comment
1921-39	11,534,286	640,794	Imposition of conservati practice after early exploitation.
1939-54	38,082,490	2,538,833	World War II and post war exploitation.
1954-68	25,024,562	1,787,469	Commencement of current management plan.

These figures suggest that a yield in the order of the 1.5 million super feet obtained in 1966/67 could be maintained virtually in perpetuity. From this it can be inferred that a continuation of the present pattern of cutting in the existing level of growing stock and with the existing price levels should lead to a continuing return of approximately 5 per cent on the capital fixed in timber.

It appears to the author that the long argued interest rate of 5 per cent for forestry investment is now being challenged more and more strongly. American workers such as Baumol (1968) and Seagraves (1970) are arguing for social discount rates of at least 10 per cent. In Australia, Grant (unpublished MSS) also argues that in this developing country public investment, including investment in forestry projects, should be directed primarily towards the many available projects capable of earning at least 10 per cent. If the current capital tied up as standing timber in irregular forests is not earning these interest rates, but is still earning only 5 per cent, the forest owner should review the implications for his management. It may be that his forests are not stocked with trees capable of earning 10 per cent, but that such trees are available. It may be that he could manipulate the growing stock to increase financial productivity.

But even if no trees are capable of earning at the desired rate, he may still be able to manipulate his pricing structure to improve their earning capacity. These matters are the subject of the next Section. If neither of the above improvements is possible, the economic justification for irregular forestry must lie in the valuation of other so-called intangible benefits, such as recreational values, at a further 5 per cent of the capital retained. If this is not considered to be a realistic valuation of the intangible benefits, management must seriously consider the feasibility of a heavier exploitation of irregular forests with the intention of investing the realised capital either in more profitable forestry projects or in other social enterprises such as education or engineering works.

11.4 Value growth in individual trees

From the explanation of the New South Wales stumpage appraisal system given in Section 11.2 it is clear that the value growth of individual trees for a potential sawlog market depends partly upon their ability to increase in nett volume and partly upon the rate at which they can increase in unit value by moving through the price/size gradient provided by the nett stumpage margins. I have therefore taken what growth figures I had available for individual trees and have combined them in what could be described as a tree-growth simulation model. I have run the model in conjunction with the NSW stumpage system and have obtained estimates of the financial performance of individual trees in various conditions. I shall begin with a statement of the technique adopted and from there proceed to discuss the many limitations of the technique. Despite these limitations, however, many important results have been obtained.

11.4.1 Tree growth projection model

Much of the data used in the formulation of the model has already been presented in Sections 7.2 and 7.4 and in the early part of Section 11.3. The basic premise is that within vigour classes within species groups it is possible to set diameter growth rates that are independent of diameter.

The eleven important commercial species found in Pine Creek S.F., and occurring generally on the north coast of NSW and in southern Queensland, were separated into three groups according to their average growth rates as indicated in Figure 10. These growth groups should not be confused with stumpage appraisal sale groups which are determined according to the expected financial returns to sawmillers in converting and marketing sawn timber. Within growth groups separation was made into six vigour classes according to the procedure of Hoschke (1967) and described in Section 7.4. Fixed annual diameter increments were set for each vigour class within each species group. The increments used are presented in Table 29 and seem to be a reasonable averaging of the data from several permanent inventories in NSW, some of which is presented in Figures 11-17. They should only be applied to trees larger than 16 inches dbhob and less than about 40 inches dbhob. In each vigour class except class 6 the increment for Group I is greater than for Group II, which is in turn greater than for Group III. The rates proposed for Group I are similar to those suggested by Curtin (1966) for a stand of more than 100 sq.ft basal area. They are markedly lower than his suggested rates for stands of less than 100 sq.ft and in this sense could perhaps be considered conservative.

On the basis of data from the periodic inventory of Pine Creek regressions were established for the relationship of merchantable height to dbhob and those adopted for this model are illustrated in Figure 18. A separate regression was adopted for each of the three growth groups. Individuals would vary considerably about these regression lines and at best they could be considered averages. It could perhaps be argued that merchantable height is fixed in the pole stage of the tree's development and that the stand averages presented represent only the results of selective removal of inferior stems resulting in higher average heights among the remaining larger trees. The author was unable to obtain conclusive evidence for this case or for the argument in favour of continuing height growth but decided to accept the latter. In any case, the rate of height growth adopted is not very rapid, particularly in Group III species, and it is not likely to have a very significant effect on the calculated volume or value growth rates. The argument for the effects of differential selection was accepted for those regions of the height/diameter curve appeared to fall with increasing diameter. The perpetuation of this artificial relationship was considered undesirable and merchantable height was maintained constant once it had reached the maximum value calculated by the appropriate regression for the species group.

Log lengths were obtained by subtracting a standard stump height of 2 feet for all sizes in all species. The one regression, discussed in Section 11.3, was used to derive centre girth of log from dbhob and merchantable height. Commercial volumes were calculated from the standard 'quarter-girth' formula:

$$\text{Gross Volume} = (\text{C.G.}/4)^2 . \; L/12$$

TABLE 29

AVERAGE ANNUAL DIAMETER INCREMENT PER TREE
(Rates Adopted for Growth Simulation Model)

(inches dbhob per annum)

Vigour Class	Species Growth Group I	II	III
1	0.365	0.297	0.145
2	0.324	0.253	0.132
3	0.282	0.208	0.118
4	0.241	0.160	0.105
5	0.200	0.116	0.091
6	0.158	0.073	0.077

where:

C.G. = centre girth under bark (inches)

L = log length (feet)

and the gross volume is given in super feet Hoppus.

It can be seen therefore that projection of centre girth and of gross volume, both of which are essential to the calculation of stumpage, are made dependent solely on the growth in dbhob. The computer program which the author has written to operate the model is designed on the following basis. The user may specify any initial diameter from which he wishes to examine subsequent financial growth. A tree may be in any one of eighteen growth conditions, represented by the six vigour classes within three species groups. The initial height, centre girth and gross volume will be determined by the relationships of height and centre girth with dbhob as mentioned above. Within each species group the initial values will be the same for all vigour classes. The program then projects the initial dbhob forward according to the eighteen possible rates listed in Table 29. The eighteen different diameters generated in this way, together with their associated values for height, centre-girth and gross volume, are printed out at simulated time intervals specified by the user.

The projection of centre-girth and gross volume, however, is not sufficient for a determination of price. It is essential to be able to project defect volume and hence nett volume. In fact the author's original aim in commencing the development of a model was founded in the need to assess the real importance of defect growth. The real problem lies in the fact that the literature contains no published attempts to predict the rate of defect growth in individual trees. To observe rates of defect growth it would almost certainly be necessary to use a technique for assessing internal defect volumes in standing trees, and again no reliable, general technique for this task appears to be available. The very great mensurational problems involved were discussed in Section 11.1, together with some discussion of factors that may affect the rate and extent of defect development. It seems clear that the development, and perhaps the application, of mensurational procedures for assessing defect volumes in standing trees may be very costly. A prior assessment of the importance of the information is therefore essential.

As a basis for the study I have examined the financial implications of three ways in which defect volume may change. The first of these growth patterns is the maintenance of a constant defect volume equal to the defect volume at the start of the growth projection. This is of course the situation for a sound tree which maintains a constant defect volume of zero. In fact, the NSW Forestry Commission stipulates a minimum defect allowance of a 4 inch diameter pipe even in apparently sound trees. A tree of 16 inches dbhob and 42 ft merchantable height should yield a log of 40 foot length, 38 inches centre girth and 300 super feet gross volume. A 4 inch pipe in such a tree represents a defect volume of 53 s.ft true, equivalent to 17.8 per cent defect. If the tree grew in gross volume, but remained sound, the minimum allowable defect volume would increase only very slightly through increase in log length, but the defect percentage would be decreasing with increasing gross volume. A second situation in which defect volume may remain constant is that described by Shigo and Larson (1969) for the spread of fungal decay in North American hardwoods. The Hymenomycetous fungi which cause decay can only attack wood which has been altered first by a process of discoloration after some wounding of the tree and then by the invasion of bacteria and non-hymenomycetous fungi. The process of discoloration can proceed only while the wound is open. Once the decay has spread to the extent of the volume of discolored wood it has reached a maximum volume provided there is no subsequent injury. This situation may obtain in some eucalypts but the possibility of multiple injuries complicating the pattern of defect development seems quite high and the action of termites in causing defect is probably not bound by any such restriction.

The second pattern of defect development tested by the model is one of maintaining a constant defect percentage. This pattern is in contrast to the previous one in which the defect percentage was decreasing as gross volume increased and defect volume remained constant. When the defect percentage remains constant the average diameter of the defect column is linearly related to dbhob, which means that the growth in the diameter of the defect column is directly proportional to the external diameter growth. The nett volume of the tree will be increasing.

The third pattern of development tested in the model is one of maintaining constant nett volume. As fast as growth adds to the gross volume at the outside of the tree, some agency of defect destroys an equivalent volume of useful wood in the centre of the bole. The author has often heard this pattern of defect development conjectured in the field when inspecting stands containing poor quality suppressed trees.

The three patterns of development which can be tested on option are therefore:

(a) Constant Defect Volume

(b) Constant Defect Percent

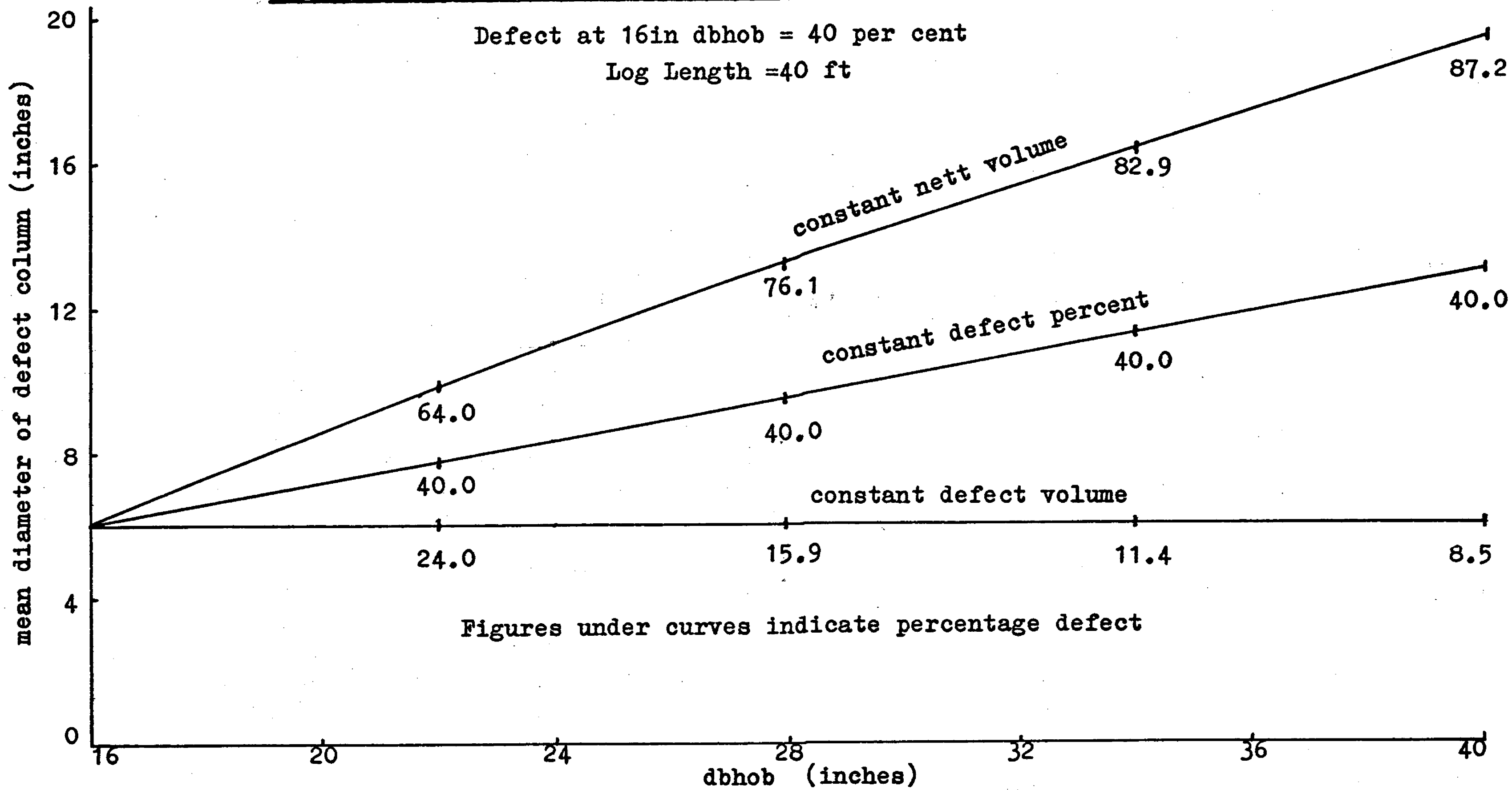
(c) Constant Nett Volume.

Figure 24 shows the way in which the diameter of the defect column increases with increasing dbhob, using as an example a 40 ft log with 40 per cent defect at 16 inches dbhob. The way in which defect percentage changes is also shown. The percentage of defect is increasing if a constant nett volume is maintained but decreasing if there is a constant defect volume.

For each run of the model the user must specify the initial diameter from which he wants to project the volume and value growth. He may specify up to four initial percentages of defect to provide a starting point for the

FIGURE 24

INCREASE IN DIAMETER OF DEFECT COLUMN WITH INCREASE IN DBHOB



projection of nett volume. The initial nett volumes may be projected according to each of the three development patterns discussed above. Through these patterns of development the projection of nett volume depends solely on the projection of gross volume which is itself ultimately related solely to the growth projection of dbhob.

The numerous available projection paths are all followed concurrently. The external growth may follow eighteen projection paths, one for each of six vigour classes within three growth groups according to species. For each of these there are a further twelve paths for the projection of nett volume, according to the four possible initial defect percentages and the three patterns of defect development. The model is therefore capable of the concurrent projection of a tree's development in 216, (12 x 18), situations. The standing value of the tree in any of these situations at a given time depends upon its gross volume, nett volume and centre girth, as well as upon the species group into which it falls for the selection of a stumpage margin. The examination of the standing value in the five principal sale species groups is therefore superimposed on the 216 growth situations, making 1080 value situations in all. No relationship between the growth species groups and the sale species groups is assumed in the structure of the model.

For each of the sale situations four values are printed. First there is the total standing value of the tree. Second there is the price per 100 s.ft gross volume. If this price is less than a specified minimum rate, the standing value is recalculated at the minimum rate per unit gross volume and a warning indication given. The third figure printed is the percentage rate of value increment since the initial value at time zero. The fourth figure is the percentage rate of value increment since last printout.

The structure of the model in terms of the number of situations examined may seem unduly complex but in fact it is possible to supply data parameters which will cause the suppression of various items of calculation and output, thus confining the run to areas of particular interest. In addition to the initial dbhob and the initial defect percentages, the user can also supply as data the mill door log value, the base rate, the minimum rate, the maximum simulated time and the printout frequency.

11.4.2 Principal limitation of the model

Clearly the model is immediately limited by the fact that it embodies the NSW Forestry Commission sawlog stumpage appraisal system as the fundamental basis for appraising financial performance. Strictly, the method is only applicable to the current marketing situation in New South Wales. But in that the NSW system is still based on the form of a residual stumpage, aiming to take into account the principal costs actually encountered in the harvesting and marketing of sawlog trees, it may not be a bad approximation for the real financial values in growing sawlogs in other States, whatever their current method of appraisal. Whether or not this argument is accepted, the use of an actual stumpage appraisal system does permit a realistic evaluation of the value of various growth situations under that system.

A second important limitation of the approach is that the study is confined to the value of sawlog trees, generally in excess of 16 inches dbhob. It is therefore better suited to the study of the larger of existing trees and is not properly applicable to the study of stands or trees from time of establishment. Smaller trees may have an entirely different potential on a pulp or pole market as in the case studied by Holmes (1968).

The third and most important limitation is that the basic growth model is a tree model not bound by any consideration of the effects of different stand characteristics. Some of the problems of such a model were discussed in Section 10.2.4. Not only will the conditions for tree growth be affected by stand characteristics, but also will be possible management alternatives be greatly affected by the distribution of various tree types within the stands. But the model can show the wide differences that can exist in the financial potential of individual trees when certain crown qualities and other characteristics will be perpetuated. Ultimately it was hoped to show whether or not there were sufficient differences in potential to make it worth the high cost of developing a technique for assessing defect in standing trees with a view to evolving tree-marking procedures to take advantage of different financial potentials.

11.4.3 Some results of the financial model

Figures 25-27 are presented to indicate the way in which the model simulates the physical development of the tree. They may serve as useful references in the analysis of the highly complex financial situation that unfolds in later discussion. The differences in the dbhob/centre-girth relationship between growth groups, as illustrated in Figure 25, are due to the different dbhob/merchantable height relationship used for each group. Shorter log lengths in Group III lead to slightly higher centre-girth for a given dbhob. Figure 26 shows the differences between growth groups in the relationship between gross volume and dbhob. Again, these differences are due to the dbhob/merchantable height relationships used. Figures 27A-C show the rate of gross volume development with time, starting from a diameter of 16 inches. Differences between vigour classes within growth groups are due to differences in diameter growth rates, and are most marked in growth group I. The differences between growth groups are the result of differences in both diameter growth rates and dbhob/merchantable height relationships. The development of other features can be deduced from the data given earlier.

FIGURE 25

RELATIONSHIP OF CENTRE GIRTH OF LOG TO DBHOB

(Financial Model)

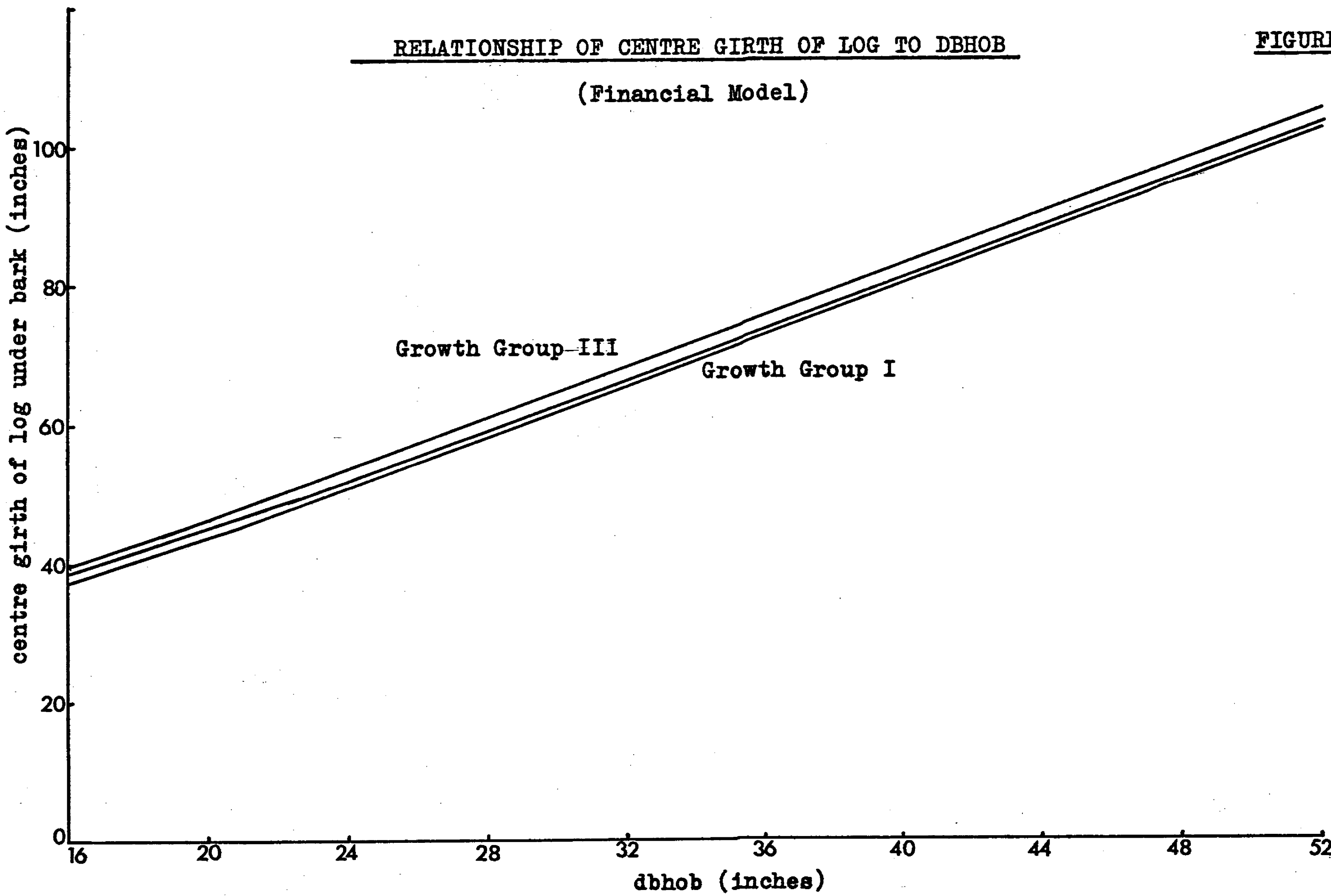
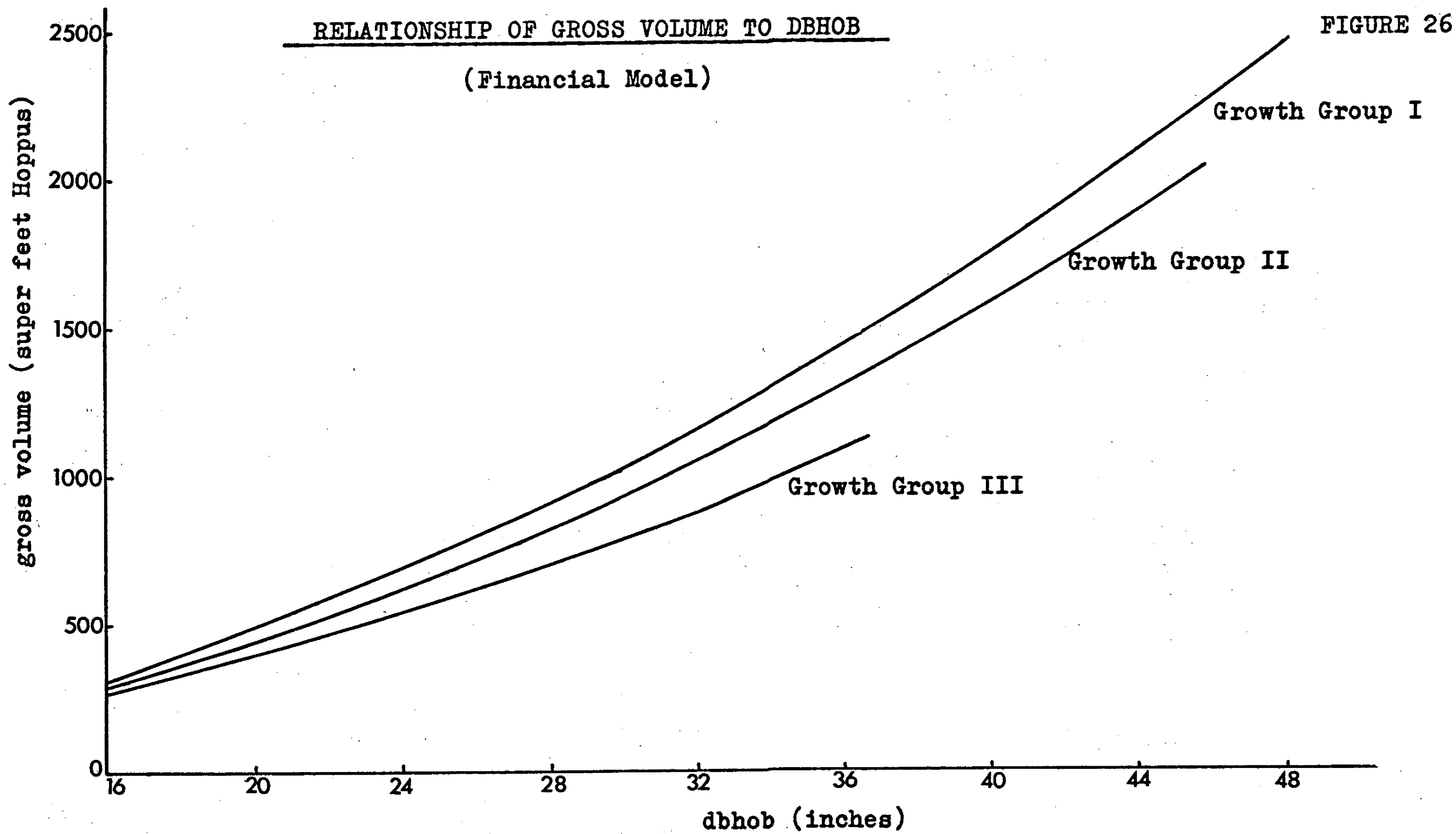


FIGURE 26

RELATIONSHIP OF GROSS VOLUME TO DBHOB

(Financial Model)



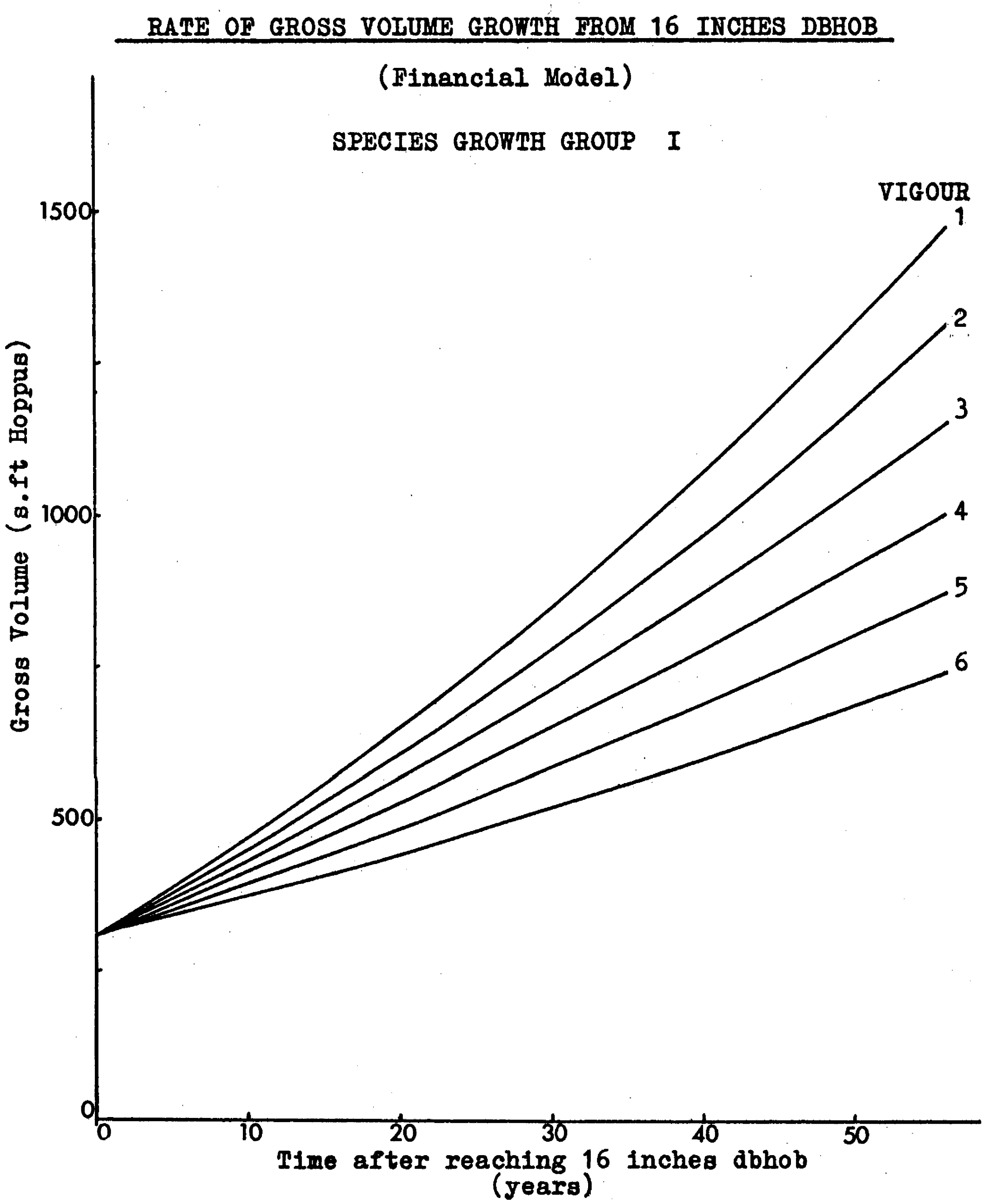

RATE OF GROSS VOLUME GROWTH FROM 16 INCHES DBHOB
(Financial Model)
SPECIES GROWTH GROUP I
VIGOUR
1
2
3
4
5
6
Gross Volume (s.ft Hoppus)
1500
1000
500
0
0
10
20
30
40
50
Time after reaching 16 inches dbhob
(years)

FIGURE 27B

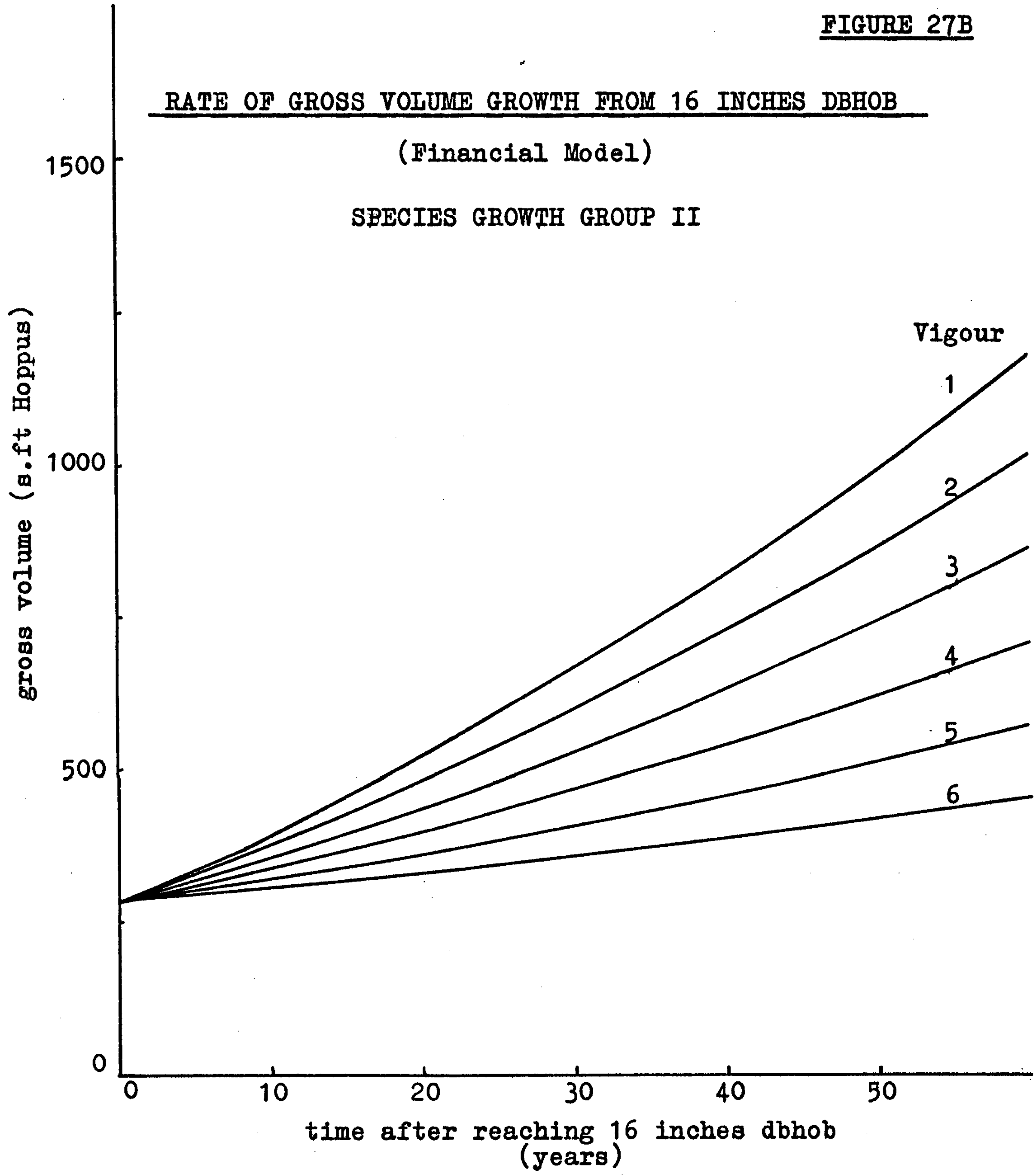
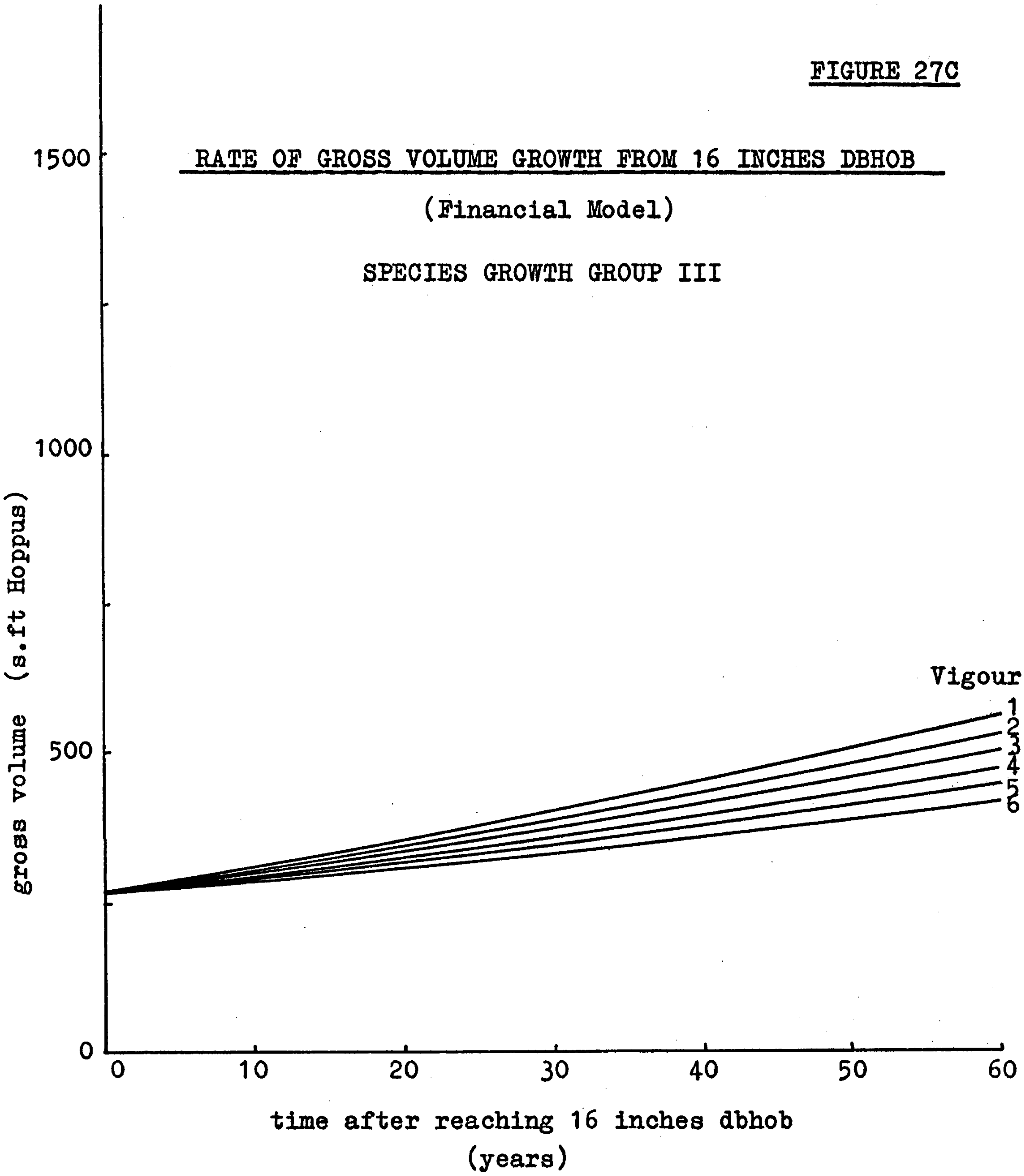

RATE OF GROSS VOLUME GROWTH FROM 16 INCHES DBHOB
(Financial Model)
SPECIES GROWTH GROUP II
Vigour
1
2
3
4
5
6
gross volume (s.ft Hoppus)
1500
1000
500
0
0
10
20
30
40
50
time after reaching 16 inches dbhob
(years)

FIGURE 27C


RATE OF GROSS VOLUME GROWTH FROM 16 INCHES DBHOB
(Financial Model)
SPECIES GROWTH GROUP III
1500
1000
500
0
gross volume (s.ft Hoppus)
Vigour
1
2
3
4
5
6
0
10
20
30
40
50
60
time after reaching 16 inches dbhob
(years)

The analysis of the financial information produced by the model has proved extremely complex. Although value growth has been projected for numerous situations it seems unreasonable to attempt to present them all here, considering the wide spectrum of topics already covered in this thesis. But I consider that even the few figures that will be discussed in depth indicate that the model has but opened the door on a whole field of study barely touched for irregular forest, namely the use of management inventory to assess financial potential for a selective cutting prescription.

When the model was first contrived it was considered that the average rate of value increment would be a useful measure of performance. Because 16 inches dbhob was considered the smallest size at which a tree could take on a value as a sawlog, it was decided to follow value increment from this point. The rate of value increment was calculated from the standard compound interest formula:

$$p_n = p_o (1 + r)^n$$

where:

p_o = initial tree value (at 16 inches dbhob)

p_n = tree value after growing for n years

r = rate of value increment.

Value increment rates calculated for different growth groups and vigour classes are indicated in Figures 28 and 29. For these and later examples the reference example is the case of a blackbutt (growth group I) of 30 per cent initial defect, in vigour class 3 (codominant, fair crown) in an appraisal situation of mill door log value $3.63 and base rate $2.41 per 100 s.ft. Figure 28 indicates that for trees of the same stumpage margin as blackbutt, but in different growth groups, there is wide variation in average percentage value increment. In Group III the value increment is less than 1.3 per cent for the 40 years after first attaining a sawlog value at 16 inches. Figure 29 indicates a wide variation in percentage value increment between vigour classes within growth group I. The most striking feature of both Figures, however, is their marked discontinuity. The points of discontinuity occur whenever the tree moves from one stumpage margin bracket to the next through an increase in centre-girth. In the case of Figure 29 the first discontinuity in each curve occurs as the expected log from the tree increases from 'small' to 'intermediate' at a dbhob of about 22.3 inches and a centre-girth of 48 inches under bark. With decreasing vigour the time at which the transition occurs after reaching 16 inches dbhob increases and correspondingly the resulting increase in average percentage value increment decreases.

Disregarding various interactions in the economy as a whole, there is one principal type of financial implication from Figure 29. Suppose society demands a return of at least 5 per cent on public investment. The standing value of the trees in the forest represents a store of public capital which could be left to appreciate as the trees grow, or which could, in simple theory, be realised and reinvested if the trees were felled. Figure 29 indicates that for the conditions stated, only trees of vigour classes 1-3 ever earn more than 5 per cent from the time they first take on a value as a sawlog. If alternative projects are available for public investment at 5 per cent interest, trees of vigour classes 4-6 should be harvested as soon as they take on a sale value.

Figure 30 highlights the fact that growth, per se, is not sufficient to ensure a high average return in any of the vigour classes. The vertical lines on Figure 30 indicate the points of transition from one stumpage margin to another through increase in centre-girth. Tree growth is not affected by the stumpage margin and either side of the transition point the rate of value increment is steadily decreasing. Increased <u>average</u> percentage value increment is attained only by the application of the new margin from the transition point. To achieve maximum benefit under this system the tree should be harvested as soon as possible after reaching the new margin since subsequent growth, as indicated in Figure 30, will not sustain returns with increasing size.

The analysis of this and other situations is made unduly complex by the fact that the stumpage margins are applied as discrete steps and not as a continuous price/size gradient. Figure 31, however, shows the way in which a continuous price/size gradient could be applied to ensure a continuing return of 5 per cent as the tree grows. The theoretical margins shown in Figure 31 were calculated in the following manner. The value of the tree at 16 inches dbhob under the present system is taken as the initial investment principal. Using the standard formula for appreciation at compound interest it is possible to calculate the value to which this principal must accumulate to earn 5 per cent for any given period.

Thus,

$$W = P_o(1.05^n)$$

where:

W = required value to earn 5 per cent

P_o = initial values at 16 inches dbhob

n = number of years for growth

In order to calculate the stumpage margin needed to bring the actual value up to the required value it is first necessary to calculate the price with no margin. If no stumpage margin for size is allowed the actual price may be calculated as

$$X = (GV_n \cdot BR) - (DV_n \cdot MDLV)$$

where:

X = actual price without margin

BR = stumpage base rate

$MDLV$ = mill door log value

GV_n = gross volume after n years

DV_n = defect volume after n years

The gross and defect volumes after any period of growth, under given conditions, are calculated by the growth model. The stumpage margin needed to equalise X, the actual price, with W, the desired price, may then be calculated as:

$$\text{Margin} = (W - X)/NV_n$$

where NV_n = nett volume after n years and the stumpage margin is to be applied to the nett volume.

Figure 31 indicates that for a tree of vigour class 3 from growth group I, i.e. one of the more vigorous trees of the forest, the stumpage margins needed to give an existing 16 inch tree an earning potential of at least 5 per cent would be greatly in excess of the existing margins beyond about 25 inches dbhob. If the existing margins represent a fair approximation of the sawmiller's capacity to pay, it is clear for the situation illustrated that it would be virtually impossible to provide a pricing structure that would economically justify the retention of existing small trees to grow them beyond 25 inches dbhob. This conclusion is made on the acceptance of a minimum earning rate of 5 per cent for public capital. If the minimum earning rate were set at 10 per cent, and only timber values were taken into account, there would be even stronger argument for harvesting as soon as the trees became saleable.

The financial argument applied above is incomplete in several respects. In the first place the forest manager is given no indication of the financial prospects of the many trees he already has in the larger size classes of his irregular forest. Figure 32 shows the complexity of the situation in respect of some of these. The tree which is currently 20 inches dbhob has greatly enhanced prospects if it can be left the 10 years needed to allow it to grow from a small-sawlog producer to an intermediate-sawlog producer. The economic advantage gained in this way is quickly lost, however, if the tree is not harvested soon after growing from one class to another, and the further prospect of changing from intermediate to medium, 30 years later, is not particularly attractive. The tree which is now 28 inches dbhob does make substantial improvement in passing from the intermediate to the medium category after 15 years, but even then the maximum rate of return on the capital retained for the period is only 3 per cent. From this discussion it can be seen that a tree-marking prescription for harvesting would be extremely complex if it aimed to secure the maximum return on the capital retained in the form of standing saleable trees. For just the few situations indicated in Figure 32 such a prescription would need to take into account which trees could move from one log size group to another before the next cutting cycle and how long it would be before those that did move could be harvested to realise on their gain in value. Yet Figure 32 illustrates only a small sample from the whole range of growth groups, vigour classes, defect classes and sale groups represented in an irregular eucalypt forest. The inventory needed to maximum advantage of this situation would need to be similarly detailed.

A different aspect of the difficulty of analysing the financial potential of the irregular forest is well illustrated by Figure 33. Average percentage rates of value increment are presented for three of the five stumpage appraisals discussed in Section 11.3. Another appraisal, Appraisal F, is also illustrated here. This appraisal has mill door log value as for D but logging cost as for E. Those used here are:

Appraisal	M.D.L.V.	Base Rate
A	3.63	2.41
D	4.03	2.81
E	3.63	1.91
F	4.03	2.31

Of those listed above, Appraisal D would naturally appear the most favourable, yet in Figure 33 it appears the least favourable in terms of the average percentage rate of value increment. The reason for this apparent anomaly is made clear in Table 30. Tree growth is the same under each appraisal and the differences in percentage value increment only arise when the tree grows from one stumpage margin to another, i.e. when it reaches 48 inches centre-girth at 22.3 inches dbhob. Although the greatest absolute gain in tree value is made under Appraisal D, the greatest percentage gain is made under Appraisal E. Figure 33 shows how this differential in percentage value increments is perpetuated as the tree continues to grow. If the forest manager were in a situation in which he was expected to fell a fixed volume of timber, and if the proceeds of his operations were needed for re-investment in some project capable of earning at least 5 per cent interest, he would do better to obtain the yield from areas under Appraisal D than under Appraisal E. For a fixed volume yield the high level of capital realised under Appraisal D could be reinvested at a higher interest rate than if it were retained in the forest. The capital retained in the forest under Appraisal E would have the same volume growth as under Appraisal D, but would have a much higher percentage rate of value increment. Moreover, if the felling were carried out under Appraisal E there would be a much lower realisation of capital for alternative investment. There is therefore a strong financial incentive for logging in the accessible forests with high stumpage values.

The same incentive applies if portion of the capital realised from felling is to be reinvested in the regeneration of the blank areas so created. If it is assumed that it would take 50 years to grow a 16 inch tree of the type described in Table 30, it is possible to calculate the present nett worth of a 16 inch tree under each appraisal. Using a discount rate of 5 per cent the present nett worth under each appraisal is as follows:

Appraisal	Value at 16 in.	P.N.W.
A	$2.13	$0.186
D	$2.99	$0.261
E	$0.59	$0.052
F	$1.45	$0.127

Thus, to earn 5 per cent interest, a maximum of 26 cents could be spent in regenerating a single tree to be harvested under Appraisal D 50 years later when it reached 16 inches dbhob. Under Appraisal E this figure drops to 5 cents per tree even though in these more inaccessible areas the actual costs of regeneration and subsequent protection are likely to be higher. Again the financial incentive is very strongly towards the logging and possible regeneration of the higher stumpage areas.

The arguments applied above in the examination of percentage value increment under different appraisals may be used equally well in the examination of different percentage defect classes as illustrated in Figure 34. The subsequent value increment on trees of low percentage defect does not represent a high rate of return on the capital so retained. In this context, however, it should be borne in mind that the discussion to this point has been confined to the situation in which defect percentage remains constant.

All the arguments just presented take into account the productivity of capital, a particularly relevant consideration when opportunities for alternative investment are available. In the case of New South Wales investments managed by the Forestry Commission are primarily timber production enterprises. The Forestry Commission does not act as an entirely self-contained business enterprise, however, and its budget is regulated by the Treasury who will compare forestry proposals with other opportunities for public investment. Prominent among the forestry proposals are the Radiata Pine plantation projects which are financed from loan moneys. Considerable care is taken in the analysis

TABLE 30

PERCENTAGE VALUE INCREASE UNDER DIFFERENT APPRAISALS

Growth Group I
Vigour Class 3
Sale Group - Bbt

Initial Defect 30%
Constant Defect Percent

dbhob	16.0	22.3	% increase
Centre girth (inches	37.6	48.0	
Gross volume (s.ft H.)	308.0	602.3	
Nett volume (s.ft H.)	215.6	421.6	
Stumpage margin ($)	-0.9	-0.2	
Value under Appraisal A ($)	2.13	7.11	334
Value under Appraisal D ($)	2.99	8.80	294
Value under Appraisal E ($)	0.59	3.38	573
Value under Appraisal F ($)	1.45	6.51	449

of costs and benefits for these proposals, not only to satisfy State Treasury officials but also the Commonwealth Treasury who provide further assistance under the Softwoods Agreements Act. Projects for the regeneration of native forest are also financed from loan funds, although at this time they are not further supported by the Commonwealth. But the maintenance, protection and improvement of the forest estate generally is financed by a proportion of previous revenue. The budget is based on estimates for future works together with carefully collated statements of past revenue and expenditure. There is no requirement, however, for a statement of the capital retained in the standing trees. Thus, although the Treasury is concerned with the productivity of new cash capital, it does not appear to be anxious to consider the productivity of capital gained through past forest growth. In these circumstances the Forestry Commission itself should pay some attention to the productivity, although here the incentive is reduced by the knowledge the Treasury must eventually regulate any investment in alternative opportunities. No doubt much of the reason for this kind of attitude lies in the realisation that the public demand much more of their forests than immediate cash advantages. Whatever the reasons, these are the conditions under which the native forests are managed and it is therefore useful to look at the revenue production potential of different classes of tree aside from the capital involved.

Figure 35 illustrates the way in which current value increment per tree increases with increasing diameter. It also shows the very marked difference between vigour classes. Without having regard to the productivity of capital this evidence suggests that the most desirable management strategy would be to allow trees to grow to as large a diameter as possible, consistent with the need to satisfy the annual timber requirement. Even large non-vigorous trees have a better value increment than small vigorous ones. This argument, however, does not take into account the constraint of limited production area. If we assume that the area occupied by a tree is roughly proportiona to its basal area, i.e. that maximum stocking is inversely proportional to basal area, a more realistic evaluation of a tree's performance is the value increment per square foot of standing basal area, as shown in Figure 36. The trend of Figure 35 is now reversed in that the annual increment per square foot of basal area decreases with increasing tree diameter. If we assume that the maximum stocking of trees of vigour class 3 would be about 130 sq.ft of basal area over the range of diameters shown in Figure 36, the annual value increment per acre would decrease from $7.00 per acre for 16 inch trees to about $5.00 per acre for 40 inch trees. In general it appears unprofitable to grow trees to larger sizes, although there is some advantage in allowing the trees to grow just through from the small log size to the intermediate. This result parallels the finding for percentage rate of value increment discussed earlier in the light of Figures 29 and 30.

Similar results are observed for different levels of defect as illustrated in Figures 37 and 38. Current value increment per tree increases with increasing diameter and is greatest in trees of least defect. On the other hand, value increment per square foot of basal area decreases with increasing diameter, and value increment per acre would behave similarly. There are very considerable differences between the defect classes. A stocking of 130 sq.ft per acre in 16 inch trees of 20 per cent defect produces an annual increment of $9.75 per acre. This figure drops to $7.02 by the time the trees reach 36 inches dbhob, but is even then still equivalent to the value increment per acre from 16 inch trees of 30 per cent defect. This suggests that a tree-marking prescription could achieve considerable gains if it were possible to take internal defect into account. Furthermore, from the evidence of Figure 36, it appears that the optimum prescription would need to be based on the interaction between diameter, percentage defect and vigour class.

Finally it is necessary to consider the effects of the different patterns of defect development described in Section 11.4.1. These are illustrated for one type of tree in Figure 39, using average percentage rate of value increment as the standard for comparison. Clearly there is a very marked difference between the situation in which either defect volume or defect percentage are constant and the situation in which nett volume remains constant. Under the NSW pricing formula the standing value of a tree must actually decrease under this pattern of defect development. Repeating the formula explained earlier:-

Price = Gross Volume x Base Rate + Nett Volume x Marg
- Defect Volume x Mill Door Log Value

Consider the case of a tree yielding 1000 s.ft gross volume and 800 s.ft nett volume in a situation in which the mill door log value is $3.63 and the base rate $2.41 per 100 s.ft, and a stumpage margin of $0.20 applies. Such a tree would be worth $18.44. If the gross volume of the tree increases by 200 s.ft to 1200 s.ft, but the nett volume remains constant at 800 s.ft, the new value of the tree is only $16.00, which is $2.44 <u>less</u> than before it grew to the larger size. The reason for this apparently anomalous situation is that the nett volume and its value to the sawmiller remains constant but the price charged is reduced by the cost of bringing the increased defect volume from forest to mill. Whenever nett volume remains constant, growth of the tree must produce negative value increment, except in two circumstances. The first is when a tree grows from one log size class to another and the increased nett margin is sufficient to offset the increased logging cost associated with the defect volume. The second situation in which growth can give a positive value increment when nett volume remains constant is illustrated in Figure 39 when the defect percentage is such that the price has reached minimum rate and the log is considered optional. At higher defect percentages the logging cost associated with defect is no

FIGURE 28

Percentage Rate of Value Increment

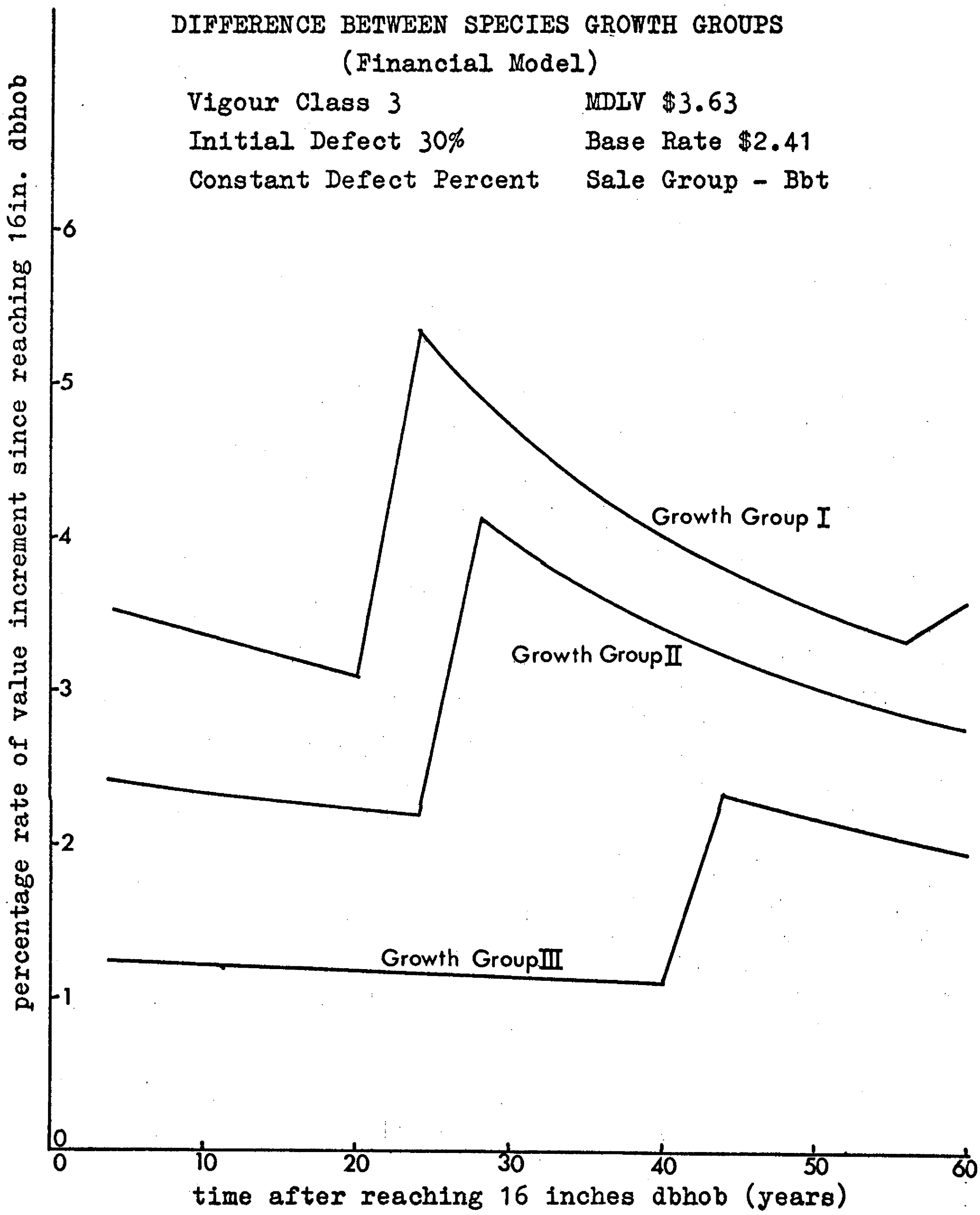


FIGURE 29

Percentage Rate of Value Increment

DIFFERENCE BETWEEN VIGOUR CLASSES

(Financial Model)

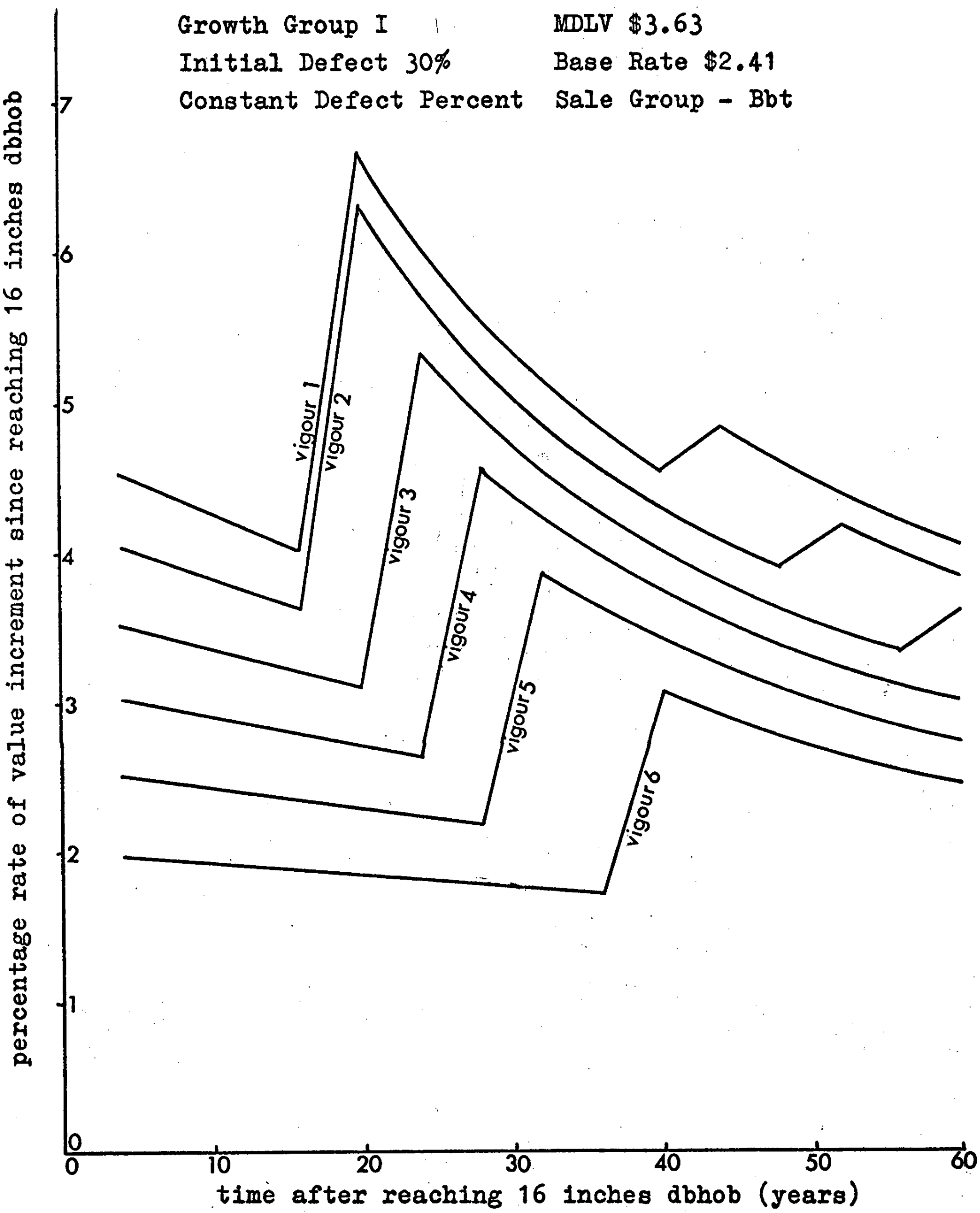
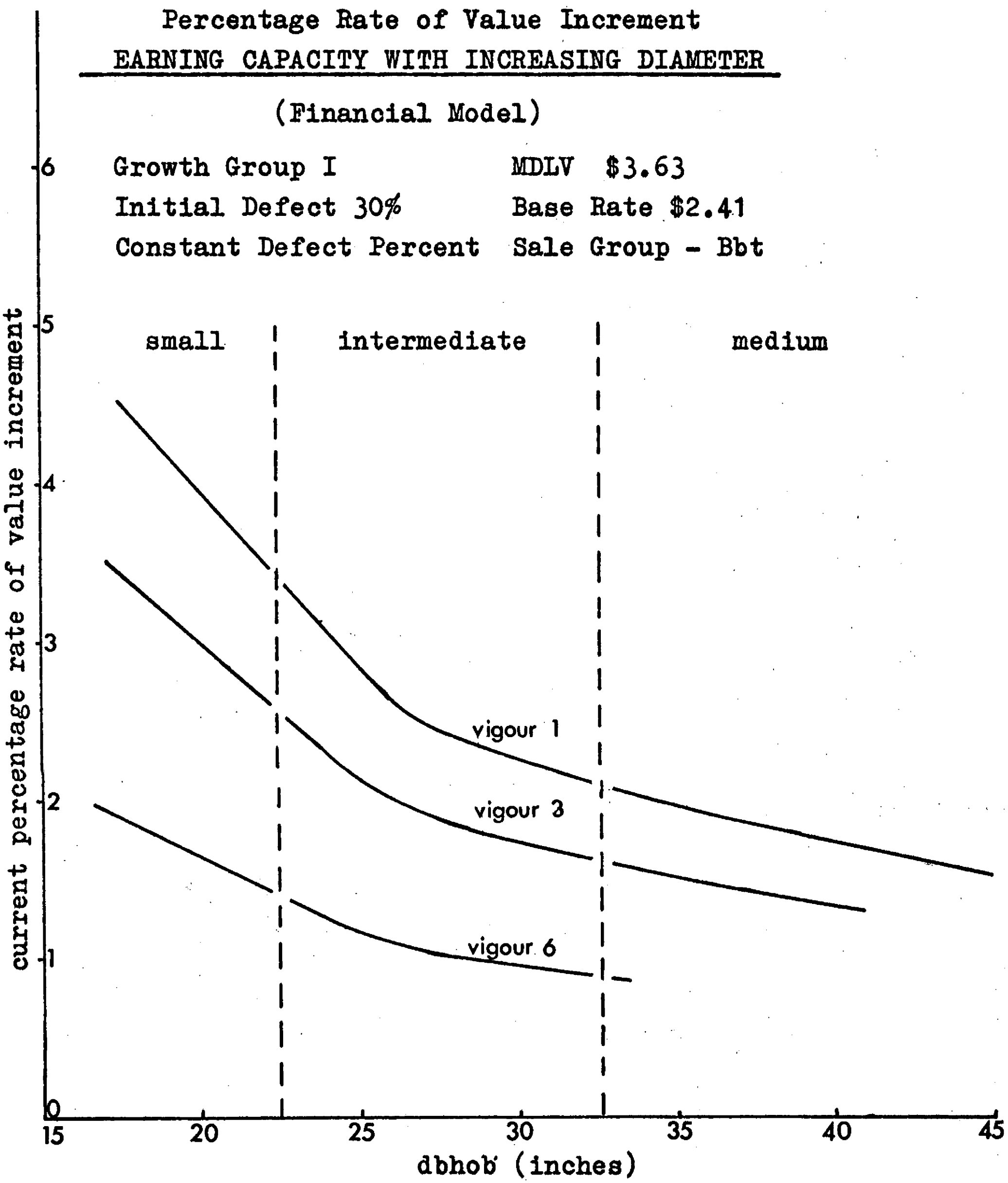


FIGURE 30



Percentage Rate of Value Increment
EARNING CAPACITY WITH INCREASING DIAMETER
(Financial Model)
Growth Group I
Initial Defect 30%
Constant Defect Percent
MDLV $3.63
Base Rate $2.41
Sale Group - Bbt
small
intermediate
medium
vigour 1
vigour 3
vigour 6
current percentage rate of value increment
0
1
2
3
4
5
6
15
20
25
30
35
40
45
dbhob (inches)

FIGURE 31

STUMPAGE MARGIN NEEDED TO SUSTAIN VALUE INCREMENT AT 5%

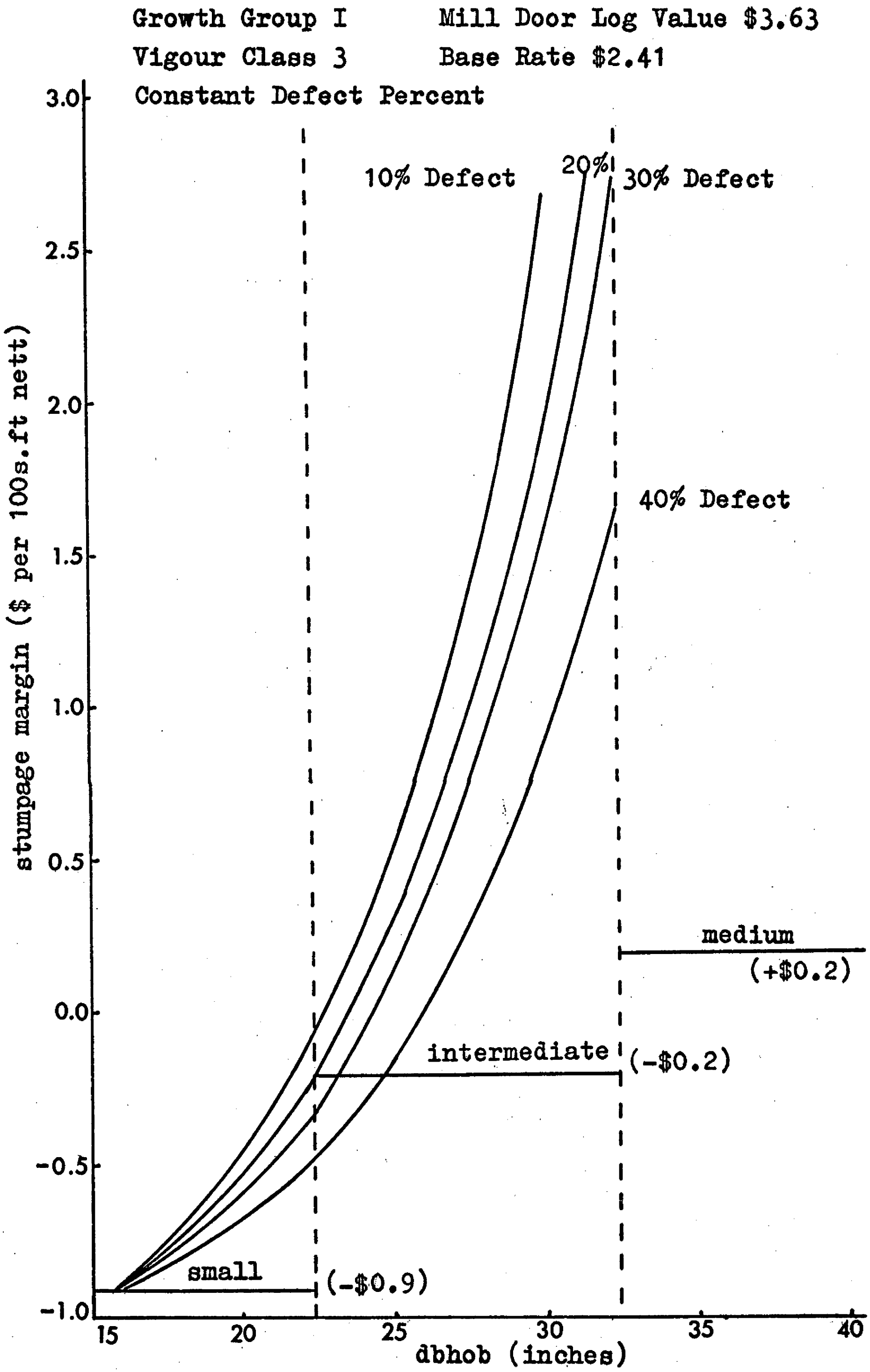


FIGURE 32

Percentage Rate of Value Increment

DIFFERENCE BETWEEN INITIAL DIAMETERS

(financial model)

Growth Group I — Mill Door Log Value $3.63

Vigour Class 3 — Base Rate $2.41

Initial Defect 30% — Sale Group - Bbt

Constant Defect Percent

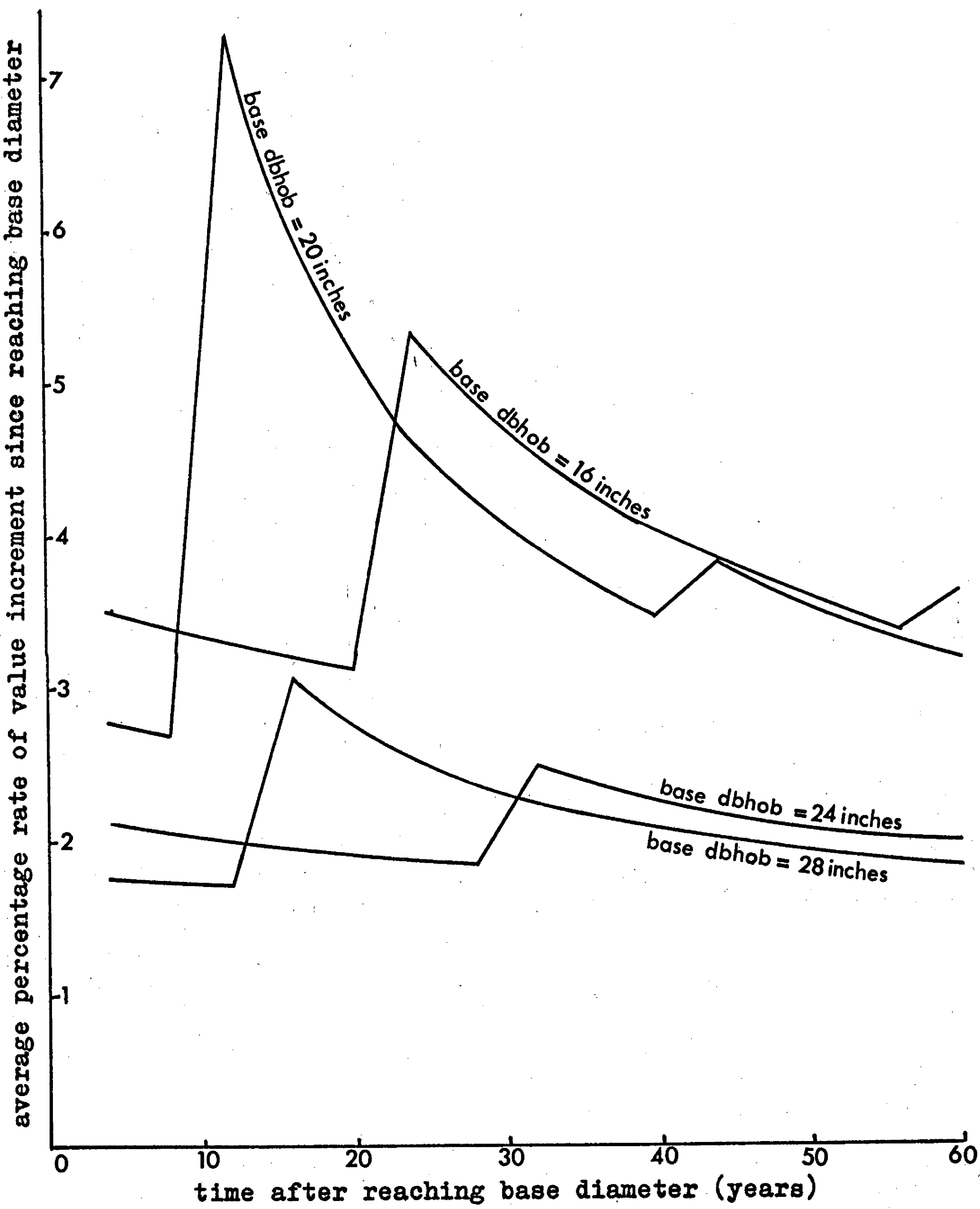


FIGURE 33

Percentage Rate of Value Increment

DIFFERENCE BETWEEN STUMPAGE APPRAISALS

(financial model)

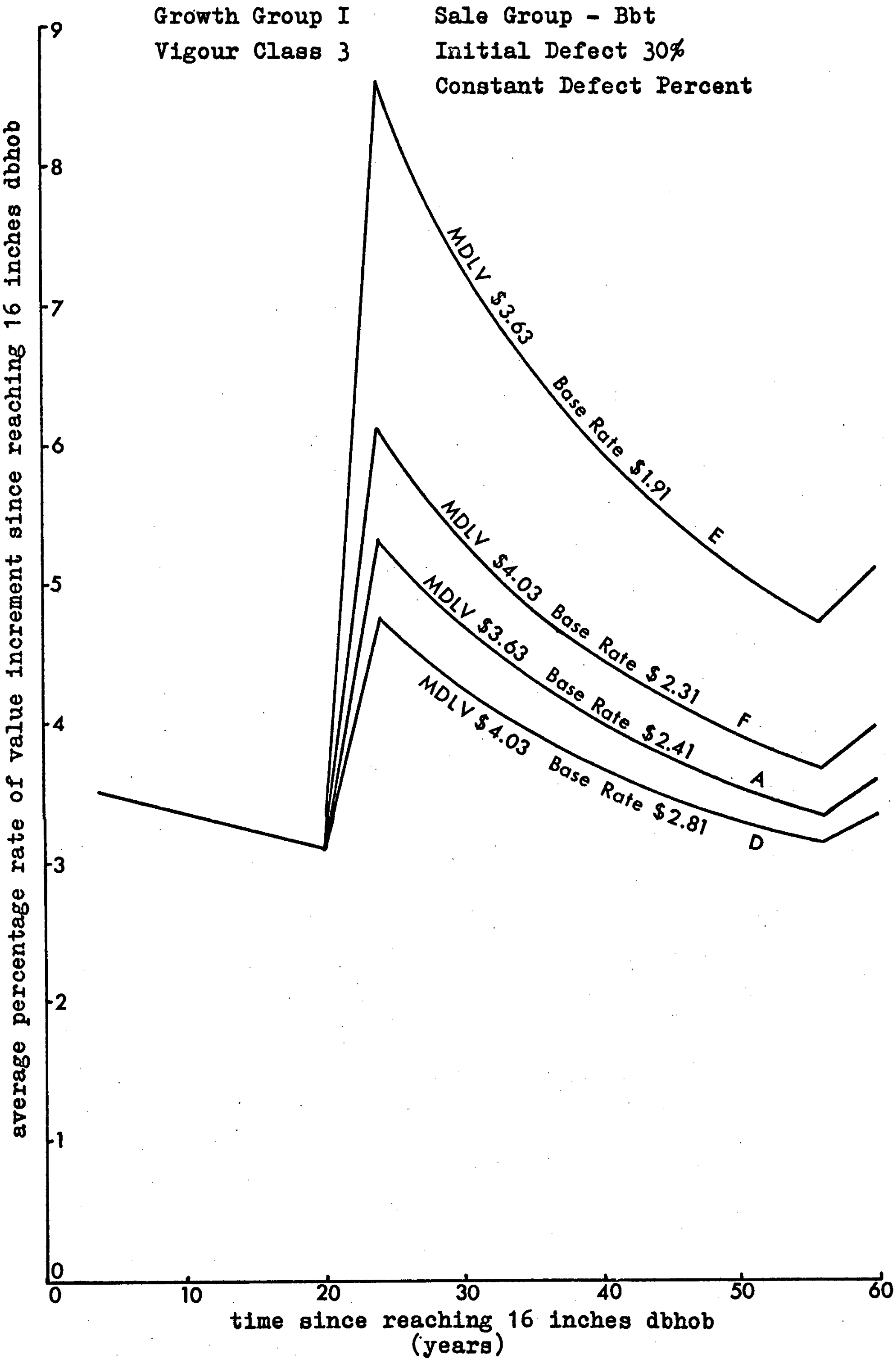


FIGURE 34

Percentage Rate of Value Increment

DIFFERENCE BETWEEN INITIAL DEFECT PERCENTAGES

(financial model)

Growth Group I   Mill Door Log Value $3.63

Vigour Class 3   Base Rate $2.41

Sale Group - Bbt   Constant Defect Percent

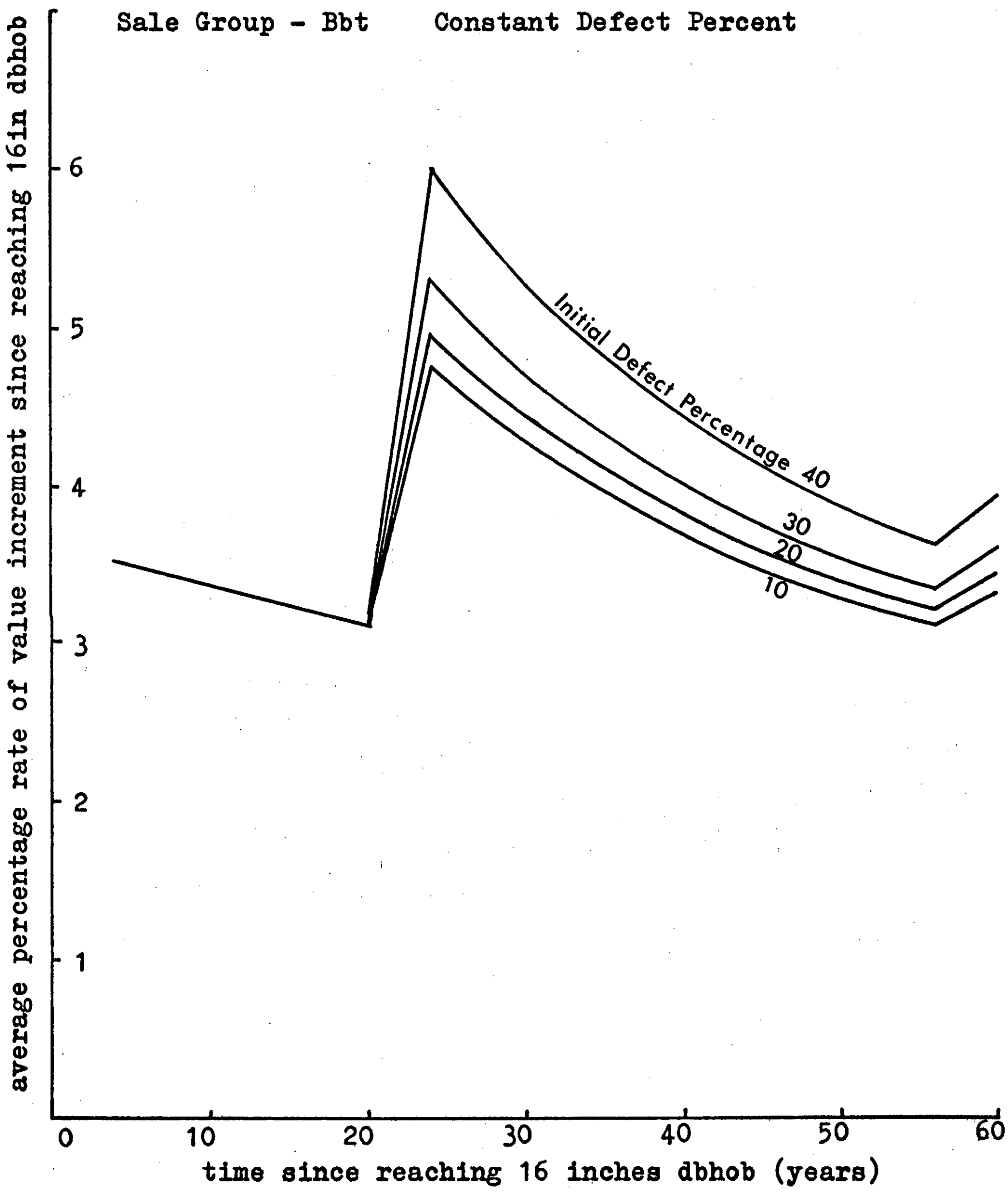
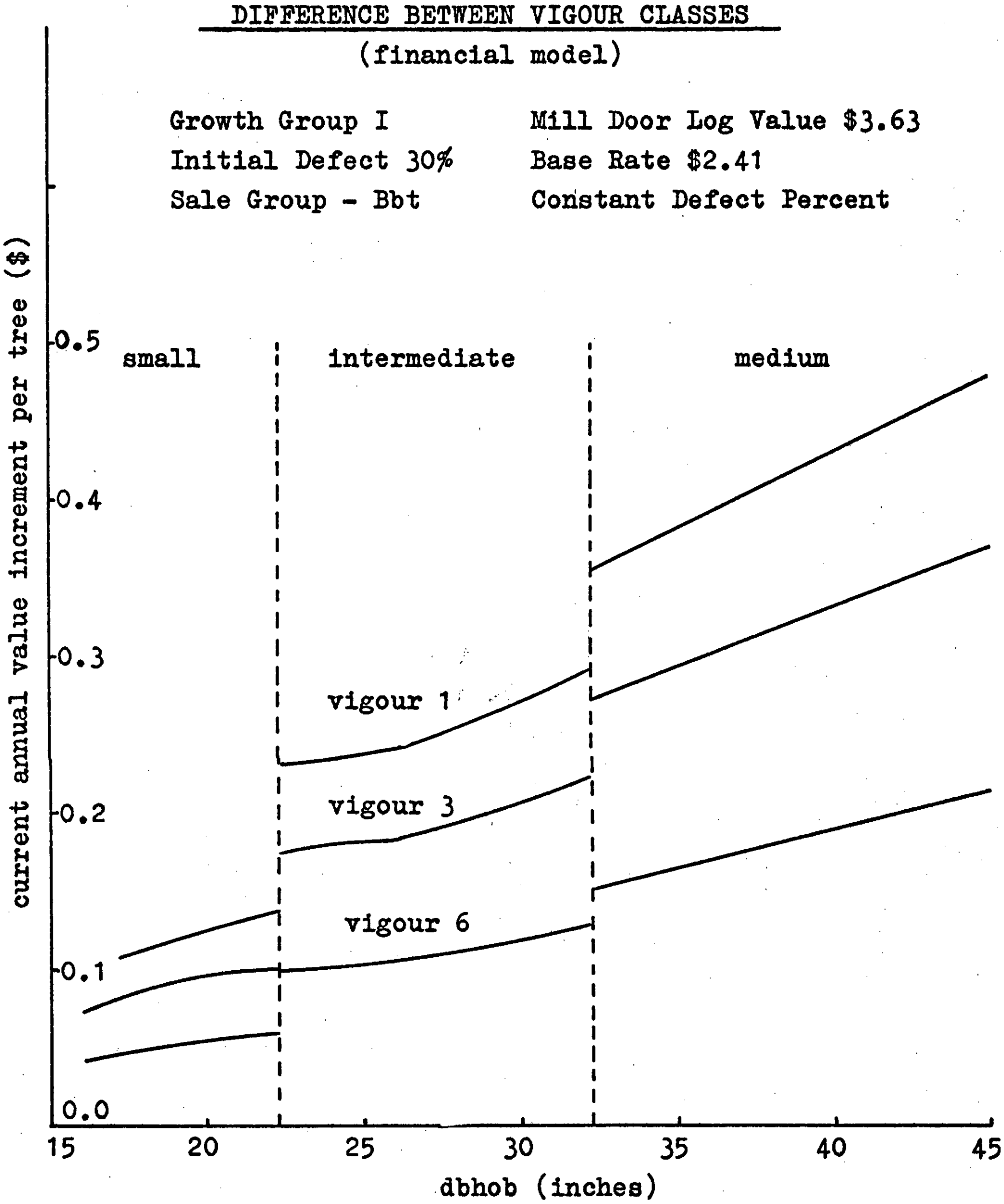


FIGURE 35

Current Value Increment With Increasing Diameter

DIFFERENCE BETWEEN VIGOUR CLASSES

(financial model)



Current Value Increment Per Unit Of Tree Basal Area

DIFFERENCE BETWEEN VIGOUR CLASSES
(financial model)

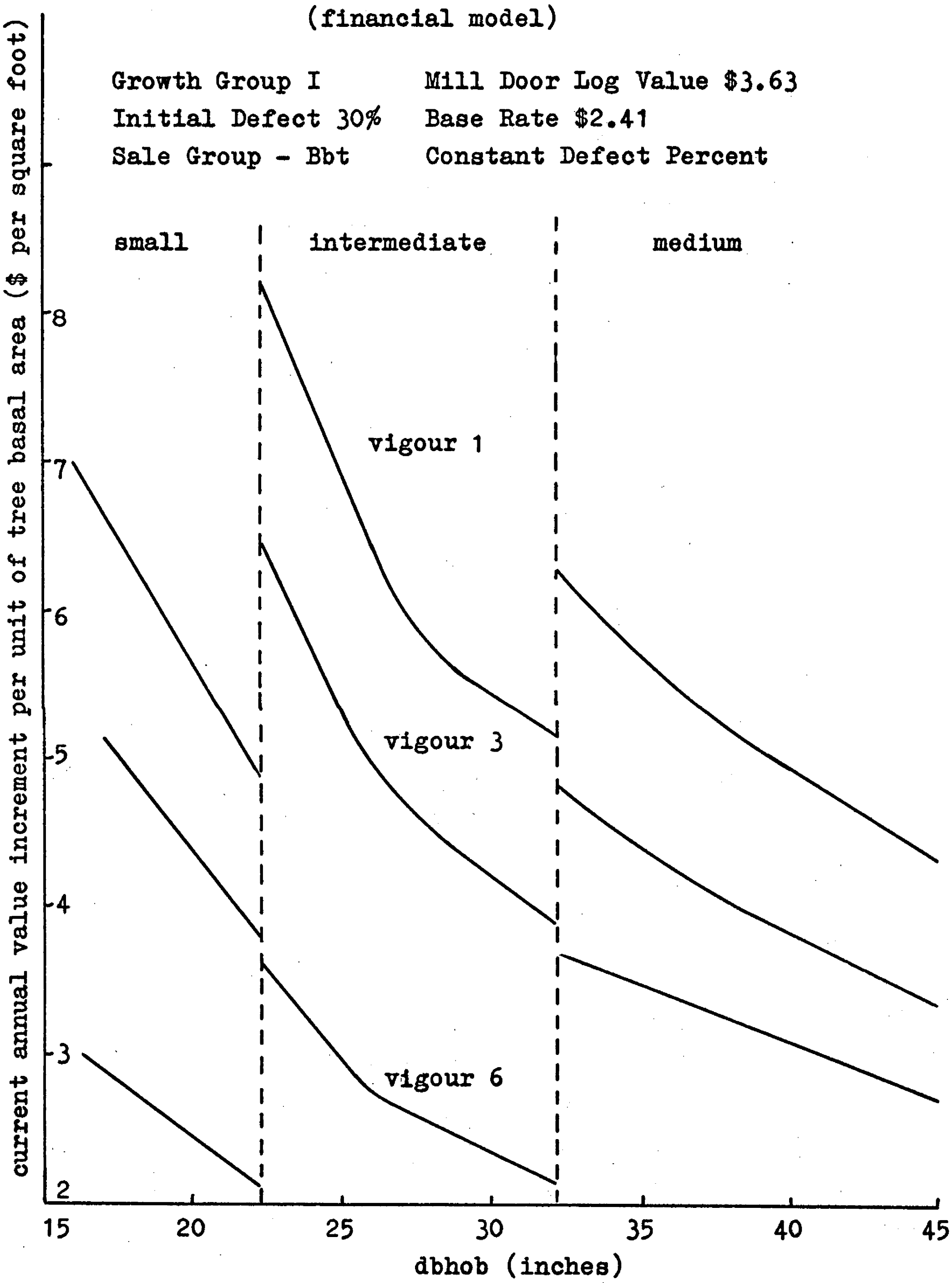


FIGURE 37

Current Value Increment With Increasing Diameter

DIFFERENCE BETWEEN DEFECT CLASSES

(financial model)

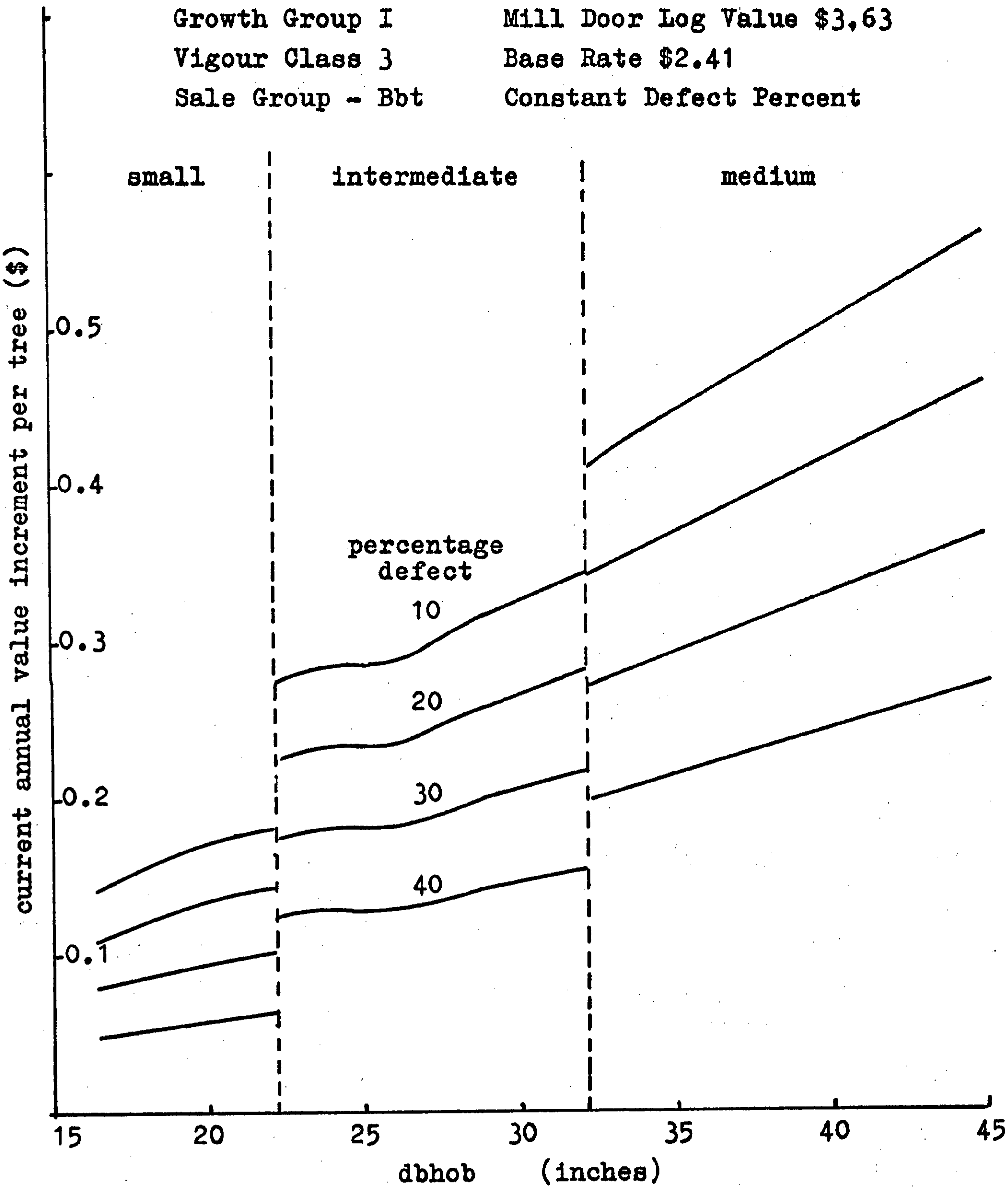


FIGURE 38

Current Value Increment Per Unit Of Tree Basal Area

DIFFERENCE BETWEEN DEFECT CLASSES

(financial model)

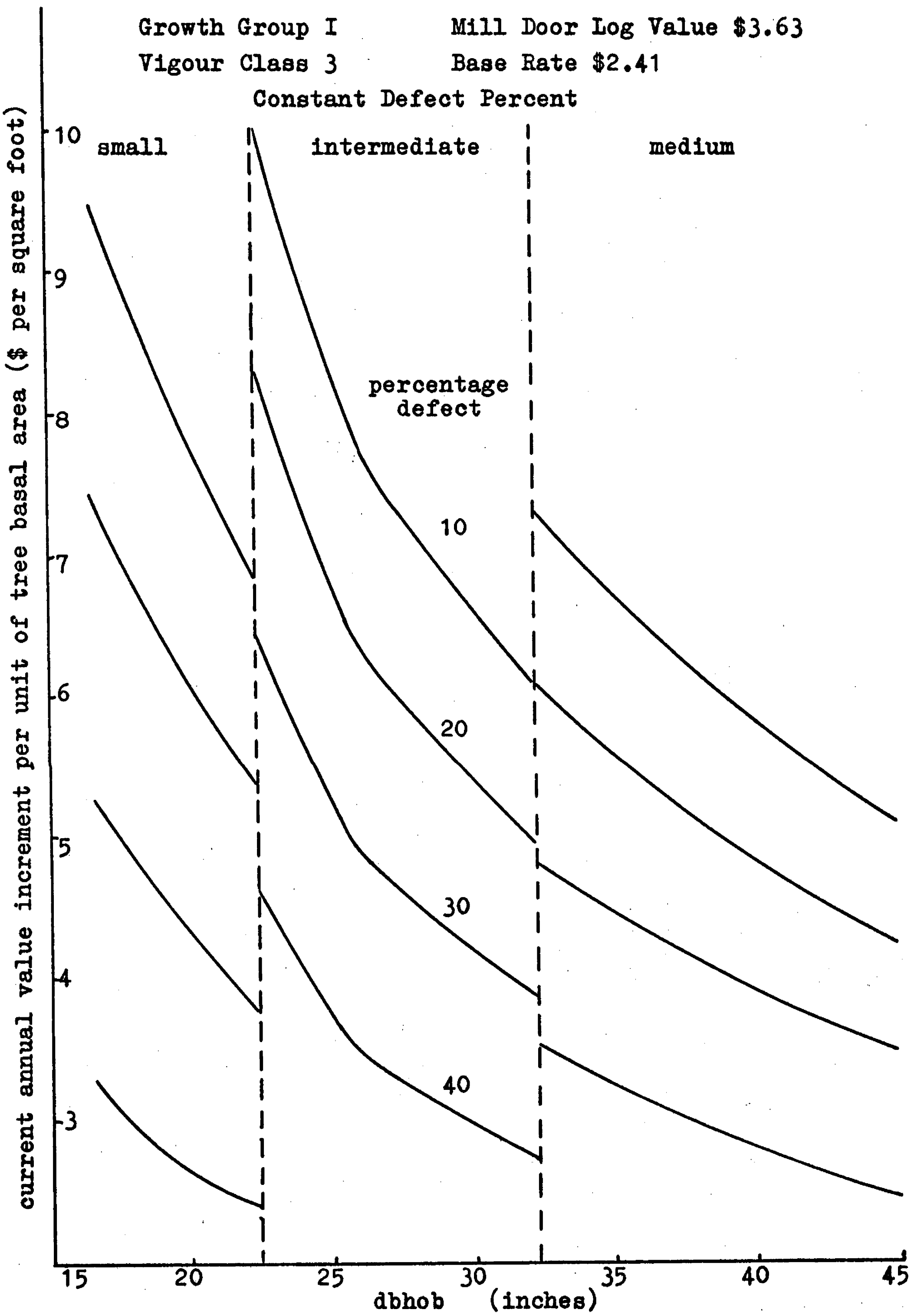
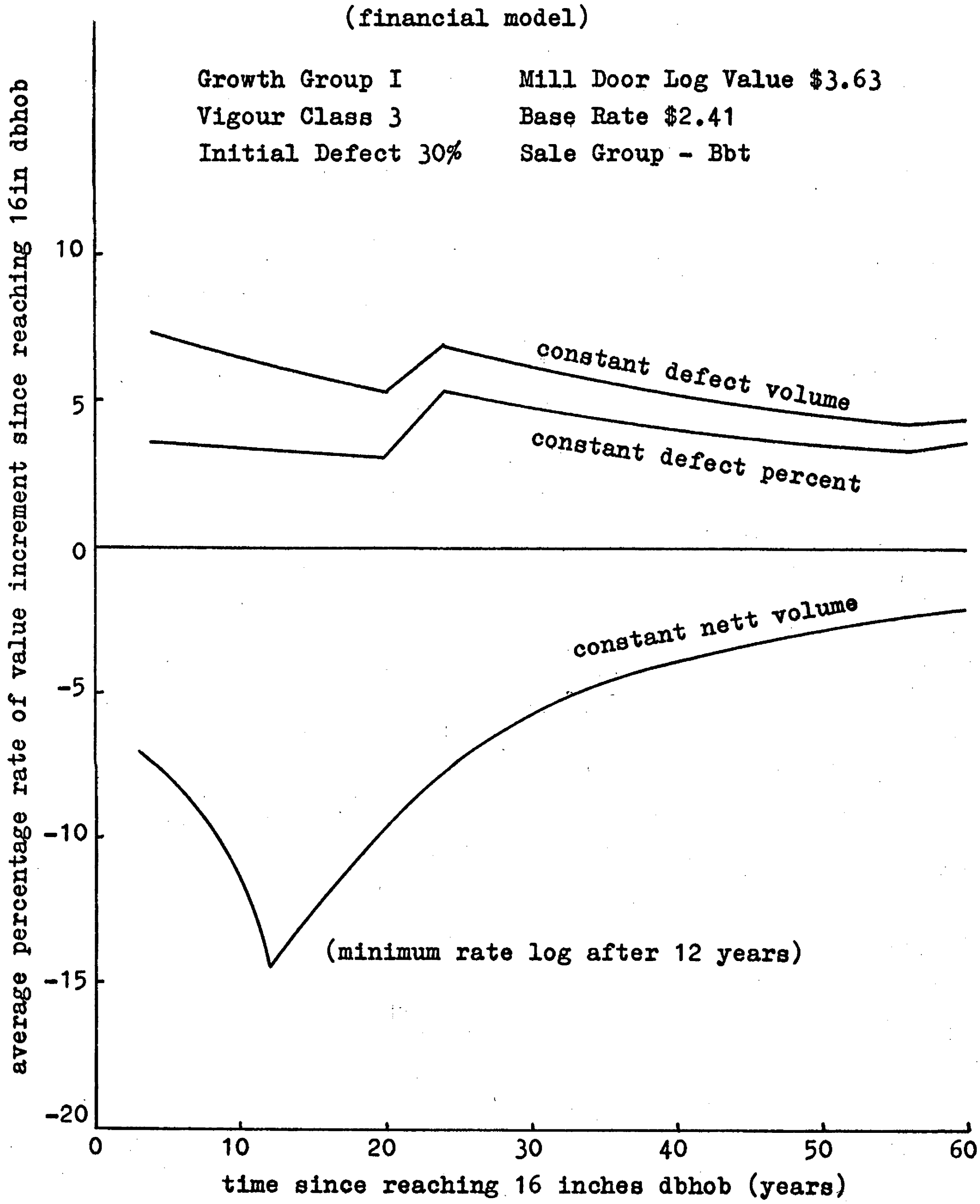


FIGURE 39

Percentage Rate of Value Increment

DIFFERENCE BETWEEN PATTERNS OF DEFECT DEVELOPMENT

(financial model)



longer taken into account and additions to the gross volume are valued at minimum rate.

It is therefore clear that any marking prescription for selective logging that was intended to maximise financial values would need to specify the early removal of trees that could only maintain a constant nett volume. Whether or not such trees exist, however, remains a problem for further research. The difference between trees maintaining a constant defect volume and trees maintaining a constant defect percentage is considerably less. And if both patterns of development do occur it is clear that there must be a continuous gradient of rates of development between these arbitrary standards. It is therefore certain that a marking prescription to optimise financial performance, whether measured as current value increment or percentage rate of value increment, would need to take account not only of diameter, percentage defect and vigour as suggested earlier, but also of the rate of defect development in relation to the gross volume development. To be applied in the field such a prescription would require the development of techniques for assessing both the current level of defect and the probable rate of change of defect in the standing tree. This technique would be used not only by the tree-marker for logging but also in the course of management inventory to provide the necessary information for yield regulation.

11.5 The defect problem in summary

This chapter opened with a discussion of the mensurational problem which can best be summarized as extremely difficult. There are numerous agencies of defect and numerous types of defect. Sometimes the defect is external and visible, but more often defect is internal, frequently indicated by no external symptoms or by symptoms which are inconsistent in their relation to the amount of defect present. To add to these problems, the significance of different types of defect will vary with the intended end use. The assessment of current levels of defect in standing trees will therefore be extremely difficult. Although it is possible to obtain better assessments on felled trees, this procedure is likely to be costly and the results obtained may still be limited to some extent to the particular end use for which the assessment is made. It may also be that felling sample trees is considered unjustifiably destructive.

Estimates of defect in a sample of felled trees can be used to derive estimates of average defect distribution on a stand basis. Section 11.3 illustrated a technique for using such estimates to predict the merchantable volume of a stand without the use of subjective assessments of individual standing trees and in such a way that the volume estimates could be adjusted in a situation of changing prices without the need for further field work.

In Section 11.4, however, it was shown that to take advantage of differences in financial productivity the derivation of a tree-marking prescription for selective logging would need to incorporate a ready means for estimating not only the current level of defect in individual standing trees but also the rate at which the volume of defect was changing. From the discussion in Section 11.1 it is clear that even if a technique for assessing defect in standing trees could be developed, it would only be developed at considerable cost, it would possibly be very unreliable and it could be quite difficult to apply in the course of routine operations. Because of the low unit value of the forest, however, any technique used either in management inventory or by the tree-marker would need to be fairly inexpensive.

Although some aspects of this chapter may appear to involve negative results only, the way has been opened for an economic evaluation of cutting procedures in selectively logged forest. The productivity of capital fixed in individua standing trees, whose only value is considered to be as a potential sawlog, is below the acceptable level of return for new public investment. This applies even to the best trees studied with the model. The economic argument for maintaining the forest as a whole may lie partly in the need to maintain national timber production but the argument for producing that timber from an irregular forest almost certainly lies in the value of other uses such as recreation and environmental preservation. The simple growth model has shown that there are differences in financial potential between individual trees. The development of a technique for rapid and accurate assessment of internal defect in standing trees would permit the formulation and application of a cutting prescription scheduling the selective harvesting of trees to take advantage of these differences of potential. A study to develop the necessary inventory technique would undoubtedly be difficult and costly. I therefore advocate that before large sums of money are spent on developing a technique for assessing internal defect in standing trees it would be preferable to initiate research to ensure that any cutting prescription secured the recreational and other values for which the forest was being maintained in an irregular condition. For timber production alone, without the need to preserve these other values, it would almost certainly be more productive to clear fell and manage only even-age stands. In this case, the assessment of defect in standing trees may not be important.

CHAPTER 12

CONCLUSIONS AND RECOMMENDATIONS

12.1 Management today

It has been established that the irregular broad-leaved forests are of considerable national importance for several reasons, not the least of which is their function as timber producers. Continued management of these forests is therefore essential in the national interest and the problem considered in this thesis is how inventory may best be used in support of this management. I have attempted to show the way in which different forest uses have been catered for in past management and I have attempted to predict, in general terms, the probable expansion of various uses in the future. But I have dwelt upon the role of inventory in commercial timber production, partly because past inventories have been confined to this function and partly because management for other purposes has not yet developed to a sufficient intensity for there to be a resolution of the quantitative parameters which could be usefully measured to the assistance of that management. This concluding chapter therefore deals with the development of a management inventory technique to assist a timber production enterprise in irregular eucalypt forest. In stressing the word irregular I am presupposing that a history of selective logging has disrupted the more uniform condition of the virgin forest and that extreme wildfire or plantation establishment has not led a return to extensive areas of even-aged forest.

In general terms the problem is to determine how to log the forest to the owner's best advantage. Any acceptable solution must at least appear to satisfy the silvicultural demands of the forest, the economic constraints of the local utilising industry and the general management philosophy or policy of the forest owners. One might also add that a forestry business, like any other industry, must operate in a manner which is politically acceptable, a particularly important consideration for the management of the large areas of publicly owned irregular forest in Australia.

Most irregular eucalypt forest, particularly in coastal New South Wales and Queensland will have a history of up to 50 years of selective cutting for sawlogs. A typical forest may cover 20,000 acres and lie within 20 miles of a feasible sawmill site, but often more than 200 miles from a major market. Past logging will have provided a fairly intensive roading system for good access and stand conditions will often vary according to the pattern of access. On the drier ridge tops with good access and little understorey there may be extensive areas of vigorous regrowth, sometimes interspersed with large, over-mature, defective remnants of earlier stands. In the moister gullies less intensive logging and a more vigorous understorey of tolerant species and lignotuberous growth may have led to a stand intermediate in size but fairly slow growing and non-productive of sawlogs.

When the forest is State-owned, as is much of the irregular eucalypt forest, there will almost certainly be some commitment of yield, probably up to 15 cubic feet per acre per annum at most. On a forest of 20,000 acres this would give a sawmiller an annual allocation of about 3 million super feet Hoppus in gross volume, or about 2 million super feet Hoppus in nett volume. Such timber would commonly sell for about $1.50 per hundred super feet nett, giving an annual return of $30,000 or $1.50 per acre per annum.

Annual charges for such items as fire protection and road maintenance in irregular forests under the control of the Forestry Commission of NSW have in recent years been in the order of $1.10 to $1.30 per acre per annum when all overheads such as wet weather and Head Office costs are taken into account. The sort of low-intensity silvicultural treatment that has led to the present yields of about 15 cu.ft per acre per annum is currently costing about $20 to $25 per acre, again including overheads, and seems to be applied to about 1 percent of the forest annually. This means that, over the whole forest, silvicultural treatment to perpetuate low-level sustained yield costs about $0.20 to $0.25 per acre per annum. It can be seen, therefore, that the bulk of revenue will be absorbed by annual running charges, i.e. if the low intensity treatment is considered as a running cost rather than as an investment. Inventory charges must be kept to a minimum unless they too may be regarded as an investment likely to result in increased returns through better management controls.

Given this background, the forest manager will probably find himself in one of the three following situations:

(a) Considerable overcommitment and the foreseeable probability of the termination of his current sawlog production from irregular stands.

(b) A fairly low, but sustainable, commitment to sell sawlogs, minimum funds for investment in silvicultural treatment, a continuing demand for wood and a political need to care for the recreational and conservational values of the forest.

(c) A predicted long-term continuation of strong demand for hardwood sawlogs, strong public pressure against plantation forestry, and perhaps the possibility of a substantial market for small material for chipwood.

Management in public irregular forests in Australia is at present usually confronted with either the first or second of these situations. However, recent tendencies in public opinion on the "environment" coupled with probable market demands and possible developments in pulping technology may make the third situation more common in the near future.

The emphasis placed on various aspects of an inventory and the management interpretation of different items of information obtained will vary according to which of the above three management situations applies. It is as well to recognise these major management distinctions early so that the different emphases of interpretation may be properly allowed for in the inventory design, as discussed in Sections 12.3 - 12.5. Nevertheless, irregular eucalypt forests do present some general problems common in various degrees to most management situations. These may be discussed before proceeding to examine particular management problems.

12.2 General inventory problems

12.2.1 Are adequate base maps available?

The base map will serve two main purposes in inventory. Firstly it will usually be the basis for delineating a sampling frame prior to commencing the assessment. This may not be so important a role when multiphase or multistage sampling with aerial photography is being used and the sampling frame can be described with sufficient reliability on the photography. Secondly the base map will usually provide the basis for estimating forest areas so that the sample mean can be inflated to a total population value. However, most commercially productive forests in eastern Australia would now be covered by some form of map so that it would not be necessary to burden inventory with the entire cost of a complete new base map.

12.2.2 Is it desirable to recognise management strata?

From a general knowledge of the forest, before any sampling commences, it may be possible to recognise certain important management strata, such as species types requiring different silvicultural treatments or country of different slope classes requiring different logging approaches. Some of the problems in defining and mapping such strata are discussed in Section 6.3. Apart from the management value of particular means sought there may be some sampling advantages in recognising strata, perhaps by allowing the avoidance of sampling in strata of no management interest or perhaps even by allowing a reduction in the number of sampling units in strata actually sampled if it is expected that the strata will be more homogeneous with respect to the parameter of most interest. However, as discussed in Section 6.3, the opportunity to recognise and delineate areas of increased homogeneity in a parameter such as merchantable volume will be uncommon in irregular eucalypt forest because of difficulties in volume typing. Against the value of stratification are the probable high costs of strata mapping and the fact that each stratum of importance, no matter what its size, will have to be allocated a sufficient number of sampling units to ensure a reliable estimate of the stratum mean. The technique of post-sampling stratification, recently applied using aerial photography in some New South Wales inventories, will not directly lead to a reduction in sampling costs for a given level of reliability, but in some situations could provide most valuable management information without the high initial cost of conventional type-mapping. This approach must be considered more often in future inventories.

12.2.3 How is gross merchantable volume to be assessed?

In the management of irregular eucalypt forest volume availability is always the dominating question, with consideration of sizes, species and wood quality being of lesser importance. The gross merchantable volume of the forest, or of a stratum, is most usually assessed by a sample of field plots on which individual trees are measured for dbhob and merchantable height, (Section 7.2). The need to assess individual trees arises from the marked variation in the total merchantability, or in the proportion of merchantable volume in individuals of the same size. Diameter and height are converted to volume by means of a volume table, now usually expressed in the form of a mathematical regression. Despite the general availability of fast electronic computers, supplied with standard regression analysis programmes, there still appears to be some reluctance to revise old volume tables. Inappropriate volume regressions must almost certainly result in biased inventory estimates, such bias often being far more critical to management decision making than estimates of precision which is in large part a function of the variability of the population. Closer attention must be paid in the future to the derivation and selection of appropriate volume tables, even to the extent of producing localised regressions for particular jobs if necessary.

12.2.4 How is gross volume converted to nett merchantable volume?

The conversion from gross volume to nett merchantable volume may be made by assessing the trees as merchantable and non-merchantable and then applying a reduction from gross to nett either from past experience in a similar area or from a felled sample of the merchantable trees. Whilst this approach is certainly fairly cheap to apply, it does suffer from the considerable risk of bias in the original subjective assessments of merchantability. Greater objectivity can be achieved by felling a sample representing the whole spectrum of merchantability. Because of the destructive nature of sampling by felling the merits of two-phase sampling are certain (Section 4.3.4) and I would strongly recommend the consideration of variable probability sampling in the second phase selection of trees to be felled (Section 4.3.7).

The above types of approach do suffer from reliability problems, not only because of possible bias in the original estimates but also because of actual variations in merchantability standards from place to place and from time to time depending upon economic conditions. Because merchantability does not depend solely upon percentage defect volume, but involves also strong interactions with log size, species and accessability, I have devised a means of using a particular stumpage appraisal system in conjunction with a felled sample from the whole spectrum of merchantability to forecase these interactions for a whole stand (Section 11.3). By this method the objective estimation of merchantable volume can be reassessed without further field work should utilising standards change. This type of technique will undoubtedly be more costly to initiate than simpler subjective estimates but I consider that it may well be justified because many expensive inventory results have fallen into disrepute after just a few years logging, sometimes because subjective assessments of merchantability are suspected of bias and sometimes because there have in fact been real changes in utilisation standards.

The "Horseshoe Management Area" in New South Wales is an important example of this type of problem. The area was assessed from aerial photographs and was estimated to contain a gross merchantable volume of 330 million super feet Hoppus. This estimate was reduced to a gross volume of 220 million super feet to allow for inaccessability. Based in experience in forest of a similar nature in more accessible coastal country defect was estimated at an average of 27 percent and tenders were called for the purchase of 160 million super feet nett. Of the 185 million super feet gross volume sold up to 1970/71 only 115 million super feet were in logs worth more than the minimum stumpage rate of 10 cents per 100 s.ft. Because of the extreme accessability problems of the area the remaining 70 million super feet of more defective trees were sold as optional logs at minimum rates and were thus excluded from the original quota for which tenders were called. The "in-quota" logs realised 83.3 million super feet nett (or 27.6 percent defect), whilst the "ex-quota" logs have realised 30.9 million super feet nett at an average defect of 55.9 percent. As most of the area is now logged it seems that the nett merchantable quota volume has been considerably over-estimated and that a difficult supply situation may result. Most of the problem is due to the unusually high quality standards for economic acceptability in difficult logging country. The detailed application of the technique I have outlined in Section 11.3 may not have been feasible over such a large area, but a series of selected trials across the range of country would have given a fairly clear indication of the general magnitude of acceptable levels of defect in the various situations.

12.2.5 What parameters are good indicators of growth?

Parameters of tree growth have been discussed in Section 7.4, whilst regressions for prediciting stand growth were discussed in Section 10.2.3. The value in attempting to predict tree or stand growth depends upon the intended use of the inventory data, as discussed in Section 12.3. Generally speaking, however, it seems that in some situations it has been possible to derive stand growth regressions based on such stand parameters as number of trees per acre, basal area per acre and mean diameter. Such regressions could form the basis for comparisons of desirable stand stockings to achieve high volume production, but because of the continuous variability of structure throughout an irregular eucalypt forest they are difficult to apply in yield control.

In irregular eucalypt forest, where there is little detailed information of age, stand history etc., the prediction of individual tree growth in such parameters as diameter, merchantable height and, through them, merchantable volume must remain a difficult task. Rating of dominance, reflecting present competitive influences, and crown quality, to some extent reflecting previous competitive influences, do offer at least some means of predicting the relative gross volume potential of different classes of tree, thus providing some basis for selective logging to improve volume productivity. As it was shown in Section 11.4 however, there are very great mensurational difficulties in attempting to go beyond this to the prediction of growth in nett merchantable volume or of growth in financial value.

12.2.6 What is the permissible budget and how should it be allocated?

It may seem a little illogical to introduce the question of the budget after some other aspects of the inventory have already been discussed, but those items that I have mentioned constitute knowledge, or techniques or facilities that *may* already be available to the forest manager before he even contemplates an inventory. The extent to which such items as maps and volume tables are already available will have an important influence on the expenditure for the more generally recognised part of inventory, the sampling of the growing stock. It is probably fair to say that the design of inventories for eucalypt forest is usually constrained by cost as it relates to manpower availability. The general aim is, therefore, to achieve the maximum possible *reliability* in the estimates of the parameter of interest within the budget constraint, although as the proposed design appears to approach the permissible budget one must look to the marginal gain from further expenditure. I have stressed the word reliability because it is not sufficient to consider only the sampling precision of the gross volume estimate. It is just as important, indeed perhaps more important, to consider possible inaccuracies and biases in techniques such as those by which that gross volume estimate was derived and by which it will be converted to nett merchantable volume. I can see no likely means of so integrating all the various components of reliability that there could be a completely objective design of inventory for maximum efficiency but I stress again that precision in one aspect of the estimate must not be equated with total reliability simply because precision is capable of objective analysis.

12.2.7 What sampling system to use?

There are numerous possible sampling designs for inventories to be based primarily on field plots (Chapter 4). Simple random sampling and systematic sampling have both often been applied in Australian forest inventories and I feel no strong preference for one rather than the other. On the one hand systematic sampling is claimed to be easy to administer in the field but has the disadvantage of not permitting the calculation of an unbiased estimate of precision. On the other hand I see no great administrative problem in setting out a random sample and I wonder at the real value of an unbiased estimate of precision when the forest manager is almost certainly unsure of the other components of reliability and of his tolerances in reliability. The possibilities for stratification (Section 4.3.1) are always worthy of consideration, whether on management or statistical grounds, but in so doing one should not overlook the possible additional costs and inaccuracies in mapping as I have already mentioned. Multi-stage sampling in the form of cluster-sampling (Section 4.3.2) also deserves more attention than it has previously received in Australian inventories, particularly if access is poor and travelling costs are high. Clustered samples are more effective in sampling local variation and less effective in sampling dispersed variation. In the most intensively managed irregular forests of the coastal region one would expect to find rather more local variation than "regional" variation, thus providing good argument for clustered samples.

12.2.8 What size and how many units will be best?

Turner (1968) showed a relationship between number of trees per sampling unit and stand merchantable volume (Section 4.3.5). With some prior knowledge of the frequency of merchantable trees it is possible to nominate a size of sampling unit to include the minimum number of merchantable trees per average plot to give adequate precision in the volume estimate. Because of the logarithmic nature of the relationship an increase in the plot size much beyond the minimum needed for adequate numbers of trees will produce very little return for the additional effort. Because the average distribution of frequencies by diameter classes is usually some function of the inverse of diameter, angle count sampling with probability proportional to basal area (Section 4.3.6) could provide a statistically efficient solution to the question of plot size for a variable forest. But where dense undergrowth makes the use of optical wedges difficult, as it will in most coastal eucalypt forest, the compromise solution of concentric plots is likely to be more efficient in practice (Section 4.3.5).

In Section 4.2.3 I have outlined the accepted method for using an estimate of the population variance to predict the number of random sampling units needed to give a certain level of precision. If an estimate can be made of the cost of measuring the plot of minimum size to give an acceptable co-efficient of variation, one can see if the required number of plots falls within the permissible budget. If the expected costs exceed or even approach the permissible budget it is worth re-examining the expected precision from various numbers of plots since the relationship between precision and number of sampling units is a curvilinear one in which there is a point of inflexion beyond which increasing numbers of plots give very little return by way of increased precision.

When stratification is contemplated on the grounds of homogeneity of variances there ought to be a cost saving through reducing the number of plots required to give acceptable precision in the overall mean. But when stratification is on management grounds, with each stratum mean to reach an acceptable level of precision and no predictable gain to be made from homogeneity of variances, the permissible budget may restrict the number of plots per stratum to such an extent that the stratum means are not precise enough to be of any management use. Thus, although I made the consideration of management strata an early priority, I recognise that it may be necessary to re-think the need for these strata when a practical sampling procedure has been devised and costs predicted.

12.3 Inventory in particular management contexts.

12.3.1 Management for liquidation of merchantable growing stock.

This is the first, and probably the simplest, of the three general management situations mentioned earlier in this chapter. Sale commitments made to industry are such that in the foreseeable future existing merchantable growing stock will be liquidated and the existing utilising industry will have to cease its operations or be transferred to another forest. The principal information requirement is a knowledge of how long the industry can be supported at a given level of cut, or perhaps how much should be cut in order to eke out supplies for a given period. In this sort of situation in eucalypt forest, growth on the existing growing stock is unlikely to be a significant factor in the yield prediction. The prime inventory task is therefore to estimate the current merchantable volume of the existing stand.

The reliability required and, to some extent the fixing of a budget for the job will depend upon the importance attached to probable financial losses in the utilising industry if its management planning is based on incorrect forecasts of mill life. It is not possible to make general forecasts of the probability of such losses or of their likely magnitude and the importance attached to these problems will vary considerably from one situation to another, particularly whenever politics enter the argument. It is paradoxical, however, that in general the shorter the expected mill-life the more likely is reliability to be important, yet the less one would be inclined to invest in the inventory of a fast-dwindling resource.

The production of yield in the liquidation situation is usually very straight forward since yield will be equal to current merchantable volume plus perhaps a small allowance for growth. In some cases, however, it may be considered desirable to retain some fraction of the merchantable stand for aesthetic, soil protection or other reasons. Such possibilities must be recognised before inventory so that the assessment can be made of trees to be retained and trees to be removed.

The following comments are made in respect of the general inventory problems discussed in Section 12.2, attempting here to emphasise the role of these various facets of inventory in liquidation management:

(a) Base Maps

Clearly, in a liquidation situation, there is little to be gained from intensive mapping of an area merely to facilitate the final logging. It is acknowledged that liquidation of the merchantable growing stock may be closely followed by redevelopment for such things as plantations or recreational area and that base maps may serve these roles too. But care must be taken that any new mapping is strongly oriented towards these eventual uses or that costs are kept to the barest minimum if the current inventory remains the prime reason for mapping.

(b) Management Strata

The recognition of management strata is often an important aspect of inventory planning, particularly where some of the strata may constitute areas reserved from logging or which will prove economically inaccessible. Permanent type-mapping of these strata will probably be of little continuing management value and, because of its high cost, ought to be avoided. The low-cost technique of post sampling stratification with air-photo interpretation must be considered closely in the liquidation situation.

(c) Volume tables

Inappropriate volume tables can cause serious problems of bias in any inventory situation; the liquidation situation is no different from any other in this regard. The adequacy of the volume table must be carefully considered.

(d) Gross to Nett Volume

The comments made in Section 12.2.4 apply generally. The problem is simplest in this liquidation situation since growth is not significant in the yield prediction and since the logging will be of most of the currently merchantable trees rather than a selection of some particular fraction. Conversions from gross to nett volume may be made from past experience, by felling a sample of the merchantable trees or even by the more complex technique described in 11.3, depending upon the value of the resources and the existing knowledge of utilisation standards.

(e) Growth

Growth is not of much importance in this situation and need not be assessed.

(f) Budget

The budget must be constrained to the minimum consistent with reasonable levels of reliability since information of the present stand is likely to be of small value to management beyond the current terminating cut.

(g) Size and Number of Plots

The comments made in Sections 12.2.7 and 12.2.8 apply generally. Clearly the plots need only be temporary, although it is as well to mark them in some simple way at time of establishment so that it may be possible to check out any major anomalies detected in data processing or in early logging of assessed areas.

12.3.2 Management for low-level sustained yield.

When it appears that the growth in merchantable volume will make a significant contribution to yield availability in the foreseeable future the estimation of growth becomes an important task of inventory. Management will probably wish to prescribe a rate and manner of cutting, that promotes growth while continuing to meet existing commitments. The first question to answer is whether it is sufficient to prescribe a rate of cut equal to the current rate of merchantable growth.

Such a prescription has been the most common goal in the intensively managed eucalypt forests, at least perhaps up to the last decade, even though it now appears that the present growing stock in these forests will be in a condition far below that for maximum merchantable growth (Sections, 2.3.3, 2.3.4 and 2.5). The timber demands of a growing population and the increasing demands of that population for greater multiple use of their forested lands will mean a continuing and probably increasing production demand from reserved State Forests. I can see sound basis for arguing that in many of the coastal forests this production requirement could best be met by intensive localised investment in even-aged stand development, particularly wherever a viable market for small trees can be expected. The continuation of present or similar levels of production from existing extensive areas of irregular forest, with the minimum of additional expenditure, would be a worthy auxiliary to such a programme. Not only is the maintenance of irregular forest more aesthetically pleasing than plantation development and probably more acceptable to the popular front of the people's conservationist army, it seems to provide a reasonably economic proposition as a low-level, low-risk investment offering some possibility of continuing supply to existing commitments in the short to medium term. In later years changing emphases in utilisation may well mean that the concentrated areas of eucalypt and softwood plantation will assume most of the production role but the irregular eucalypt forests will still be called upon to play their many roles in characters other than timber production.

With such a management intention estimates of current growth become a subject of inventory importance. In Sections 5.2 - 5.4 I have argued the relative merits of estimating current growth through successive measures of temporary sampling units, permanent sampling units and samples with partial replacement of units. Inventory systems of permanent plots run the risk of bias through preferential treatment in the course of routine management operations. Against this they offer high precision in the estimate of current growth, opportunity to examine components of growth, opportunity to study measurement bias and, to some extent, to study the accuracy of measurement and data recording. There may even be opportunity to use permanent plots to monitor routine silvicultural operations. Sampling with partial replacement of units appears to provide a reasonable compromise solution to the problems of cost, precision and bias, whilst ever the precision in the estimate of current growth remains a particularly important factor.

However, obtaining an estimate of current growing stock is by no means a complete answer to yield regulation problems. The forest manager has still to determine which trees to cut in order to obtain the prescribed yield. In Section 10.2.5 I have reviewed several possible approaches to relating prescribed cut to estimated growth. The decision merely to equate future cut with past growth implies the expectation that future conditions in the forest will closely resemble those of the past during which the growth was observed. To borrow modern diplomatic jargon, this is "a low-key initiative", economical, conservative and fairly safe in the short-term provided inventory is repeated fairly frequently. The first approach therefore is to leave the decisions of which trees to cut and where to find them to the field forester's good judgement and years of experience!

The second approach, dealt with at some length, is that of "Cutting Cycle Analysis", a method which seeks a rational relationship between volume availability and the cutting prescription to be applied for selective logging. An arithmetic method is provided for juggling diameter growth rates, cutting limits and cutting cycle lengths so as to provide a yield estimate for various cutting strategies. Yet it fails to provide any estimate of the way in which different cutting prescriptions will affect previously observed growth rates. Thus only short-term predictions can be accepted with any confidence. After considerable work with the method I reluctantly refrain from recommending its use. It is fraught with risk for the over-zealous and for the conservative it achieves little more than the previous approach of equating permissible yield with past growth and leaving the rest to the forester's good judgement.

The third approach was to attempt to predict forest growth as the sum of the growth on a number of individual stands described by stand parameters such as basal area, number of trees per acre and so on. Whilst it may be possible to derive predictive regressions for growth under a variety of stand conditions, it is difficult to apply the technique for predicting forest yield since individual sample plots in irregular forests are not representative of stands around them. Any yield prediction method based on the aggregate effects in a number of stands must be susceptible to the order in which the stands are worked, yet the order of working cannot be realistically determined from the parameter values of plots which are not representative of substantial stands around them.

Bearing in mind that this section concerns the situations where the forest manager has elected to remain fairly satisfied with past growth and yield performance, I therefore recommend the use of the first, very simple yield prediction approach proposed. The yield should be set equal to the immediate past growth and the selection of trees to be cut left to the forester's past experience. This is certainly unsophisticated but probably realistic since it involves minimum capital investment in an enterprise likely to be low yielding.

With this management intention the following comments can be made on the general inventory problems raised in Section 12.2 :-

a) Base maps and type maps.

In view of the general intention to sustain yield it is worth paying some attention to the reliability of existing forest maps, both in terms of their original compilation and in considering whether the detail shown is up to date. Some field checking or recharting may be desirable before inventory bearing in mind that some of the information will be of use in subsequent management operations. For example, the map may serve as a basis for recording logging and silvicultural treatment information which will be of valuable assistance in later management planning.

Again it may be worthwhile to extend map revision to the preparation of a type map of important management strata for the reasons set out in Section 12.2.2. But is must also be remembered that one of the attractions in aiming to continue the low-level sustained yield approach is not the low yields per se but the low level of investment required. Mapping costs should be kept low, bearing in mind that the approach assumes a fair degree of familiarity with the management characteristics of the forest in the first place.

b) Volume assessment.

The comments made in Section 12.2.3 relating to the assessment of gross volume apply generally. Growth in gross volume can be estimated as the difference between estimates of gross volume on successive occasions. With permanent plots adjustment can be made for ingrowth and removals. With temporary plots on each occasion ingrowth may be difficult to estimate but removals could probably be obtained from independent records of yield. The inability to determine the proportion of growth due to ingrowth will not be particularly important unless the age-class structure is such that the ingrowth in the coming cutting cycle is likely to make a markedly changed contribution to production.

Nett-volume growth may be similarly estimated but in this case there is some risk of bias due to the effects of selection in logging. Over a number of cutting cycles with logging selection generally directed towards the poorer and apparently more defective trees, the total nett volume growth and the ratio of nett volume to gross volume should gradually increase. However, in this management situation, where it is generally intended to sustain yield by silvicultural practices similar to those applied in the past, the proportion of nett volume in the previous yield is still probably the best guide to nett volume availability in the future. The technique for estimating the full distribution of defect in the stand, as recommended for the liquidation situation, is not appropriate here since the defect obtained in selective logging will depend on the type of tree selected for cutting.

c) Predictions of tree growth

It is assumed the effects of the conservative selective logging will not be such as to disturb the whole pattern of growth and yield availability and require an assessment of the distribution of trees of different growth potentials. But even under conservative management for low-level sustained yield there is probably something to be gained from using assessments of crown quality and dominance quantitatively to describe existing logging practices with a view to making some improvements to the growth potential of the residual stand. This type of adjustment to cutting prescriptions, based on the observations of a number of routine plots in stands all managed under much the same sort of regime will not necessarily lead to stand conditions conducive to optimal volume growth in the long term but it may achieve moderate increases in productivity in the short to medium term.

12.3.2 Management for long-term productivity improvement

Management for a substantial long-term improvement in productivity is the third general approach open to the manager of irregular eucalypt forest. Under the heading "productivity" can be included the rate of merchantable nett volume production and the value of that production.

The history of repeated selective logging and conservative silviculture by which the forest derived its present irregular structure has also established a growing stock whose merchantable nett volume productivity is predictably very low, (Section 2.3.3, 2.3.4 and 2.5). Florence and Phillis (1971) have suggested that heavier cutting and more intensive silviculture will be needed to bring irregular eucalypt forest to greater long-term productivity.

The prediction of yield for the short-term future under such a prescription would depend not upon estimates of current growth but upon a detailed knowledge of the present growing stock in the terms to be used to define the cutting prescription. For example, if the cutting prescription defined different intensities of cut for trees of various crown classes, dominance classes, bole qualities and diameters, it would be necessary to have at least a reasonable estimate of the volume distribution by these classes in order to make a reliable forecast of the short-term yield.

Estimation of the longer term yield prospects will have to be based on a knowledge of the growth response of stands managed under the proposed type of silvicultural conditions. Although it may be possible to obtain some forecast of the probable growth trends under different regimes by studying in detail the measurements of routine permanent plots in conservatively managed stands, a full estimate of the growth potential will only be obtained from the continued observation of a properly planned series of experimental treatments. I therefore recommend that, when a forest manager contemplates a fairly heavy investment in a programme of intensive selective logging and silvicultural treatment, he should first study the results of a planned series of experimental treatments in order to define a suitable prescription and to estimate the yield potential of the treated stands. Secondly, he should undertake a fairly intensive temporary inventory to enable him to predict the probable short term yield from the treatment of the existing stand. I must also recommend against the use of Continuous Forest Inventory systems of permanent plots in these circumstances since, on the one hand, they are unlikely to embrace the full range of silvicultural conditions of interest and, on the other hand, they are likely to be inefficient and perhaps even biased estimators of the present growing stock.

In assessing the current growing stock most of the general inventory problems discussed in Section 12.2 can be dealt with as in the liquidation management situation since a heavy cut will be expected in the first cutting cycle and in later years the yield potential will be more related to the conditions of the stand than to the characteristics of the present growing stock. There are two principal differences, however, and these are as follows:

a) Mapping and management strata.

Because of the intention for the long-term continuation of management there is greater scope for the preparation of reliable maps and the recognition of management strata, particularly in relation to such parameters as slope, rock, access etc., not relating specifically to the characteristics of the existing stands.

b) Detail in the information on current stocking.

Greater detail crown qualities, species and size distributions will be required to predict the short term yield under a selective cut than would be required for a liquidation cut. Information on the amount of useless material to be removed in treatment would also help in the forecasting of treatment costs.

In evaluating the longer term productivity in the treated stands it would be desirable to be able to consider not only nett volume production but also value production. There has been very little work of this type done previously in Australian eucalypt forests, so that the studies presented in Chapter 11 represent an important new contribution to management planning. From the sawmilling viewpoint, value production is dependent on the interaction of volume, size and defect development. To devise techniques for estimating the rate of defect development in standing trees, however, was demonstrated to be undoubtedly a most difficult and costly process. Accordingly the study of financial productivity evolved with two principal aims. First there was the attempt to make estimates of absolute financial productivity of various types of individual trees under three hypothetical systems of defect development, namely constant nett volume, constant defect percentage and constant defect volume. Second there was the attempt to compare the financial potential of different classes of tree to see whether the gains from a selection system based on financial potential would be sufficient to warrant the cost and effort of trying to develop techniques for assessing rates of defect growth in individual standing trees. The financial simulator developed for this purpose was indeed rudimentary and capable of further development at a later date yet the results obtained do pose some important questions for management.

Merchantable trees retained in the forest in the course of selective logging represent capital capable of realisation by sale, then to be applied to alternative investments. For the stumpage appraisal system used in the exercise, despite substantial price/size margins, it appears that almost every class of tree is incapable of maintaining an earning rate of even 5 percent much beyond the size at which it first becomes saleable. Moreover, it is the trees which are currently worth most, those in which most potential investment capital is retained, which are the worst performers in terms of percentage rate of income. This trend appears whether looking at the best quality trees or the trees best situated for market. If the productivity of capital is not taken into account the larger its diameter so also the greater its individual annual value production in most circumstances. But again, when account is taken of the fact that maximum stocking is some function of the inverse of diameter it appears that the bigger the trees the lower is the financial production potential per unit forest area.

Clearly the few theoretical illustrations made do not logically lead to the conclusion that owners of irregular eucalypt forest should immediately begin clear-felling all merchantable trees starting with the best stems in the most accessible areas. Obvious arguments against such a philosophy include the following:

(a) The need to rationalise supply through time in relation to other suitable and competitive resources.

(b) The social and political advantages of continuing decentralised timber industry.

(c) The contention that timber royalty alone is not a reasonable basis for comparing the value of irregular eucalypt forest with other forms of investment.

Nevertheless, I contend that the defect study has thrown down an appreciable challenge to a view that is at least common in the subconscious of many forest managers that, in selective logging, the bigger and better looking the tree from a utilisation viewpoint the more it is worth retaining. The extent to which it is worth pursuing further a technique for assessing defect in standing trees depends upon the extent to which forest managers are prepared to take financial productivity into account, particularly the productivity of retained capital capable of alternative investment. It may be much more worthwhile to consider the characteristics of the tree which make it a desirable component of a recreational setting.

12.4 Conclusion

Finally, I conclude that large areas of irregular broad-leaved forest will be retained in Australia, as much for its environmental and recreational values as for its timber production potential. I expect that, for the most part, low-cost extensive management will be attempted in the future. For such management, with low cash returns per acre and small new cash re-investment, I must advocate low-cost inventories, probably with temporary samples, the use of aerial photography if feasible and the minimum of costly sophistication in field measurements. I am confident that the major timber growers in Australia, the Forest Services, will seek to continue to meet expected future demands through heavy, localised investment in plantations. Should this programme be brought to an end by financial pressures or the growing political lobby of the "environmentalists" I consider that there still exists a reasonable alternative in more intensive logging and silvicultural treatment of native irregular forest. The information necessary for this type of management will not be derived efficiently from continuous forest inventory to measure the current average growth of existing low-productivity stands but from properly designed experimentation to examine the treatment costs, financial returns, "environmental" values and resultant merchantable growth from a range of cutting strategies. Investigation and documentation of results are needed now if the Forestry profession is to be able to respond succinctly to public criticism of production management techniques.

It is regretted that it has not been possible in this final chapter to provide a "Common Sense Cookery Book" of inventory recipes for all occasions. The vagaries of past management and the difficulties of this type of forest as a sampling proposition do make it difficult to make many specific recommendations without all the numerous qualifications put forward in the discussion of previous chapters. But it is hoped that recommendations and remarks presented for the three management situations hypothesized in this chapter will constitute a positive contribution to the improved management of a type of forest whose values must surely grow in public recognition.

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LIST OF SPECIES NAMES

Common Name	Scientific Name
Alpine Ash	E. delegatensis R.T. Baker
Blackbutt	E. pilularis Sm.
Bloodwood	E. gummifera (Gaertn.) Hochr.
Blue Gum	E. saligna Sm.
Flooded Gum	E. grandis Hill ex Maiden
Grey Gum	E. propinqua Deane and Maiden
Ironbark	E. paniculata Sm.
Jarrah	E. marginata Sm.
Messmate	E. obliqua L'Herit
Mountain Ash	E. regnans F. Muell.
Red Mahogany	E. resinifera Sm.
Silvertop Ash	E. sieberi L. Johnson
Spotted Gum	E. maculata Hook.
Tallowwood	E. microcorys F. Muell.
Tasmanian Blue Gum	E. globulus Labill
White Mahogany	E. acmenioides Schau.
Brushbox	Tristania conferta R. Br.
Turpentine	Syncarpia glomulifera Sm.
Red Cedar	Cedrela australis
Radiata Pine	Pinus radiata D. Don

CIRCULAR AND RECTANGULAR PLOTS ON THE SAME CENTRES

29 Random 0.5-acre Plots

Cpt. 26 - Pine Creek S.F.

(50% area in common)

Plot Number	Basal Area (sq.feet) Circular	Rectangular
1	25.76	44.41
2	35.58	20.32
3	44.80	44.08
4	44.51	47.62
5	57.43	45.32
6	32.99	44.63
7	36.27	24.47
8	46.43	21.45
9	46.21	41.10
10	37.76	38.40
11	30.05	38.64
12	31.28	32.08
13	29.57	36.29
14	49.42	55.98
15	42.32	37.88
16	20.34	28.56
17	39.76	57.92
18	49.59	22.27
19	29.86	25.10
20	18.94	34.58
21	49.92	42.23
22	33.67	44.59
23	63.67	54.11
24	10.44	31.23
25	47.62	23.45
26	27.26	38.09
27	24.08	34.03
28	36.04	34.90
29	11.70	17.33

SAMPLING WITH PARTIAL REPLACEMENT EXAMPLE

(Plots measured in 1963 and 1965)

	Actual Volume 1963 sft H	Actual B.Area 1963 sq.ft	Regression Volume 1965 sft H	Regression Growth 63-65 sft H	Actual Volume 1965 sft H	Actual Growth 63-65 sft H
1	2709	14.0	3008	299	2821	112
2	2487	15.6	2757	270	2543	56
3	3221	17.7	3516	295	3410	189
4	10814	48.7	11283	469	11096	282
5	7615	50.2	7871	256	7730	115
6	11560	83.2	11744	184	11772	212
7	14033	66.8	14528	495	14414	381
8	6959	46.5	7210	251	7210	251
9	5345	28.6	5668	323	5601	256
10	8739	52.0	9048	309	8832	93
11	8329	45.6	8674	345	8508	179
12	6929	41.4	7227	298	7206	277
13	7616	36.0	8008	392	8145	529
14	3632	17.6	3954	322	4014	382
15	9181	48.9	9547	366	9839	658
16	7280	32.2	7688	408	7908	628
17	6255	37.8	6546	291	6470	215
18	4482	27.6	4761	279	4850	368
19	4566	25.1	4874	308	4825	259
20	10112	54.6	10481	369	10528	416
21	12289	64.9	12694	490	12780	491
22	10848	59.0	11220	372	11349	501
23	3545	22.0	3819	274	4324	779
24	7773	37.1	8165	392	8062	289
25	11020	56.0	11432	412	11472	452
26	8591	41.3	8993	402	9047	456
27	6000	36.2	6290	290	6250	250
28	8249	41.6	8627	378	8399	150
29	6545	41.2	6821	276	6802	257
30	2362	22.5	2558	196	2460	98
31	10126	63.9	10407	281	10262	136
32	6254	34.1	6580	326	6844	590
33	12538	73.6	12875	337	13098	560
34	8399	45.9	8745	346	8850	451
35	3482	27.9	3696	214	3892	410
36	12134	64.4	12534	400	12432	298
37	5337	31.1	5635	298	5614	277
38	10489	59.9	10830	341	10725	236
39	2114	16.8	2349	235	2308	194

SAMPLING WITH PARTIAL REPLACEMENT EXAMPLE
(plots measured in 1963 only)

	Actual Volume 1963 sft H	Actual B.Area 1963 sq.ft	Regression Volume 1965 sft H	Regression Growth 63-65 sft H	Actual Volume 1965 sft H	Actual Growth 63-65 sft H
1	2659	11.6	2978	319	2802	143
2	5918	27.9	6283	365	6142	224
3	6796	41.2	7088	292	7470	674
4	13501	69.6	13936	435	13942	441
5	4811	36.9	5021	210	4922	111
6	10279	51.9	10684	405	10431	152
7	7904	49.4	8186	282	8137	233
8	9486	55.7	9806	320	9867	381
9	11037	49.1	11516	479	11568	531
10	16909	72.3	17530	621	17060	151
11	7130	38.5	7468	338	7642	512
12	5873	37.1	6147	274	6261	388
13	14120	71.0	14580	460	14679	559
14	13883	66.5	14372	489	14258	375
15	10890	65.4	11204	314	11176	286
16	5969	35.6	6263	294	6223	254
17	16340	74.9	16901	561	17107	767
18	8691	43.2	9081	390	9232	541
19	3869	19.6	4186	317	4232	363
20	12534	65.4	12949	416	13026	492
21	7167	42.5	7469	302	7503	336
22	6970	36.8	7315	345	7231	261
23	5532	37.6	5780	248	5654	122
24	7862	49.0	8145	283	7989	127
25	6489	29.8	6871	382	7300	811
26	5543	38.1	5787	244	5703	160
27	7848	53.2	8090	242	8209	361
28	15383	76.1	15873	490	15783	400
29	1216	9.9	1462	246	1340	124
30	7926	45.9	8243	317	8234	308

NSW INVENTORY TIME STUDIES

Mogo State Forest

Plot type:	Temporary	
Plot shape:	Rectangular 1.5 acre	15 chn x 1 chn
Trees measured:	4-16 inches dbhob	0.5 acres
	16+ inches dbhob	1.5 acres
Number of Plots:	125	
Forest Area:	55,000 acres	

Newry State Forest

Plot type:	Temporary	
Plot shape:	Rectangular 1.5 acre	15 chn x 1 chn
Trees measured:	8-20 inches dbhob	0.5 acres
	20+ inches dbhob	1.5 acres
Number of plots:	97	
Forest area:	11,100 acres	

Pine Creek State Forest

Plot type:	Permanent (5th measurement)	
Plot shape:	Rectangular 0.5 acre	5 chn x 1 chn
Trees measured:	8+ inches dbhob	0.5 acres
Number of plots:	114	
Forest area:	8,400 acres	

Nambucca State Forest

Plot type:	Permanent	
Plot shape:	Originally rectangular 0.5 acre	5 chn x 1 chn
	Increased at last measure to 1.5 acre	5 chn x 3 chn
Trees measured:	4-12 inches dbhob	0.25 acres
	12-20 inches dbhob	0.5 acres
	20+ inches dbhob	1.5 acres
Number of plots:	100	
Forest area:	4,500 acres.	

NSW INVENTORY TIME STUDIES

Average Time Per Plot
(minutes)

	Mogo	Newry	Pine Ck	Nambucca
Drive to plot	23.8	15.5	8	9.1
Walk to plot	15.2	19.5	9	10.7
Measure plot	57.1	51.2	59	60.9*
Walk from plot	14.3	14.5	5	3.5

* This time was divided as follows:

40.3 Remeasure 0.5 acre plot

20.6 Increase plot size to 1.5 acre for trees larger than 20 inches dbhob.

DATA FOR LINEAR REGRESSION EXAMPLE

Observation	Basal Area (sq.ft/ac.)	Basal Area Increment (sq.ft/ac./ann.)
1	24	1.3
2	26	1.6
3	28	1.2
4	28	1.4
5	28	1.9
6	30	1.7
7	32	1.4
8	32	1.9
9	34	1.5
10	34	1.8
11	36	1.4
12	36	1.7
13	38	1.6
14	38	1.9
15	40	1.5
16	40	1.8
17	42	1.6
18	44	2.0
19	52	2.2
20	56	1.8
21	64	1.9
22	68	2.6
23	74	1.9
24	82	2.8
25	124	3.2
26	120	3.6 A
27	128	3.8 A
(26)	(120)	(2.6) B
(27)	(128)	(2.7) B

RECORDING PROCEDURE FOR SYSTEMATIC DOT-GRID COUNTING

An example of the dot-grid counting method of area estimation is given in Figure 9 and discussed in Section 6.4.3. The tabular result sheet below is designed to overcome the problem of overcounting when individual compartment areas are estimated and later summed. The suggestion here is that the grid origin and orientation be kept constant for a count of the complete map. A systematic count should proceed down each column of dots.

	Grid Column Number																		
Compart.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
External	7	5	4	3	1	1	1	1	1	1	1	1	1	2	1	2	2	1	36
1		4	5	6	8	9	7	7	6	6	5	4	4	4	3	3	0	0	81
2			2	4	7	9	10	9	8	7	7	5	4	2	1	1	0	0	76
3							1	4	6	6	5	6	6	6	6	6	5	5	62
4										1	1	2	3	4	5	4	7	7	34
5																			0
6							1	2	3	3	4	5	5	4	6	6	7	8	54
External	18	16	14	12	9	6	5	2	1	1	2	2	2	3	3	3	4	4	107
Total	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	450

REGRESSIONS FOR CONVERTING DBHOB TO DBHUB

TRENTHAM MANAGEMENT PLAN

Forests Commission of Victoria

(1969)

DBHUB = a + b.DBHOB

Condition	Species	a	b
Unburnt	Messmate	-1.475	0.927
	Peppermint	-1.110	0.980
	White Gum	-1.012	0.963
	Grey Gum	-1.012	0.963
	Swamp Gum	-0.840	0.936
Lightly Burnt	Messmate	-1.180	0.945
	Peppermint	-0.695	0.975
	White Gum	-0.835	0.949
	Grey Gum	-0.835	0.949
	Swamp Gum	-0.840	0.936
Severely Burnt	Messmate	-0.895	0.967
	Peppermint	-0.695	0.975
	White Gum	-0.780	0.958
	Grey Gum	-0.780	0.958
	Swamp Gum	-0.840	0.936

CUTTING CYCLE ANALYSIS EXAMPLE

CUTTING CYCLE 1

28-32 inch class

Period I

Number encountered	= (5.71/10) x 550
	= 314.05
Fraction cut at t_0	= (32-30) / (32-28)
	= 0.5
Fraction cut at $t_{5.71}$	= (34-30) / (34-30)
	= 1.0
Average fraction cut	= 0.75
Number cut	= 0.75 x 314.05
	= 235.54
Mean dbhob of those cut	= (0.5x31 + 1.0x32) / (0.5+1.0)
	= 31.67
Mean volume per tree cut	= 1322
Class yield	= 235.54 x 1322
	= 311447 s.ft
Number remaining	= 78.51

Period II

Number encountered	= (4.29/10) x 550
	= 235.95
Number cut	= 235.95
Mean dbhob of those cut	= 0.5(32.0 + 33.5)
	= 32.75
Mean volume per tree cut	= 1417
Class yield	= 235.95 x 1417
	= 334272 s.ft

CUTTING CYCLE ANALYSIS EXAMPLE

CUTTING CYCLE 1

24-28 inch class

Period I

Number encountered	=	(5.71/10) x 805
	=	459.66
Number cut	=	0

Period II

Number encountered	=	(4.29/10) x 805
	=	345.35
Fraction cut at $t_{5.71}$	=	(30-30) / (30-26)
	=	0
Fraction cut at t_{10}	=	(31.5-30) / (31.5-27.5)
	=	0.375
Average fraction cut	=	0.1875
Number cut	=	0.1875 x 345.35
	=	64.75
Mean dbhob of those cut	=	30 + 0.33(31.5-30)
	=	30.5
Mean volume per tree cut	=	1224
Class yield	=	64.75 x 1224
	=	79224 s.ft

Total yield for 1st cutting cycle = 1,165,438 s.ft

REGRESSIONS FOR THE PREDICTION OF STAND GROWTH

from Turner, (1966)

The subjection to intensive multiple regression analysis of the data from C.F.I. plots on an irregular eucalypt forest has shown that it is possible to develop regression models which explain a considerable amount of the variation in stand growth factors. The following equations are suggested:

1. Basal area growth excluding ingrowth

   NGXI(BA) = -0.205 + 0.00216(NT) + 0.0154(%BB) + 0.529(SGA)

2. Basal area ingrowth

   I(BA) = 2.08 - 0.0806(MD) - 0.00953(BAA) + 0.403(SGA)

3. Basal area growth including ingrowth

   NGWI(BA) = 0.537 + 0.0216(NT) + 0.0100(%BB) + 0.808(SGA)

4. Volume growth excluding ingrowth

   NGXI(V) = 43.9 + 0.00204(NH^2) + 2.63(%BB) + 116(SGA)

5. Volume growth including ingrowth

   NGWI(V) = -44.7 + 0.0113(SDH) + 2.38(%BB) + 118(SGA)

   NGWI(V) = 64.9 + 0.00291(NH^2) + 2.47(%BB) + 124(SGA)

6. Useful volume growth including ingrowth

   NGWI(UV) = 0.929(NGWI(V))

EXPLANATION OF VARIABLES USED IN APPENDIX X(A)

NGXI(BA)	nett annual basal area growth excluding ingrowth (sq.ft)
I(BA)	annual basal area ingrowth to 4-8 inch class
NGWI(BA)	nett annual basal area growth including ingrowth
NGXI(V)	nett annual volume growth excluding ingrowth
NGWI(V)	nett annual volume growth including ingrowth
NGWI(UV)	nett annual volume growth of useful trees, including ingrowth
NT	number of trees per acre
%BB	percentage of blackbutt by basal area
SGA	soil group A SGA = 1 if soil is Group A SGA = 0 if soil is Group B
MD	mean diameter of trees on plot
BAA	basal area per acre
NH^2	number of trees x mean merch. height squared
SDH	sum of (diameter x merch. height).

PINE CREEK STATE FOREST

1971

Percentage Species Composition in Numbers of Trees

Species	Less than 20in. dbhob			Greater than 20in. dbhob		
	Ridge	Gully	Combined	Ridge	Gully	Combined
Blackbutt	20.81	2.88	13.75	56.92	8.19	42.16
Tallowwood	19.03	7.55	14.50	11.74	5.30	9.80
Flooded Gum	6.34	57.50	26.48	2.83	43.86	15.07
Bloodwood	9.41	5.54	7.90	3.51	3.69	3.59
Grey Gum	7.01	2.40	5.18	1.58	0.00	1.15
Red Mahogany	5.60	1.31	3.92	2.83	0.80	2.26
White Mahogany	9.93	3.94	7.57	3.17	4.49	3.59
Ironbark	5.68	2.52	4.43	3.96	3.05	3.59
Brushbox	2.12	2.63	2.31	3.17	11.94	5.93
Turpentine	11.12	11.00	11.09	8.03	18.68	11.22
Blue Gum	2.95	2.73	2.87	2.26	0.00	1.64
Total	100.00	100.00	100.00	100.00	100.00	100.00

VIGOUR CLASS DEFINITIONS

From Trimble, 1969.

Vigour 1.

A tree in this class has a large, healthy, full crown in a dominant or codominant position. Half the crown or more is exposed to direct sunlight. The crown is dense, with no evidence of disease or injury. Crown quality and position is more important than total length. The bark and twigs have good colour and vigorous appearance.

Vigour 2.

A tree in this vigour class has a fair-sized crown in a codominant position. Less than half the crown is exposed to direct sunlight. The crown is less dense and not so perfect as that of a Vigour 1 tree. This class may also include a large-crowned tree that fails to meet the requirements of Vigour 1 because of mechanical injury or dying limbs.

Vigour 3.

A tree in this class has a medium to small crown usually in an intermediate position. Only the tip is exposed to direct sunlight. The crown may be open, with some dead or broken limbs, or thinly foliated. This class also included trees with fair to large crowns in a codominant position that cannot meet the requirements for a Vigour 1 tree.

Vigour 4.

A tree in this class usually has a small crown in an overtopped position. This class includes all living trees that fail to meet the requirements of higher vigour classes.

DEFINITIONS OF TREE CLASSES

Grosenbaugh (1955)

GROWN-UP: A tree of saleable dimensions, whose saleability depends on other factors.

PAYER: A saleable tree - one whose stumpage has a current market value greater than zero. When it cannot be established by actual bid of prospective purchaser, locally acceptable minima must be arbitrarily specified; specifications should cover species, tree dimension and shape, quantity of acceptable products per tree, description of minimum acceptable product, proportion of harvested bole which must yield acceptable products, maximum allowable product defects such as knots, decay, stain, insects, etc.

Grower: A payer whose expectancy of living for the next 10 years is at least 0.9 while its expected ratio of $\frac{\text{stumpage value 10 years hence}}{\text{stumpage value now}}$ will be at least 4/3 if it survives and is given adequate space. Obviously the expected future value of such a tree is at least 9/10 x 4/3 = 6/5 current value, or an increase of at least 1.8 per cent compound interest. Characteristics useful in classifying trees as growers include size, form, species, site, vigour (crown, bark, root) and freedom from knots, lean, serious pathogens, etc. Some people call such trees 'crop trees' or 'good growing stock'. It is not difficult to calculate the ratio of $\frac{\text{volume 10 years hence}}{\text{volume now}}$. This ratio is $\frac{(D-N)^2.N}{(d-n)^2.n}$ if one postulates the dbh and number-of-log increase from d to D and from n to N in 10 years; the ratio thus calculated assumes volume measured in board feet (Int.¼in rule). Of course, increment in value due to factors other than volume growth (such as price inflation, quality improvement, lower unit operating costs) must be guessed, and is usually ignored.

Schneider's somewhat simpler approximation is:

$$\text{Growth percent} = \frac{400}{D.R}$$

where D is dbh in inches and R is the number of rings per inch; D.R should not exceed 133 when growth of more than 3 per cent is desired.

Cipher: A payer whose expectancy of living for the next ten-year period exceeds 0.9 but which does not have an expected ratio of $\frac{\text{stumpage value 10 years hence}}{\text{stumpage value now}}$ equal to at least 4/3, and which does not compete with any grower, doll or cub (see below). Some people call such trees 'financially mature'.

Topper: A payer similar to a cipher but overtopping a doll or cub (see below)

Slower: The least potentially productive of several payers (not riskers or killers - see below) competing in inadequate growing space. It should be cut in thinning.

Risker: A payer whose expectancy of living for the next 10-year period is less than 0.9. It should be cut to salvage potential loss through mortality.

Killer: A payer infested with contagious pathogens.

CRUD: A grown-up that cannot be sold because of species, form, knots, rot, insects or other defects.

Null: A crud not competing with any grower, doll, or cub (see below).

Cork: A crud overtopping a doll or cub (see below).

Pang: A crud seriously competing with a grower or harbouring contagious pathogens.

DEB: A tree at least 4.5 feet tall but smaller than a grown-up.

Doll: A desirable deb which is a potential grower, given adequate space and time.

Drip: An undesirable deb which is unlikely to become a grower, even though given space and time, but which is not interfering with a doll or cub.

Drag: An undesirable deb interfering with a doll or cub.

KID: A tree seedling less than 4.5 feet tall

Cub: A desirable kid which is a potential doll.

Cur: An undesirable kid which will probably become a drip or drag.

TYPICAL N.S.W. HARDWOOD STUMPAGE APPRAISAL

(Applicable to parts of Pine Creek S.F.)

	$	$
Mill run price f.o.r. at key market		15.46
Rail distance to market 365 miles		
Rail freight to market	3.76	
Value at local rail yard		11.70
Sawn haul to rail, 4 miles, A class	0.08	
Load, unload, load onto rail	0.38	
Value in millyard		11.24
Manufacturing margin	5.80	5.44
Recovery on nett Hoppus 66.67%		
MILL DOOR LOG VALUE		$3.63
Log haul to mill, 5 miles of B class	0.15	
Load and unload	0.23	
Snigging 12,000s.ft/day	0.52	
Felling	0.32	
BASE RATE		$2.41
(Group B spp./5'6" - 7'11"c.g.)		

STUMPAGE MARGINS

NSW Forestry Commission Hardwood Stumpage System.

Variations from Group B, Medium

(per 100 s.ft nett)

Species Group	Large *8'+	Medium 5'6"-7'11"	Intermediate 4'-5'5"	Small 4'-
A	$1.20	0.60	0.10	-0.90
B	0.50	0.00	-0.40	-0.90
C	0.00	-0.40	-0.70	-1.20
D	-0.30	-0.60	-0.90	-1.20
BBT	0.70	0.20	-0.20	-0.90

* Log sizes are according to centre girth under bark.

Sale Species Groups

A	Ironbark, Tallowwood
B	Blue Gum, Flooded Gum, Red Mahogany
C	Grey Gum, White Mahogany
D	Turpentine, Brushbox, Bloodwood
BBT	Blackbutt.

BASIC CONTROL DATA FOR 'CUTAN'TRIAL

Projection Data

dbhob	a	b	c	d
0-4	0.00	0.42	0.000	0.0
4-8	0.00	0.42	0.000	0.0
8-12	3.24	0.40	0.004	28.7
12-16	2.82	0.39	0.004	39.7
16-20	2.31	0.38	0.004	47.4
20-24	2.11	0.37	0.004	52.0
24-28	1.72	0.37	0.000	53.4
28-32	1.24	0.37	0.000	51.6
32-36	0.28	0.36	0.000	46.7
36-40	0.11	0.36	0.000	38.6
40-44	0.14	0.36	0.000	27.3
44-48	0.00	0.35	0.000	20.0

Where:

a = initial stocking (stems per acre)
b = annual diameter growth (inches)
c = annual mortality percentage
d = merchantable height (feet)

Analysis Specifications

Cycle length = 10 years
Number of projection periods per cycle = 20
Cutting limit - Cycle 1 = 29 inches dbhob
Cutting limit - Cycles 2-4 = 28 inches dbhob

Volume Table

$$V = 105.297 - 34.106B - 2.115H + 5.117B.H - 0.00917B.H^2$$

Where:-

V = merchantable volume per tree (s.ft Hoppus)
B = tree basal area (square feet)
H = merchantable height (feet)