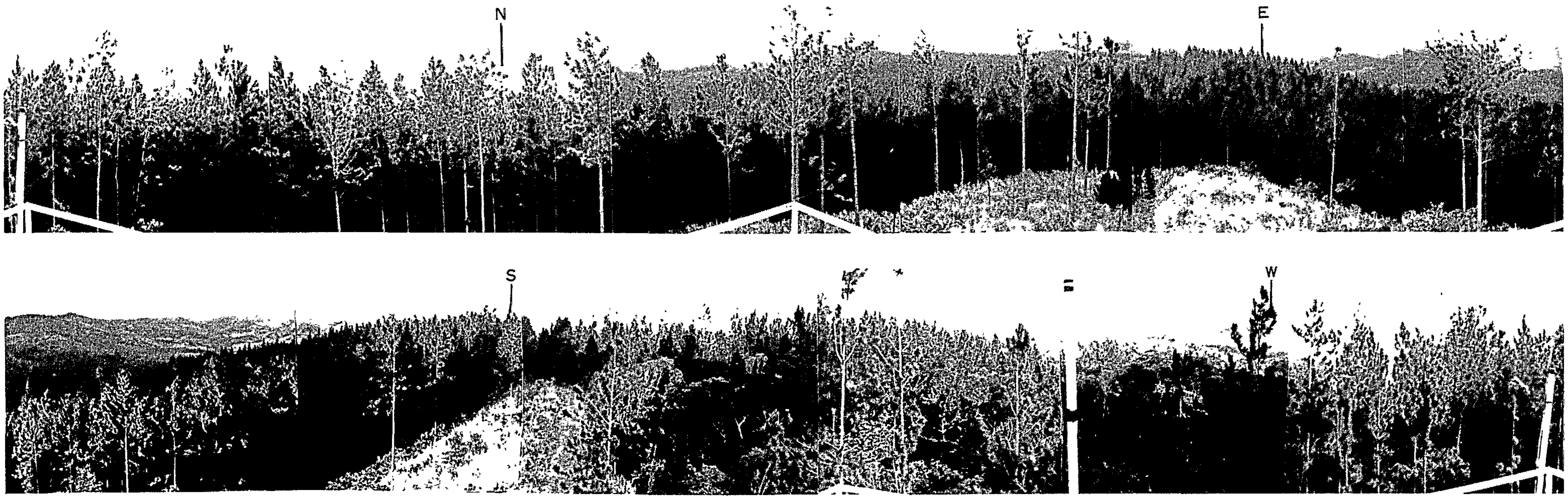
REPORT OF FOREST INVENTORY ON PINE PLANTATION IN VANUA LEVU FIJI

December, 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

(J.I.C.A.)



The panorama from the fire tower in compartment 3

NO.

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CONTENTS

PREFACE

It is a great pleasure for me to present this "Report of Forest Inventory on Pine Plantation in Vanua Levu, Fiji" to the Government of Fiji.

This report embodies the result of a forest inventory survey which was conducted in Seaqaqa and Koroutari area, Vanua Levu for 45 days from 28th July by a Japanese survey team commissioned by the Japan International Cooperation Agency following the request of the Government of Fiji to the Government of Japan.

The survey team, headed by Mr. Tomohisa Fukumori, had a series of discussions with the officials concerned of the Government of Fiji and conducted a wide ranging field survey.

I hope that this report will be useful as a basic reference for forest development of the region.

I wish to express my deep appreciation to the officials concerned of the Government of Fiji for their close cooperation extended to the Japanese team.

December, 1980

Keisuke Arita
President
Japan International Cooperation Agency

1. SURVEY OUTLINE

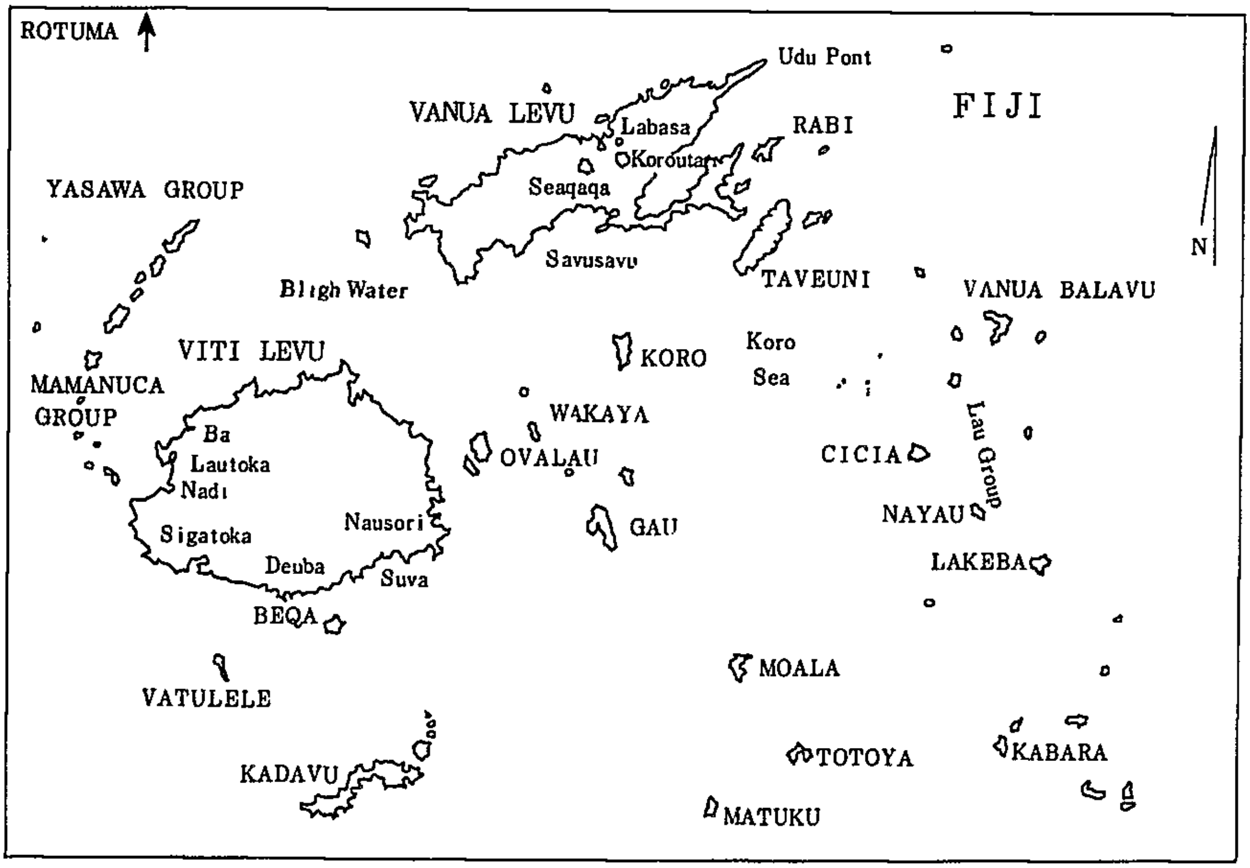
1.1 Purpose

The purpose of the survey was to ascertain, by aerial photograph analysis, the distribution and resources of Carribean Pine plantation planted by Fiji government in Seaqaqa and Koroutari on Vanua Levu, and to include studies on thinning, etc., practices and present data on intended future practices.

1.2 Outline of the survey area

The survey areas are located on Seaqaqa and Koroutari in Vanua Levu. They are managed by the Fiji government but leased. (See Figures 1.1 and 1.2).

Fig. 1.1 Location map of Fiji



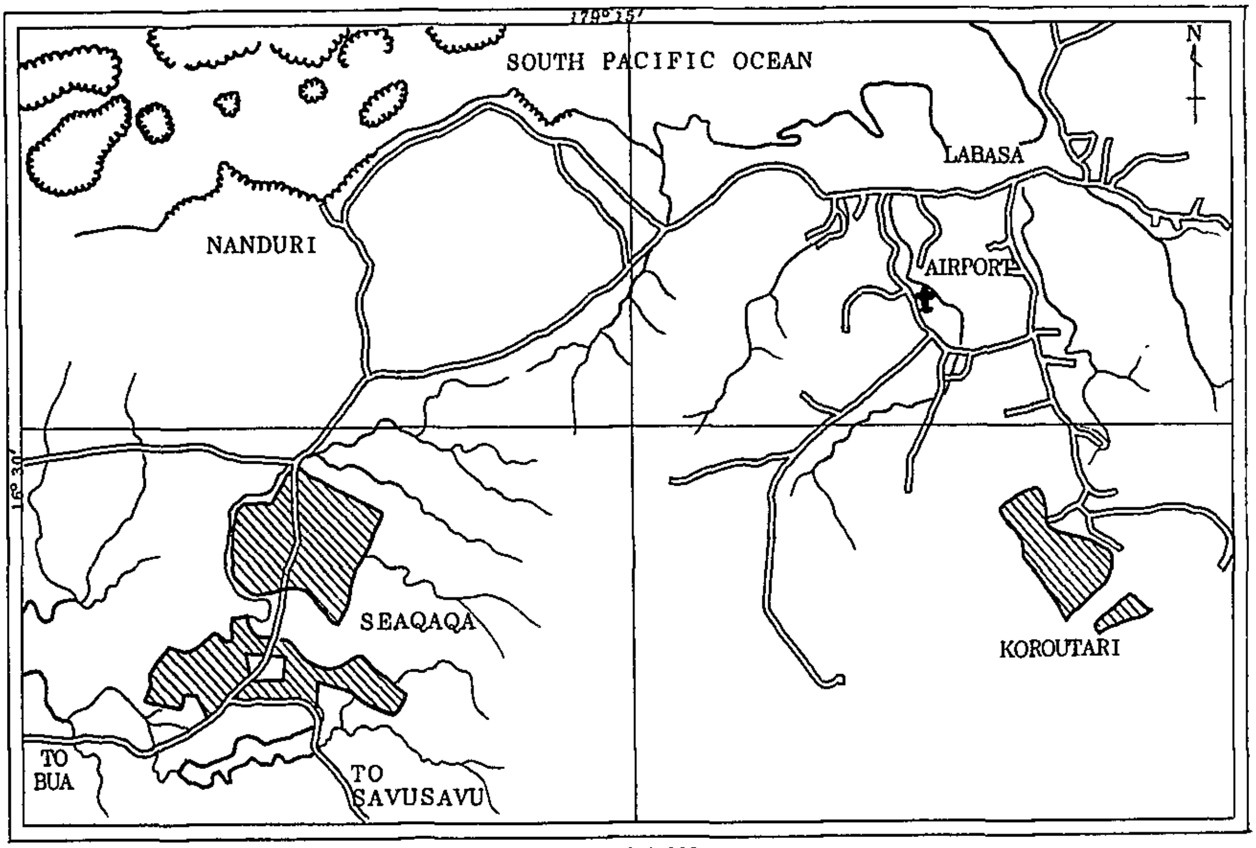
(1) Location and extent.

Vanua Levu is located between the latitude of 16° 15'S and 17°00'S and the longitude of 178°30' and 180°00'E. The area is 5,500 km^2. This is 30% of the total area of the Fiji islands. The survey areas are located almost in the centre of Vanua Levu and they are 1,570 ha in Seaqaqa and 300 ha in Koroutari (See Figure 1.2).

(2) Topography and geology.

The majority of the main islands of Fiji are almost of an ancient volcanic nature, with occasional volcanic parent material, and Cretaceous and Tertiary sedimentary deposits occuring on the old continental shelf. Vanua Levu has many complicated undulations, and the coastline is heavily indented. In particular, the windward south-east coast is deeply indented forming a mountainous peninsula connected to the mainland by a narrow isthmus The island is elongated in a north-east to south-west direction, and the watershed divides the island centrally into a dry region in the north-west and a wet region in the south-east. The Seaqaqa and Koroutari areas are both located on the north-west side of the watershed and are therefore in the dry region, but as they lie close to the watershed, they cannot be defined as typical dry areas. The Seaqaqa area is about 5 kms north–west of the watershed (at about 600 m altitude) and forms a relatively flat alluvial basin between two rivers upper reaches. Ndreketi river that is the largest in Vanua Levu running west, the Koroyuli river running north. With regard to the Koroutari area is located in between a plain that stretches inland from the coast and the watershed that altitude is about 800 m, thus giving the area a steep surface.

Fig. 1.2 Location map of Seaqaqa and Koroutari

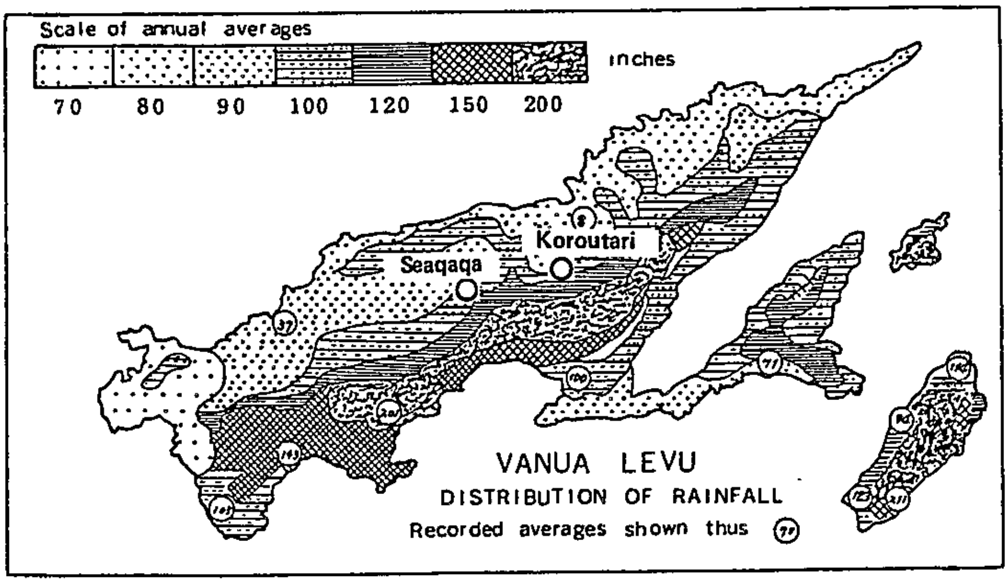


SCALE 1 : 250,000

(3) Climate.

The climate of Fiji is a tropical maritime climate, with high temperatures but usually modified by the maritime influence. The predominant wind is the South East Trade Wind which tends to easterly throughout the year. For this reason, the windward side of the Vanua Levu watershed, which runs north-east to south-west, is a wet region, while the leeward side is a dry region. Hurricanes and cyclones are brought by the low pressures occuring in the period between November and April, sometimes causing considerable damage. Recently, they have occured in 2 – 3 year intervals, in 1973, 1975, 1978 and 1980, and the cyclone of this April resulted in a large quantity of fallen timber in both the Seaqaqa and Koroutari areas. Figure 1-3 shows the distribution of annual precipitation for Vanua Levu.

Fig. 1.3 Vanua Levu Distribution of rainfall



(4) Outline of Seaqaqa Forest Station.

The Seaqaqa Forest Station area of jurisdiction covers 1,900 ha and was established in 1959. The staffs are four planters, one research worker, and one mechanic. The permanent work force totals about 30. The facilities are as follows:

Station office	1
Official residence	14
Guest house	1
Residential hall	2
Garage	2
Storehouse	1
Timber store	1
Oil station	1
Workshop	1
Power plant	1
Radiotelegraph	1 set.
Filtration plant	1
Fire lookout tower	2
Timber yard	

Nursery
Forest road

Machinery is as follows:

MF 165 Caterpillar tractor	1
D3 Crawler tractor	1
165 trailer	1
Shark loader	1
Land rover	3
Small truck (3 ton)	2
Mixing truck	1
Fire engine (7 ton)	1
Air compressor	1
Generator (240 V)	1
Preservative equipment (for post making)	1

As this year's work was practiced only thinning, but not final cutting, the main task was the dealing with fallen timber resulting from the cyclone. Production for the five months, April to August, is shown in Table 1.1.

Table 1.1 Production for the five months April to August in Seaqaqa

Category	Volume	Unit selling price	Selling price
~0 150m³/one log	212.2 m³	10.90 F$/m³	2,312.98 F$
0.150 ~ 0 30 m³	1,143 7	13 20	15,096 84
0.30 m³ ~	847.3	15.50	13,133 15
total	2,203 2	burden cost 1.70	3,745.44
		total	34,288 41

This selling price is an agreed price between three private timber companies, and is included truck loading on site. The five months of April to August is the peak production period, and the annual average production is about 50,000 F$. With regard to costs, the annual budget details for January to December are given below, but by October costs have exceeded the budget.

Timber production labour costs	29,000 F$
Timber production parts	9,250
Timber production machinery (including fuel)	8,400
Equipment (vehicles, etc.)	11,600
Station machinery	1,700
Tools	400
Labour (other than timber production)	28,000
Road maintenance	400
Building maintenance	500
Technological training	3,000
Technological transport etc.m	–
Technological parts, and other	1,500
TOTAL	93,750

Both the Seaqaqa and Koroutari plantation areas are leased privately to the government under contract, and are planted as government afforestation. A summary of the contract is given here.

When the contract is agreed, 2.5 F$ per acre is paid as a gift Until planting or for five years after the contract is signed, 10 cents per acre is paid annually. After planting, or after the first five years of the contract, 50 cents per acre is paid annually. On final cutting, 3% of the stumpage price (guaranteed minimum $20 per acre) is paid. The terms of the contract were fixed in 1956 by the Native Land Trust Board, and renegotiation will be done next year.

1.3 Survey Team, and associates in Fiji.

The Caribbean Pine Survey team for the Seaqaqa and Koroutari areas consisted of the following members:

Overall group

Leader	Tomohisa Fukumori	Adviser, Japan Forstry Technical Association
	Hiroshi Watanabe	Technical Department Manager, Japan Forestry Technical Association.

Survey group

Leader	Shigeo Yamada	Director, Japan Forestry Technical Association.
	Akira Shirai	Technical Expert, Japan Forestry Technical Association.
	Katsuo Yamashita	Technical Expert, Japan Forestry Technical Association.
	Hitoshi Kato	Engineer, Japan Forestry Technical Association.

With regard to individual responsibilities, Mr. Yamada was in charge of the overall survey, Mr. Yamashita and Mr. Kato were in charge of the resource survey, and Mr. Shirai was in charge of thinning guidance and other fields.

Associates in Fiji were as follows:

The Forestry Agency	Conservator of Forests	G H. D. Williams.
,,	Deputy Conservator of Forests	K. T. Yabaki.
,,	Senior Assistant Conservator of Forests	A Oram
,,	Administrative Manager	J. T. Usumaki.
Labasa Regional Forest Office		B. Mordak.
,,		P. Moi.
Seaqaqa District Forest Office	Supervisor	I. Wainiqolo.
Koroutari District Forest Office	Supervisor	T. Manawalala.

1.4 Outline of Caribbean Pine

1.4.1 Special characteristics of Caribbean Pine var.

The native Caribbean Pine is the islands in the Caribbean Sea. The varieties introduced to Fiji consist of four varieties named according to their specific native.

(1) Pinus caribaea var. hondurensis

This variety is found in Belize (British Honduras), Guatemala, Honduras and Nicaragua. It's vertical distribution is from 0–100 m in Belize. Under good soil conditions, heights

of 45 m can be reached. The special morphological features are, in comparison with var. cuban: branches are long with greater intervals between branches, there are 3 or 4 needles per leaf, and very unusually 5 needles may be found. With regard to its growth in Fiji, in comparison with var. cuban, it has good vertical growth, with six or seven year-old trees showing differences of 1 – 1.5 m in height.

(2) Pinus caribaea var. caribaea.

This variety is found in the western parts of Cuba and Pinos Island, and in Cuba the vertical distribution is 0 – 280 m. In Fiji, it is very similar to var. hondurensis and they cannot be distinguished visually.

(3) Pinus caribaea var. cuban.

This variety is widely distributed on the main island of Cuba, and in Fiji. This indicates very different morphology from the other three varieties. This height growth is comparatively slow and it liable develops 'taperness'. The branches are relatively thick, and intervals between branches are short. The angle between branch and trunk is relatively acute and length of branches is generally short. It is a expected tree for suffering relatively little from cyclones, etc., The leaf arrangement has five needles.

(4) Pinus caribaea var. bahamensis.

This variety is originated in the islands of the Bahamas and the Caicos Islands, and in the survey areas, it occurs only in the Koroutari area.

Morphologically it cannot be distinguished visually from var. hondurensis and var. caribaea.

1.4.2 Environmental conditions at native land.

The areas in which Caribbean Pine grows naturally are those having a frost-free climate with warm temperatures throughout the year. In the Bahama Islands, and the islands of the Caribbean, the lowest temperature is 22.1°C, in January, and the highest temperature is 28.3°C in August. However, Belize's, climate except on the coast, is more varied. For example, the temperatures in mountainous inland occasionally fall as low as 5°C.

With regard to precipitation, the Caribbean Islands are usually dry in winter, from November to April, and June to October is wet. In Cuba, 1780 mm of precipitation is recorded, at around 330 m above see level; in the south-west piedmont region, it is 1300 mm, and in the southern coastal plains, 1060 mm. In the Bahama Islands, the average annual precipitation is between 1200 mm and 1500 mm.

Soil conditions in the Bahama and Caicos Islands are the coral reef plateaus. The soil is very shallow, under 3 cm, and the pH value is about 8. On the coral reef plateaus it is impossible for the roots of the Caribbean Pine to penetrate to the ground water table, but because of the water storing capability of coral, the trees can survive the dry season. In central America, the trees will not survive in clayey soils having bad ventilation, but will survive in well ventilated sands or silts even if these soils are relatively infertile.

1.4.3 Growth characteristics of Caribbean Pine.

The Caribbean Pine has high tolerant to dry conditions, and there are occupied in Nigeria, during which the relative humidity falls below 10% at the higher altitudes around 1200 m, the trees still grow. However it is said that during dry seasons a phenomenum may occur in which the needles curl and the natural growth is prevented. With regard to the root system, this varies according to the circumstances of soil water. For Example, Caribbean Pines planted in highly absorbent sand in Zululand, South Africa, form well developed vertical roots down to the water table. On the other hand, in coral reef zones, such as on the Bahama Islands, the root system develops horizontally over the coral layer and grows without forming vertical roots.

The main growth characteristics of the Caribbean Pine can be occured as foxtails and needleless shoots. Foxtails are the result of a lack of side branch growth in the early stages, so that the top of the trunk assumes the sppearance of a fox's tail. Amongst the four varieties of Caribbean Pine found in Fiji, foxtails occur frequently in var hondurensis, and rarely in var. cuban. The advantages of foxtails indicate that they produce timber without nodes and they require less growing space. However, the disadvantages are that the diameter increment is reduced, the chances of being blown down are increased, and the fibres tend to be short. In Fiji, when the trees reach ten to fifteen years old, side branches begin to develop from the top, and with regard to adult trees, despite the large intervals between branches, it seems that the trees assume a more normal appearance. With regard to thinning, the advice is to thin as much as possible. Of adult trees over fifteen years old, some have leaves directly attached to the trunk, indicating that at an early stage, the tree was a foxtail. There are two views on the reasons for the occurrence of foxtails. One is that, since the proportion of foxtails to normal trees increases at lower altitudes where there is a thick soil, the cause is environmental. The other suggests that heredity is the cause. Because planting in Fiji has recently moved to slopes, young trees developing foxtails only exist at relatively high elevations, and therefore it could not be ascertained that the cause was due to site factors.

Needleless shoots occur when needles fail to grow on a new shoot, and needle buds are arranged in a fish scale pattern. In this survey area, needleless shoots are not in evidence. Forkedtree are common over fifteen years old. Forking occurs 1 – 2 m from the top, where the diameter is less than 10 cms. Even within a single variety, the occurrence of forking is varied from place to place. In areas where forking is common, a percentage of the occurrence was measured at 20% For this reason, some people feels that the cause of forking is new growth after cyclone damage, but there is as yet no firmed evidence.

1.4.4 Damage and prevention.

(1) Wind damage.

The places of origin of the Caribbean Pine, the islands of the Caribbean sea, are often hit by hurricanes, and these are sometimes known to blow down trees, or initiate fires which subsequently destroy surrounding areas

In the survey area, a cyclone passed through in April of this year, causing considerable damage. This damage is detailed below.

At 69 sample plots, we calculated the ratio of abnormal trees (excluding foxtails). Result are shown in Table 1.2.

Abnormal trees included those uprooted, those with broken trunks, extreme forking, and natural withered. Of these forms of damage, uprooted trees indicated 10%, broken trunks 50%, extreme forking 20%, and withered 20%. Cyclone damage was accounted for uprooting and broken trunks, which constituted 60% (10% + 50%) of the total damage The average percentage of damage in the total sampling area was 3.1%, and 60% of this, i.e. 1.8%, was the result of the cyclone.

With regard to cyclone damage, there has tended to be more damage in the Seaqaqa area than in the Koroutari area. Geographically, serious damage is caused at the head of a valley, where the valley is narrow, and where the wind blows up the valley, and in the area extending to the ridge. An examination, by analyzing the sample plot data, was made to find out in which stand the damage was greatest, but no clear tendancy was found. However, it does seem that damage trees are occured in stands in which trees heve a smaller than average diameter of breast height. Although we could not measure the heights accurately because of broken trunks, but it appears that those trees having a

Table 1.2 Ratio of abnormal tree

Sample plot No.		Ratio of abnormal tree (%)	Sample plot No.		Ratio of abnormal tree (%)	Sample plot No.		Ratio of abnormal tree (%)	Sample plot No.		Ratio of abnormal tree (%)
1	S− 1	3 9	19	S−24	5.7	37	S−19	1 1	55	Y−32	2.0
2	S− 2	1.6	20	S−11	4.0	38	Y−17	1.4	56	S−30	11.5
3	Y− 4	0	21	S−10	0	39	Y−18	0	57	S−32	0.1
4	Y− 5	0	22	S− 9	0	40	Y−19	2.4	58	Y−33	0
5	S− 4	0	23	S−26	0	41	Y−20	1.1	59	S−31	3 8
6	S− 3	2.7	24	Y−12	0	42	Y−22	1.1	60	S−34	0
7	S− 5	5 9	25	S−12	16.5	43	S−21	5 5	61	Y−35	1.7
8	Y− 6	5 8	26	S−13	4.4	44	S−20	15.9	62	S−33	9.6
9	Y− 2	1.9	27	S−14	0	45	S−23	3.6	63	Y−34	2.4
10	Y− 3	0	28	Y−15	4.1	46	S−22	5.1	64	S−27	1 4
11	Y− 7	0	29	Y−16	0	47	Y−21	0	65	Y−28	0
12	Y− 8	0	30	Y−13	3.2	48	Y−23	0	66	S−28	6.5
13	S− 8	6.7	31	Y−14	0	49	Y−26	1.0	67	Y−29	2.9
14	S− 6	10 9	32	S−18	3 1	50	Y−27	8.7	68	S−29	2 8
15	S− 7	1.1	33	S−17	4.7	51	Y−25	1.3	69	Y−30	0
16	Y− 9	0	34	S−25	12.4	52	Y−24	0			
17	Y−11	2.4	35	S−16	6.8	53	Y− 1	4 0			
18	Y−10	2.4	36	S−15	1.1	54	Y−31	3 9			

high form height ratio, so presenting large wind resistance, and occured much damge.

(2) Other damage.

With regard to blight, some cases of Cercospora pini-densiflorae have occured in Malaysia and Brazil. Dothistroma pini occurs world-wide, but there is no possibility occurrence in Fiji as the temperature suitable for its spore germination and growth is less than 20°C. Lophodermium pinastri has been reported in New Zealand, Australia and Fiji, but it has not been found in the survey area.

In the Seaqaqa area, an insect 1 – 2 mm in diameter, called the Bark beetle has been found. This insect burrows between the bark and the timber and eats away some 2 – 3 mm of timber. When the tree is felled and the bark removed, a striped pattern is apparent on the timber, but, it is not problem for growth.

1.4.5 Wood quality and use.

The quality of the Caribbean Pine timber is placed in the group as known Southern yellow pine on the American market. For comparison, the differences of quality between the Caribbean pine and Pinus densiflora SIEB. et ZUCC. are given here. Air-dried specific gravity of Pinus densiflora has a value of 0 53 and that of Caribbean pine is 0.75. Caribbean Pine is heavier than Densiflora. With regard to shrinkage percentage, both have the

same value in a tangential direction, but in the radial direction, Pinus densiflora has a value of 0.14 – 1.17%, Caribbean Pine has the 0.22% or more, indicating a larger value for Caribbean Pine The Bending Young factor, the bending strength and the longitudinal compression strength have similar values for both, but shearing strength (kg/cm^2) for Pinus densiflora is 96 – 120, whereas for Caribbean Pine is 121 – 150. With regard to tangential cut surface hardness (kg/mm^2), Pinus densiflora has a value of 0.9 – 1.5, and Caribbean Pine, 2.6 – 3.8. With regard to friction (tangential cut surface friction in mm/100revs) Pinus densiflora has a value of 0 054 – 0.080, whereas Caribbean Pine has a value of 0.010 – 0.020, and as a rule, Caribbean Pine tends to be heavier and harder than Pinus densiflora.

In generally use, it is felt to be suitable as timber for construction, packing cases, public work and as wood pulp. The uses of Caribbean Pine in Fiji are outlined below.

After preservation treatment, it is used for fence posts, fruit tree supports, ground sills, telegraph poles, construction, furniture, panelling and packing cases, etc.. At the present, timber form thinning in Seaqaqa is used for fence posts, and packing cases. However the demand is low, and there is an excess supply. Final cutting timber has not yet been reached, so there is no past record of usage, but Fiji Forest Industry in Labasa proposes to use it as plywood core material.

However, domestic demand in Fiji is not likely to be strong, so it is expected that exports will be made to Japan.

1.4.6 Nursery technology.

All seed required in Seqaqaq is obtained from existing mother trees within this area. Seeds are sown in germination beds That consist of one meter wide and haveing a soil depth of 10 cms, covered by approximately 5 mm of sand. Seeds are sown on these beds and covered with sand. Direct sunshine is avoided, and the beds are kept well watered. After two or three weeks spend, the seedlings grow to about 5 cms height, after which they are transplanted to plastic pots of 6 – 7 cms, diameter and 10 cms deep. The seedlings are planted in the pots in sifted soil. In three to four weeks the seedlings grow to 15 – 20 cms height. They are then planted out. Planting out should be carried out in the wet season. Planting interval is 9 x 9 ft^2 (2.7 x 2.7 m^2) or 8 x 10 ft^2 (2.4 x 3 m^2). Stand density are 1,350 per hectare.

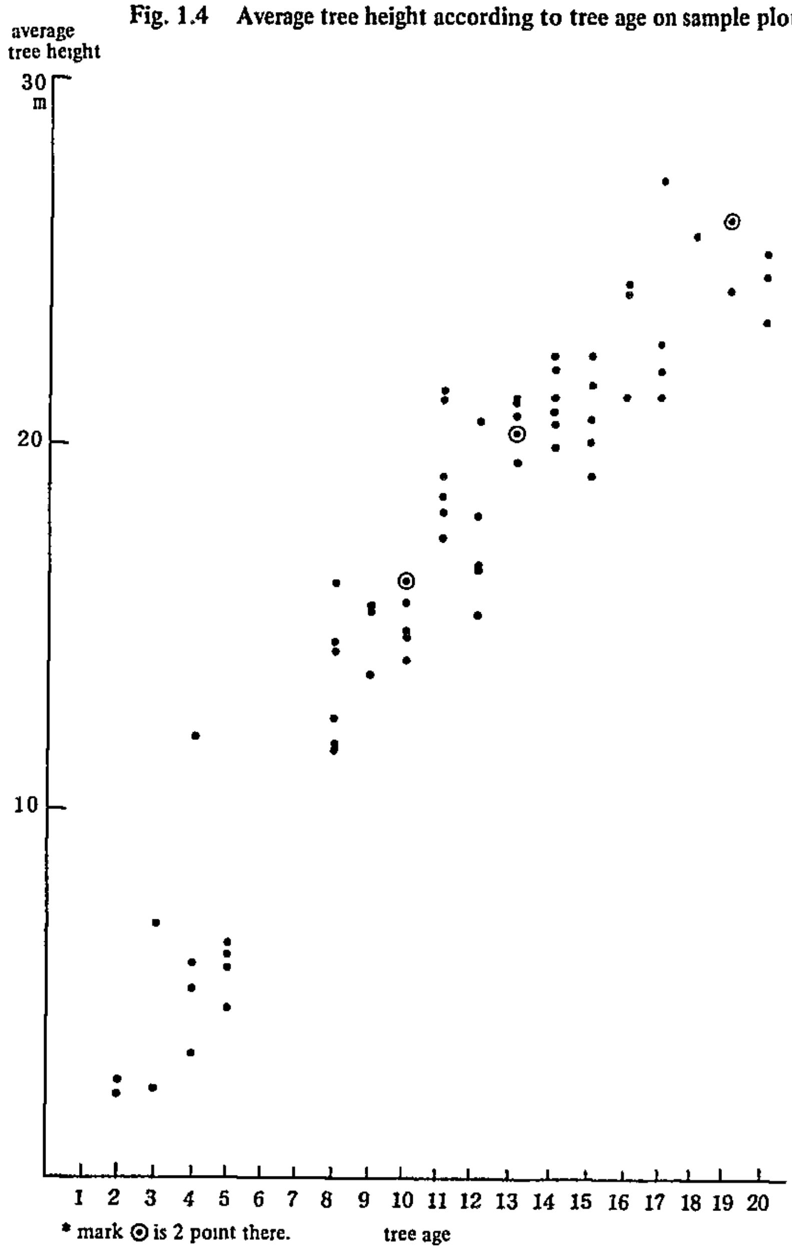
1.4.7 Special ecological features.

The special ecological features regarding Caribbean Pine are shown in clause 3.3 Stand Density Control Diagram. However this diagram is compiled from 69 samples, and therefore cannot represent the total ecological stand element. In this chapter, explanations are mainly made on the basis from the results on sample plot surveys.

(1) Average tree height according to tree age.

Figure 1.4 shows the average tree height according to tree age in the sample plots. This indicates that 20 year old trees attain an average tree height of 25 – 27 m, which represents a fast height growth. On the Hiroshima area, in Japan, Even if having good growing conditions areas Pinus densiflora has an average height 4.8 m at 10 years old, and 11.4 m at 20 years old, (16.2 m at 30 years, 19.7 m at 40 years, 22.1 m at 50 years and 23.5 m at 60 years). Compared with this, Caribbean Pine reaches twice the height at an age of 20 years.

Fig. 1.4 Average tree height according to tree age on sample plot



(2) Average diameter breast height according to tree age.

Figure 1.5 shows the average diameter breast height according to tree age in the sample plots. This indicates that 20 year old trees attain an average of approximately 30 cm and at 10 years, 20 cm. In the Hiroshima area, Japan, even if having good growing conditions areas Pinus densiflora has an average diameter breast height 3.6 cm at 10 years, 10.5 cm at 20 years. In comparison, Caribbean Pine grows to three times the diameter over the first 20 years.

Fig. 1.5 Average D.B.H. according to tree age

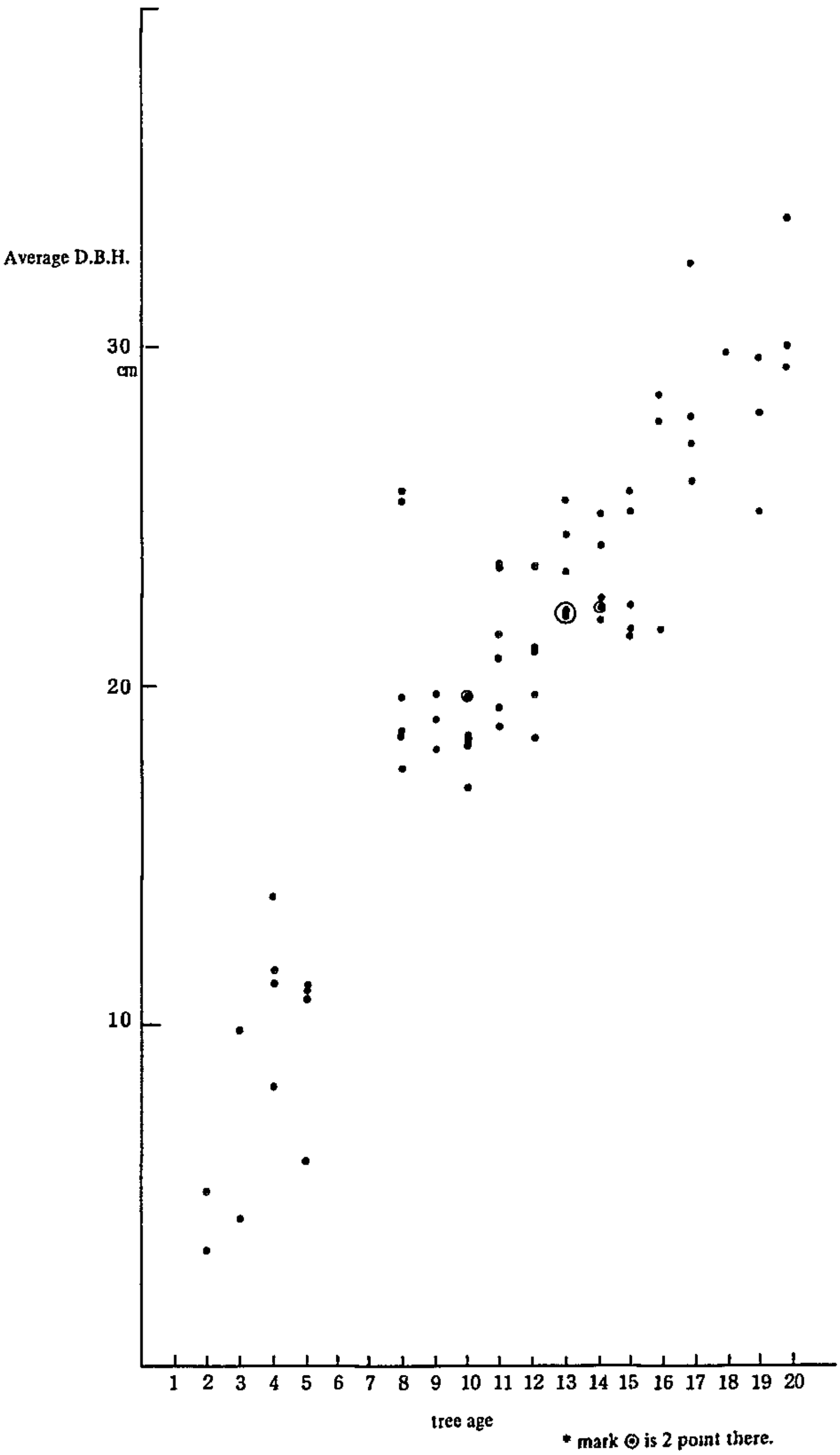
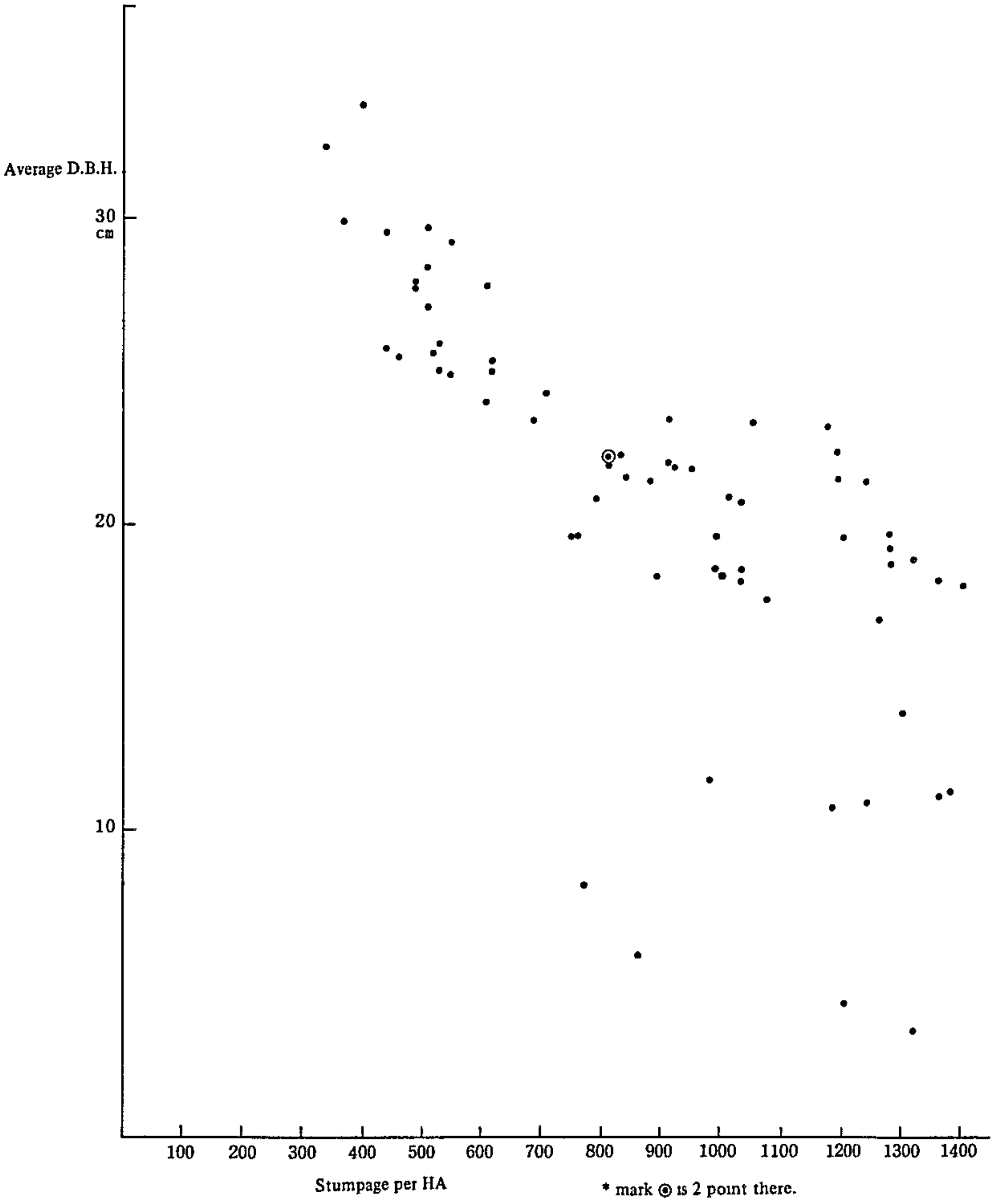


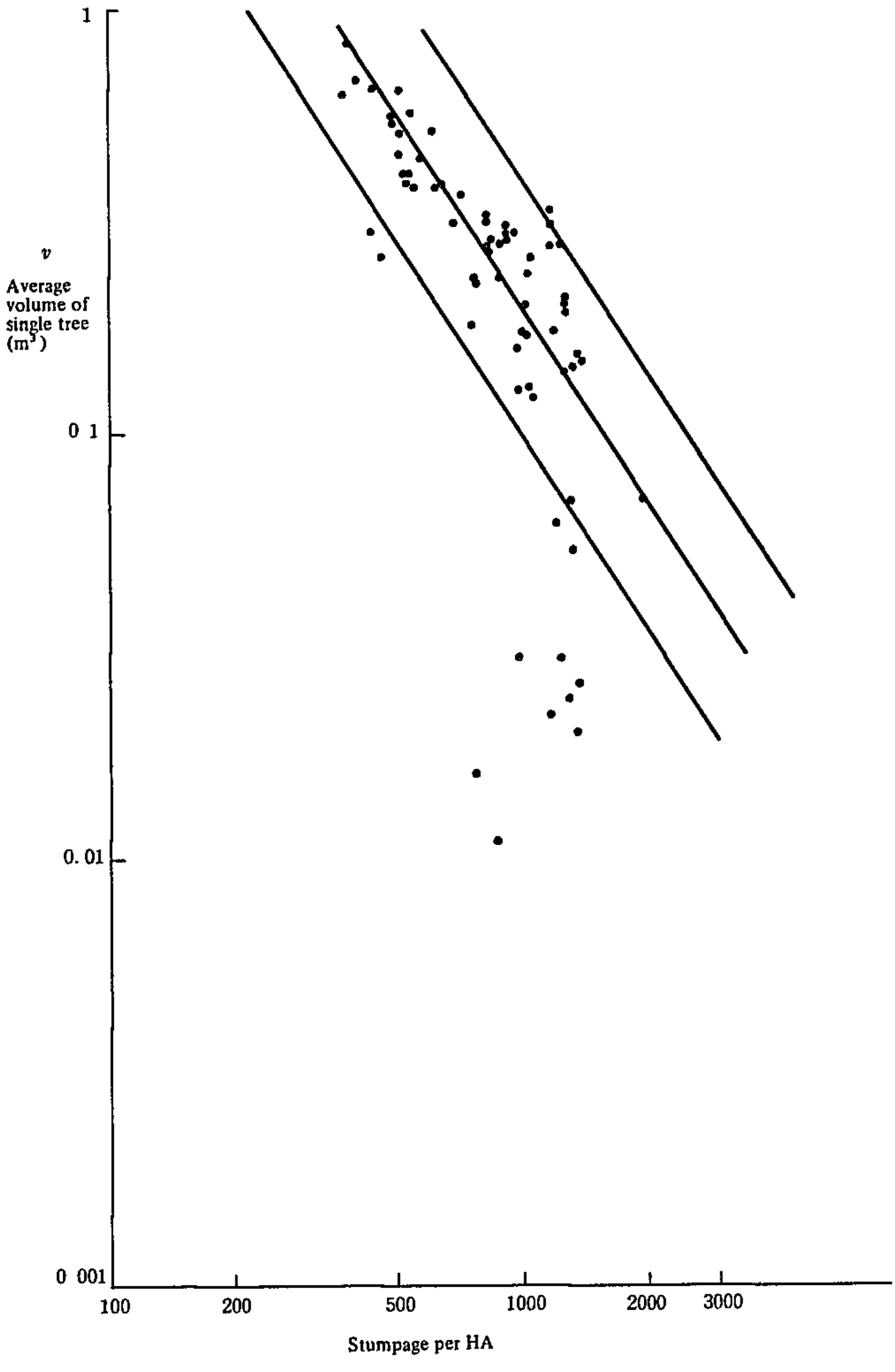
Fig. 1.6 Relationship between stumpage per HA and average D.B.H.



(3) Relationship between stumpage per hectare and average diameter breast height.

Figure 1.6 shows the relationship between stumpage per hectare and average diameter breast height in the sample plots.

Fig. 1.7 Relationship between stumpage per HA and average volume of single tree



Obviously, the grater the stumpage per hectare, the smaller the average diameter breast height. This is the basical rule in plant ecosystem. However, Figure 1.6 shows, this rule does not apply to trees with average diameters breast height of less than 15 cms. The rule applies where competition exists between individual trees, and the figure indicates that, in this survey area with 1,300 trees/ha, the state of competition takes a long time to reach. In Japan, Pinus dinsiflora is planted to a density of 3000 – 4500 ha and this will be discussed in section 3. The reason for this density is to encourage the rapid development of crown closure in order to make a good quality and prevent development of undergrowth.

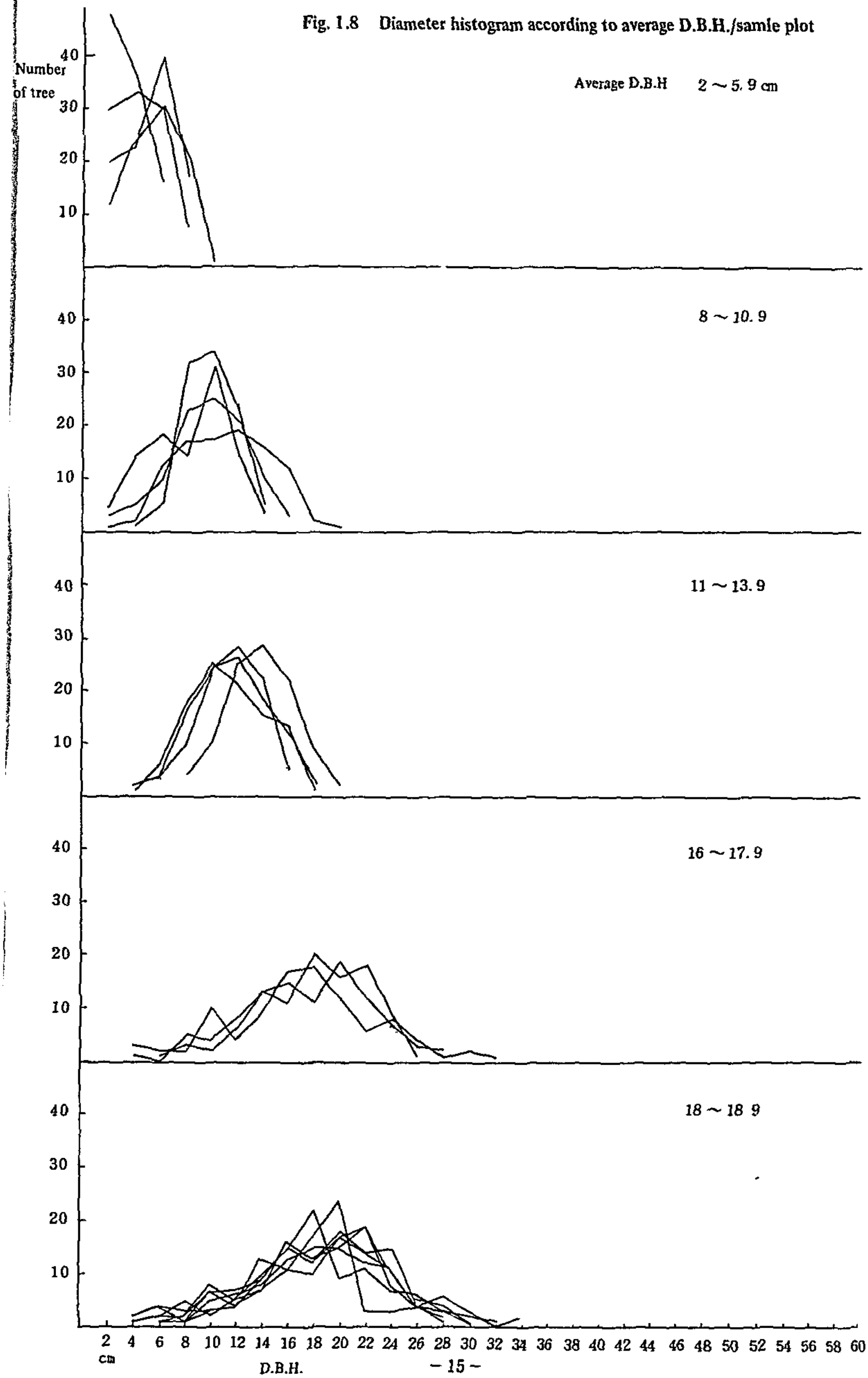
(4) Relationship between stumpage per hectare and average volume of single tree.

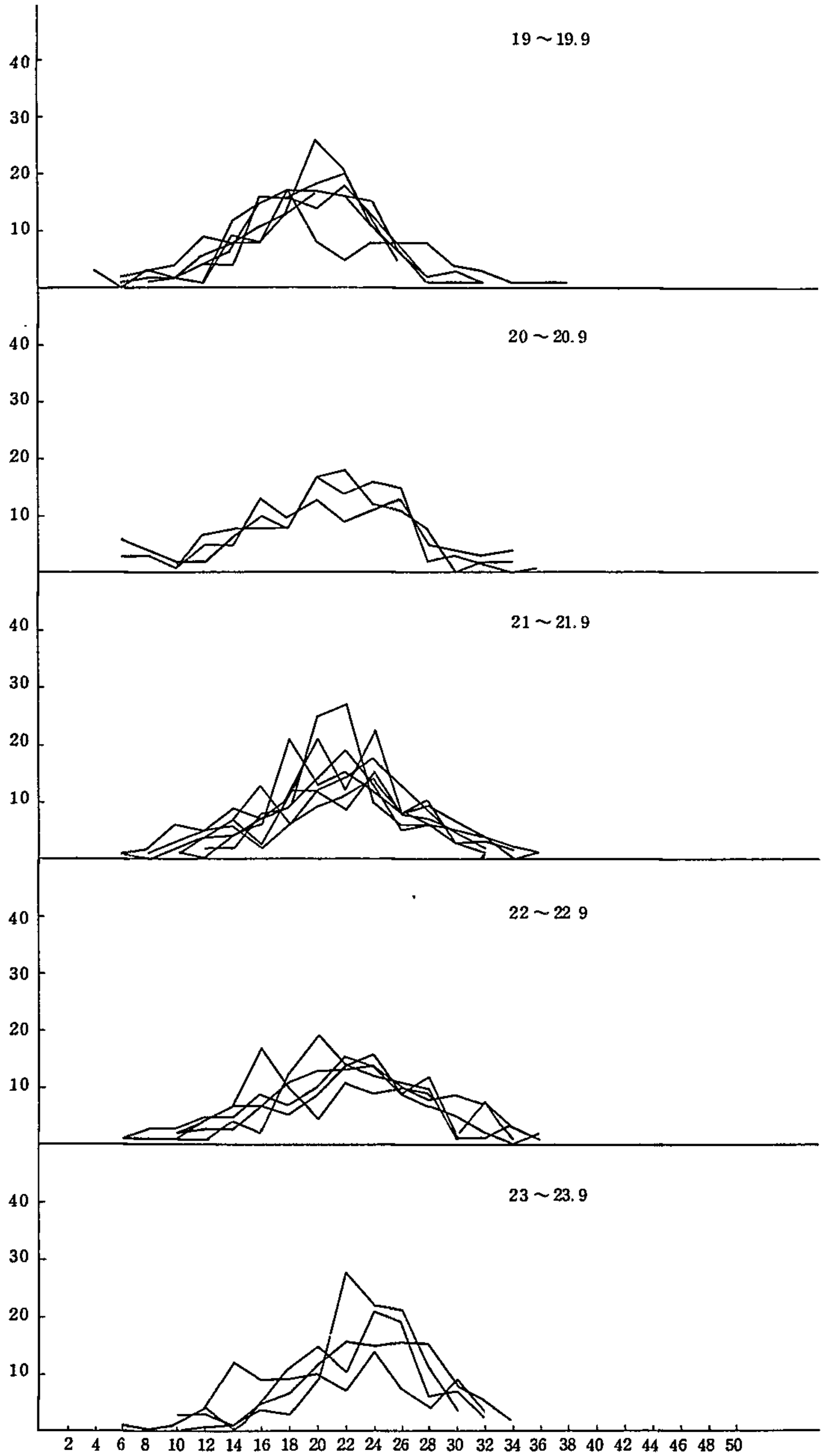
Figure 1.7 shows the relationship between stumpage per hectare and the average volume of single tree. This is called the C-D effect (Competition Density Effect) and it will be explained in Section 3. In plant ecology, this relationship can be expressed as $v = CN^{-d}$, under full density conditions (where v = average volume of single tree, N = stumpage per hectare). C is decided depends on the type of plant, but d varies little from plant to plant, and normally approximates to 3/2. From $\tan\theta = 3/2$, θ is found to be 56°10'. In Figure 1.7, the lines have an angle of 56°10'. and the distribution of plotted values along the line shows that the value of 3/2 as the power in the formula is suitable for Caribbean Pine. With regard to plotted values which do not fall along the line, these indicate incomplete full density.

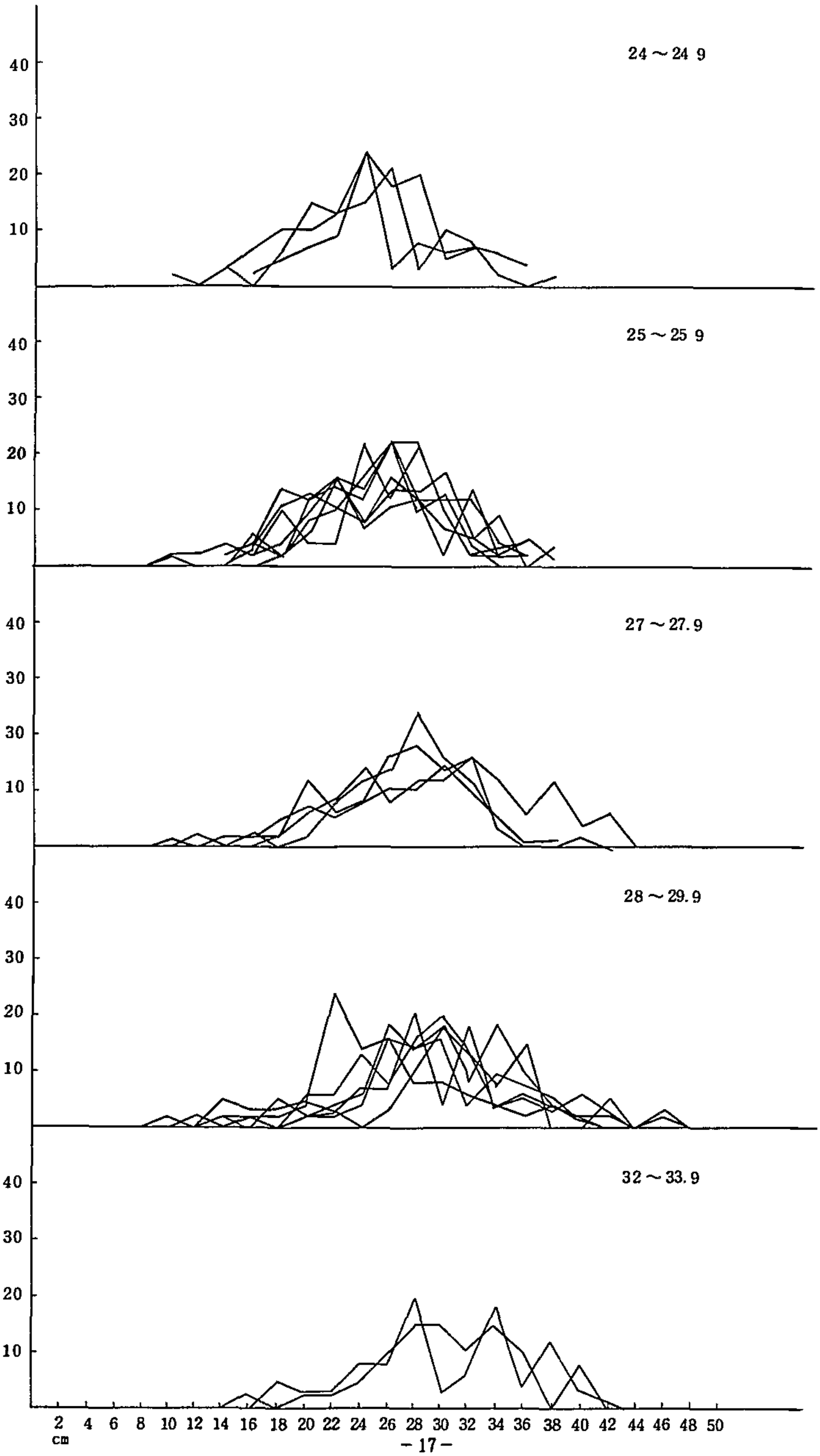
(5) Stand composition.

As a means of expressing the stand composition in this section, diameter distributions are discussed. The diameter histogram according to average diameter per sample plot are shown in Figure 1.8. Where the average diameter is greater than 10 cm an almost Normal Distribution appears. The greater the average diameter, variance becomes greater. This is a general tendancy with regard to trees, and the Caribbean Pine displays no special characteristics in this respect. However, in comparison with Japanese cedar and Pinus densiflora, the Caribbean Pine has a smaller variance for stands of large average diameter, and the diameter classes are evenly distributed. This indicates that competition between stands is not very severe, and that low class thinning has been carried out thoroughly.

Fig. 1.8　Diameter histogram according to average D.B.H./samle plot




19～19.9
20～20.9
21～21.9
22～22.9
23～23.9
40
30
20
10
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
cm


24 ～ 24 9
25 ～ 25 9
27 ～ 27.9
28 ～ 29.9
32 ～ 33.9
40
30
20
10
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
cm

2. SURVEY OF CARIBBEAN PINE RESOURCES

2.1 Survey Method

The purposes of the Caribbean Pine resource survey are 1) produce a Forest Inventory Note according to Compartment, Sub-compartment and Forest Type, and 2) estimate the total growing stock.

i) First step, we compiled new stock map. Based on former stock maps, Compartment and Sub-compartment drew to new stock map, and after carrying out Forest Type classification by interpretation of aerial photographs Further uncertain boundaries were decided by ground survey.

ii) An explanation of the Forest Inventory Note is given in section 2.8. With regard to volume per hectare, this was estimated by using aerial photograph stand volume tables for method of Quantification (I), and is a kind of regression estimate with regard to fixed data. Also the average tree height, and basal area, were calculated by the same method.

iii) The estimation of the total volume in the area was made from accumulation values from the Forest Inventory Note

2.2 Sample Plot Survey

The selection of sample plots was made from stock maps, that are published by Fiji Government. These sample are selected with areas proportional allocation according to each planted year.

The results are given in Table 2.1

Table 2.1 Number of sample plot according to each planted year

Planted year	Number of sample plot			Planted year	Number of sample plot		
	SEAQAQA	KOROUTARI			SEAQAQA	KOROUTARI	
1960	3		3	1970	5	1	6
61	2	1	3	71	1	2	3
62	1		1	72	2	4	6
63	4		4	73			
64	3		3	74			
65	5		5	75		4	4
66	6		6	76	1	3	4
67	6		6	77	1	1	2
68	5		5	78	2		2
69	6		6	Total	53	16	69

The sample plots were chosen where thinning and felling by wind has been minimal over the last two years, where the forest type in the sample plot was almost homogeneous to the surrounding forest type, and where the forest type in the sample plot is evenly distributed. With regard to the size of the sample plot, this was chosen to be 0.1 ha, because the forest types were evenly distributed. Therefore a rectangular 20 m x 50 m was adopted, to enable the plot to be oriented at 45° to the line of the planting rows.

We measured subject matter what is showed 'TALLY SHEET' (Table 2-2). All tree

Table 2.2 Tally Sheet

Every Tree Measurement

D.B.H.	Normal Tree									Fox tail		Another Abnormal Tree		Sum Total Count	Volume of Single tree	Basal Area of Single tree
	Upper class		Low class		Total	Tree Height										
	Count	Sub Total	Count	Sub Total		Count	Av.	Sm.		Count	Sub Total	Count	Sub Total			
4																00013
6																00028
8																00050
10																00079
12																00113
14																00154
16																00201
18																00254
20																00314
22																00380
24																00452
26																00531
28																00616
30																00707
32																0.0804
34																00908
36																01018
38																01134
40																01257
42																01385
44																01521
46																01662
48																01810
50																01964
52																0.2124
54																0.2290
56																02463
58																02642
60																02827
Total							U.A.H. / A.H.								)100	
Ave.							A.)100							D.B.H Av.	)100	

diameter breast height were measured according to upper class, low class, foxtails and abnormal trees (cyclone damaged). And every diameter class about three trees measured total tree heights by BLUME-LEISS.

2.3 Sample Plot Survey Results.

The following details were recorded on a Tally Sheet: average tree height of upper class trees, average tree height, average diameter breast height, number of stand per hectare, volume per hectare (under bark), proportion of foxtails, and proportion of abnormal trees

The results are given in Table 2.3. The species column shows the variety of Caribbean Pine.

Ph . . . . .Pinus caribaea var. hondurensis

Pc. . . . . .Pinus caribaea var. caribaea.

Pcu . . . .Pinus caribaea var. cuban.

The volume equation which was used to calculate the volume of single trees was developed by the Commonwealth Forestry Institute, Oxford, and the formulae are as follows:

Total volume (ft^3 under bark) = $0.175 + 0.00183D^2H$ (yards, pounds)

where D = D.B.H

H = height.

↓

V (under bark) = $0.005 + 0.00002636D^2H$ (metric)

Using these formulae, Volume Tables were composed as in Table 2.4.

2.4 Estimation of Average Tree Height and Basal Area

The average tree height and basal area are the main items in the Forest Inventory Note, and are the important factors in the carrying out of thinning method, and understanding the stand conditions. The average tree height can be obtained directly from aerial photographs interpretation, but accuracy is somewhat unreliable. In this survey, both of average tree height and basal area were estimated by items from standard land conditions according to method of Quantification (I).

2.4.1 Estimation of average tree height

Amongst the factors corelated to average tree height the most easily read data from existing data, aerial photographs and topographical maps, are tree age, crown density, inclination and topography, etc.

Calculated results were showed table 2.5, scores, and multiple correlation coefficient, and a simple correlation matrix. With regard to crown density, the aerial photographs were taken in 1978 and there is two years discrepancy in interpretation.

The score values are used to obtain an average tree height by adding each of the scroes for the appropriate category under each of the factors.

Table 2.3 Results of sample plot survey

Sample No.	Compartment & Sub.	Plantd Year	Spp. & Var.	Upper Height (m)	Average Height (m)	Average D.B.H (cm)	Number of stand (/ha)	Volume (m³) (Under bark)	Basal Area (m²/ha)	Average >100 Height (m)	Average >100 D.B.H (cm)	Volume >100 (m³)	Foxtail (%) Stand rate	Abnromal tree (%) Stand rate
1	$1-a_1-1$	63	Pc	22.3	22.1	27.1	510	2358	30.35	24.4	33.4	732	0	3.9
2	$1-a_2-1$	63	Pc	23.0	22.8	27.8	610	319.7	39.15	26.5	37.6	99.6	0	1.6
3	$1-a_3-1$	60	Pc	25.6	25.4	33.7	400	277.0	32.31	27.5	38.6	109.6	0	0
4	$1-a_3-1$	60	Pc	23.8	23.5	29.2	550	320.3	38.41	27.8	38.2	107.9	0	0
5	$1-a_4-1$	63	Pc	27.5	27.4	32.3	380	319.7	33.21	29.8	430	151.2	0	0
6	$1-a_5-1$	60	Pc	25.0	24.8	29.9	370	240.4	27.53	27.3	38.0	105.7	0	27
7	$1-a_6-1$	62	Pc	26.2	25.9	29.7	510	331.0	36.81	27.9	37.4	104.0	0	5.9
8	$1-b_2-1$	65	Pc	22.7	22.5	25.6	520	217.9	27.54	25.0	31.6	68.0	0	5.8
9	$2-a_1-1$	63	Pc	21.4	21.4	25.9	530	223.3	29.27	24.6	34.4	78.1	0	1.9
10	$2-a_3-2$	64	Pc	25.2	24.5	27.7	490	269.3	3104	280	34.4	879	0	0
11	$2-a_3-2$	64	Pc	24.5	24.2	28.4	510	263.7	3085	27.1	37.2	101.2	0	0
12	$2-a_3-3$	64	Pc	21.8	21.4	21.5	840	2481	32.13	25.3	30.2	617	0	0
13	$2-b_1-1$	65	Pc	19.7	19.2	21.5	1,190	334.2	46.79	236	31.2	61.9	0	6.7
14	$2-b_2-1$	66	Pc	22.1	21.4	22.4	1,190	4008	40.08	25.6	340	789	0	10.9
15	$2-c-1$	68	Ph. B	22.0	20.7	18.3	890	209.4	26.33	25.5	29.8	60.7	0	1.1
16	$3-a_1-1$	65	Pc	22.5	20.8	22.2	810	268.3	33.91	259	32.6	73.8	0	0
17	$3-a_4-1$	66	Pc	20.1	20.0	22.2	830	230.0	32.75	23.5	29.4	54.8	0	2.4
18	$3-a_3-1$	66	Pc	22.1	21.0	22.2	820	2653	34.05	25.4	31.8	688	0	2.4
19	$4-a-1$	65	Pc	23.2	21.7	25.0	530	210.6	27.47	244	326	69.2	0	5.7
20	$5-a_3-1$	65	Pc	201	20.1	21.4	1,240	355.0	47.97	244	328	70.3	0	40
21	$6-d-1$	78	Pc	2.2	2.2	3.4	1,320	7.2	1.40	3.0	6.0	08	0	0
22	$7-d_1-1$	78	Pc	2.6	2.6	51	1,970	14.0	4.67	31	8.2	1.1	1.0	0
23	$10-a_3-1$	67	Pc	21.7	20.9	23.2	1,170	399.6	5241	24.7	31.8	666	0	0
24	$11-a_1-1$	66	Ph	21.2	207	21.8	950	289.5	38.13	24.0	31.4	631	0	0
25	$13-a-2$	70	Pc	15.8	15.7	18.1	1,030	177.3	28.97	21.5	28.0	46.5	0	16.5
26	$14-a_1-1$	70	Pc	14.9	14.9	18.2	1,360	209.9	37.87	17.9	26.4	30.9	0	4.4
27	$15-d_1-1$	77	Pc	2.4	24	43	1,200	7.5	2.04	3.0	7.6	1.0	0	0
28	$20-a-1$	61	Pc	26.3	26.3	27.9	490	276.8	3067	279	340	86.5	0	4.1
29	$20-a-1$	61	Pc	26.5	26.3	29.5	440	287.8	31.05	29.8	36.6	106.1	0	0
30	$20-c-1$	66	Pc	231	22.5	24.0	620	239.5	2977	26.2	32.2	72.6	0	3.2
31	$20-c-1$	66	Pc	22.4	22.1	24.9	550	213.9	27.50	244	30.2	59.5	0	0
32	$22-a-2$	69	Pc.cu	19.6	19.2	19.2	1,280	270.1	3908	22.2	264	41.4	0	3.1
33	$23-a_1-1$	69	Pc.cu	182	18.2	18.7	1,280	2547	37.40	235	270	460	0	4.7
34	$26-a_2-3$	69	Pc	176	17.5	23.3	1,050	2771	46.03	19.4	288	430	0	124
35	$26-a_4-1$	69	Pc	18.8	186	20.7	1,030	251.0	37.37	226	30.0	548	0	6.8
36	$27-a_3-1$	69	Pc	21.6	21.5	21.4	880	250.0	3273	254	28.8	56.4	0	1.1

Sample No.	Compartment & Sub.	Plantd Year	Spp. & Var.	Upper Height (m)	Average Height (m)	Average D.B.H (cm)	Number of stand (/ha)	Volume (m³) (Under bark)	Basal Area (m²/ha)	Average >100 Height (m)	Average >100 D.B.H (cm)	Volume >100 (m³)	Foxtail (%) Stand rate	Abnormal tree (%) Stand rate
37	32−a_1−1	69	Pc.cu	21.3	21.3	23.4	910	306.8	40.44	25.5	31.0	65.6	0	1.1
38	36−a −1	67	Pc	21.3	21.2	243	710	264.1	34.69	24.7	34.0	891	0	1.4
39	36−a −1	67	Pc	21.6	21.3	25.3	640	253.5	34.26	23.5	336	71.1	0	0
40	37−a −1	67	Pc	20.4	20.4	21.9	810	228.4	31.74	23.6	29.2	538	0	2.4
41	40−a −1	67	Pc	21.5	20.4	21.9	920	2817	37.23	256	32.0	70.4	0	1.1
42	41−a −2	67	Pc	20.3	19.6	22.0	910	264.2	36.78	24.1	31.4	63.7	0	1.1
43	45−a −1	71	Ph	16.7	15.5	197	1,280	269.4	40.60	181	27.0	354	0	5.5
44	45−a −2	72	Ph	16.2	16.2	25.7	440	132.2	23.31	17.7	31.0	468	0	15.9
45	47−d_1−1	76	Pc	5.8	5.8	11.2	1,380	370	14.36	7.7	15.4	54	6.5	36
46	48−a −1	72	Ph	12.0	11.8	18.5	990	1268	2861	141	25.2	24.2	0	5.1
47	50−a −2	68	Ph	17.3	16.6	20.8	790	184.7	2944	21.1	31.2	55.1	0	0
48	50−a −7	68	Ph	18.3	16.7	19.6	760	1788	26.37	23.1	31.8	634	0	0
49	51−a_1−1	70	Ph	17.0	16.3	18.3	1,000	175.7	2825	213	266	40.7	0	1.0
50	51−a_1−2	70	Ph	15.9	14.8	16.9	1,260	1797	31.60	18.0	29.8	39.2	0	8.7
51	51−a_2−1	70	Ph	163	16.3	196	750	136.7	2350	18.2	260	332	0	1.3
52	55−b_1−4	68	Ph	18.2	181	23.4	690	222.2	3277	226	358	77.3	0	0
53	56−a −2	68	Pc.cu	15.6	15.4	20.9	1,010	207.3	36.77	18.5	29.2	42.7	0	40
54	5−a_2−1	76	Pc	5.1	5.1	8.2	770	13.0	454	7.2	12.4	34	130	3.9
55	5−a_2−1	76	Pc	3.3	3.3	116	980	31.3	11.16	7.6	164	6.2	10.2	2.0
56	5−a_3−1	76	Pc	120	12.0	13.8	1,300	94.1	20.05	15.2	184	141	10.0	11.5
57	17−a_1−1	70	Pc	17.3	14.1	19.6	1,200	211.2	38.47	191	28.2	41.1	0	01
58	17−a_3−1	61	Pc	24.4	24.4	25.0	570	2566	29.41	289	34.2	90.2	0	0
59	17−a_5−1	77	Pc	6.9	6.9	9.8	1,300	31.2	1023	87	13.4	46	6.2	3.8
60	23−a_5−1	75	Pc	46	46	59	860	9.8	2.75	8.0	10.0	2.6	35	0
61	23−a_5−1	75	Pc	57	5.7	10.7	1,180	26.7	9.42	80	14.6	5.0	10.2	1.7
62	24−a −1	75	Pc	6.1	6.1	11.1	1,360	38.5	14.26	8.0	16.2	6.0	6.6	9.6
63	24−a −1	75	Pc	6.5	6.4	109	1,240	37.3	1288	83	16.8	6.8	56	2.4
64	27−a −5	71	Pc	15.6	15.6	18.0	1,400	2103	3748	170	244	27.2	0	1.4
65	28−a −1	71	Ph	14.3	137	18.9	1,320	1959	37.69	170	27.2	33.8	0	0
66	31−a_1−2	72	Ph	146	146	254	460	1235	2406	160	30.8	41.4	0	6.5
67	31−a_1−3	72	Ph	12.2	11.7	18.5	1,030	135.9	3003	151	27.2	30.1	0	2.9
68	32−a −2	72	Ph	12.5	12.5	17.5	1,070	1304	2768	15.2	254	26.5	0	2.8
69	32−a −1	72	Ph	14.5	14.4	196	990	1606	31.09	16.0	250	26.9	0	0

Table 2.4 Volume table of Caribbean Pine

H / D	4	6	8	10	12	14	16	18	20
3	0.006	0008	0010	0.013	0.016	0.020	0025	0.031	
4	0.007	0.009	0.012	0.016	0.020	0.026	0.032	0039	0047
5	0.007	0.010	0.013	0.018	0.024	0.031	0.039	0.048	0.058
6	0008	0.011	0.015	0.021	0.028	0036	0.045	0.056	0.068
7	0.008	0.012	0.017	0023	0.032	0.041	0.052	0.065	0079
8	0.008	0013	0018	0.026	0.035	0.046	0.059	0.073	0.089
9	0.009	0.014	0020	0.029	0.039	0.051	0.066	0.082	0100
10	0.009	0.014	0.022	0.031	0.043	0.057	0072	0.090	0.110
11	0010	0.015	0.024	0.034	0.047	0.062	0079	0099	0.121
12	0.010	0.016	0.025	0037	0051	0.067	0.086	0107	0132
13		0.017	0.027	0039	0054	0.072	0093	0.116	0.142
14			0029	0042	0.058	0.077	0.099	0125	0153
15				0.045	0062	0082	0.106	0.133	0.163
16				0.047	0.066	0.088	0.113	0.142	0.174
17					0.070	0.093	0.120	0.150	0.184
18					0.073	0.098	0.126	0.159	0.195
19						0.103	0.133	0.167	0.205
20						0.108	0140	0.176	0216
21							0.147	0184	0.226
22							0.153	0.193	0.237
23								0.201	0.248
24								0.210	0.258
25									0269
26									0.279
27									0.290
28									0.300
29									0.311

H / D	22	24	26	28	30	32	34	36	38	40
5	0.069									
6	0.082									
7	0.094	0.111								
8	0.107	0.126								
9	0.120	0142	0.165							
10	0.133	0.157	0.183							
11	0.145	0.172	0.201	0.232						
12	0.158	0187	0.219	0.253						
13	0.171	0.202	0237	0.274	0.313	0.356	0.401	0.449	0.500	0553
14	0.184	0.218	0.254	0.294	0.337	0.383	0.432	0.483	0538	0595
15	0.196	0.233	0.272	0.315	0.361	0.410	0.462	0.517	0.576	0.638
16	0.209	0.248	0.290	0.336	0.385	0.437	0.493	0552	0.614	0.680
17	0.222	0.263	0.308	0.356	0.408	0.464	0523	0.586	0.652	0.722
18	0.235	0278	0.326	0.377	0.432	0491	0.553	0620	0.690	0.764
19	0.247	0.293	0.344	0.398	0.456	0.518	0.584	0.654	0.728	0806
20	0.260	0309	0.361	0.418	0.479	0.545	0.614	0.688	0766	0.849
21	0.273	0.324	0379	0.439	0.503	0.572	0.645	0.722	0.804	0.891
22	0.286	0.339	0.397	0.460	0.527	0599	0.675	0757	0.842	0.933
23	0.298	0.354	0.415	0.480	0.551	0626	0.706	0.791	0.880	0975
24	0.311	0.369	0.433	0.501	0.574	0.653	0736	0825	0.919	1.017
25	0.324	0.385	0.450	0.522	0.598	0.680	0.767	0.859	0.957	1059
26	0.337	0.400	0.468	0542	0.622	0707	0.797	0.893	0.995	1102
27	0.349	0.415	0.486	0563	0.646	0.734	0.828	0.927	1.033	1.144
28	0.362	0.430	0.504	0.584	0.669	0761	0.858	0962	1.071	1186
29	0.375	0.445	0.522	0604	0.693	0788	0.889	0996	1109	1.228
30	0.388	0.461	0.540	0.625	0.717	0.815	0.919	1030	1.147	1.270
31	0.401	0.476	0.557	0.646	0.740	0.842	0.950	1.064	1.185	1.312
32		0.491	0.575	0.666	0.764	0.869	0.980	1.098	1.223	1.355
33		0.506	0.593	0.687	0788	0.896	1011	1.132	1.261	1.397
34		0.521	0611	0708	0.812	0.923	1041	1.167	1.299	1.439
35		0.536	0.629	0.728	0.835	0.950	1.072	1.201	1.337	1.481

H / D	42	44	46	48	50	52	54	56	58	60
13	0.609	0.668	0.730	0.795	0.862	0.932	1.004	1.080	1.158	1.239
14	0.656	0719	0.786	0.855	0.928	1.003	1.081	1.162	1.246	1.334
15	0702	0.770	0.842	0916	0.993	1.074	1.158	1.245	1335	1.428
16	0749	0.822	0897	0.977	1.059	1.145	1.235	1.328	1.424	1523
17	0.795	0.873	0.953	1.037	1.125	1.217	1.312	1.410	1.512	1.618
18	0.842	0.924	1.009	1.098	1.191	1.288	1.389	1.493	1.601	1.713
19	0.888	0.975	1.065	1.159	1.257	1.359	1.465	1.576	1.690	1.808
20	0.935	1.026	1.121	1.220	1.323	1.431	1.542	1.658	1.779	1903
21	0.981	1.077	1176	1.280	1.389	1.502	1.619	1.741	1867	1.998
22	1.028	1.128	1232	1.341	1455	1.573	1696	1824	1.956	2.093
23	1.074	1.179	1.288	1402	1.521	1644	1773	1.906	2045	2.189
24	1.121	1.230	1.344	1.463	1.587	1716	1.850	1.989	2.133	2.283
25	1.167	1.281	1.399	1.523	1.652	1787	1927	2.072	2.222	2.377
26	1.214	1.332	1.455	1.584	1.718	1.858	2.004	2154	2.311	2472
27	1.260	1.383	1511	1.645	1784	1.929	2.080	2.237	2.399	2.567
28	1.307	1.434	1.567	1706	1.850	2001	2.157	2320	2.488	2.662
29	1.353	1.485	1.623	1766	1.916	2.072	2.234	2402	2.577	2.757
30	1.400	1.536	1.678	1827	1.982	2.143	2.311	2485	2.665	2.852
31	1446	1.587	1.734	1.888	2048	2.215	2.388	2.568	2754	2.947
32	1493	1.638	1.790	1.948	2114	2.286	2.465	2.650	2.843	3042
33	1.539	1.689	1846	2.009	2.180	2.357	2.542	2.733	2.931	3.137
34	1.586	1.740	1.901	2.070	2.246	2.428	2.618	2.816	3.020	3231
35	1632	1791	1957	2.131	2.311	2.500	2.695	2.898	3.109	3.326

H / D	62	64	66	68	70	72	74	76	78	80
13	1.322	1.409	1.498	1.5.90	1.684	1.781	1.882	1984	2.090	2.198
14	1.424	1.517	1613	1.711	1813	1.918	2026	2.137	2.250	2.367
15	1.525	1.625	1727	1833	1.942	2.055	2.170	2.289	2.411	2.536
16	1.626	1.733	1.842	1.955	2.072	2.191	2.315	2.441	2.571	2704
17	1.728	1.840	1. 57	2.077	2.201	2.328	2.459	2.593	2.731	2873
18	1.829	1.948	2.072	2.199	2.330	2.465	2.603	2746	2.892	3042
19	1.930	2.056	2.187	2.321	2.459	2.601	2748	2.898	3.052	3.210
20	2.032	2.164	2.301	2443	2.588	2.738	2892	3.050	3.212	3.379
21	2.133	2.272	2.416	2.565	2717	2.875	3036	3.202	3.373	3.548
22	2.234	2.380	2.531	2687	2.847	3.011	3.181	3.355	3.533	3716
23	2.336	2.488	2646	2.808	2.976	3.148	3.325	3.507	3.694	3.885
24	2.437	2.596	2.761	2.930	3.105	3.285	3.469	3.659	3.854	4.054
25	2.538	2.704	2.876	3.052	3.234	3421	3614	3811	4014	4.223
26	2.640	2.812	2.990	3.174	3.363	3.558	3758	3.964	4.175	4.391
27	2.741	2.920	3105	3.296	3.492	3.695	3.902	4.116	4.335	4.560
28	2.842	3.028	3.220	3.418	3.622	3.831	4047	4.268	4.495	4.729
29	2.944	3.136	3.335	3.540	3751	3968	4.191	4.420	4.656	4.897
30	3.045	3.244	3450	3.662	3880	4.005	4.335	4.573	4.816	5.066
31	3146	3.352	3.565	3.784	4.009	4141	4.480	4.725	4.977	5.235
32	3.247	3.460	3.679	3.905	4.138	4278	4.624	4.877	5.137	5.404
33	3.349	3.568	3.794	4.027	4.267	4.514	4.768	5.029	5.297	5.572
34	3450	3.676	3.909	4.149	4.397	4651	4.913	5182	5.458	5.741
35	3.551	3.784	4.024	4271	4.526	4.788	5057	5.334	5.618	5.910

Table 2.5 Score value of average height

Item	Category	Score	Score range
Tree age	0 ~ 2	− 21.48	21.48
	3 ~ 5	− 17.70	
	6 ~ 8	− 10.68	
	9 ~ 11	− 7.64	
	12 ~ 14	− 4 79	
	15 ~ 17	− 2 38	
	18 ~	0 00	
Crown density	0 ~ 30 %	− 1 07	2 42
	31 ~ 50	− 2 42	
	51 ~ 70	0.17	
	71 ~ 90	0 59	
	91 ~ 100	0 00	
Inclination	0 ~ 9°	− 1.16	1.16
	10 ~ 19	− 0 81	
	20 ~	0.00	
Topography	Convex	25 76	2.28
	Concave	23.86	
	Paralel slope	25.65	
	Frat	26 14	

Multiple correlation 0.960

Simple correlation matrix

	average height	tree age	crown density	inclination	topography
average height	1	0.929	0.854	− 0.510	− 0.022
tree age	0.929	1	0 857	− 0 395	− 0 083
crown density	0.854	0 857	1	− 0.395	− 0 019
inclination	− 0.510	− 0.395	− 0.395	1	0 190
topography	− 0.022	− 0.083	− 0 019	0 190	1

The multiple correlation coefficient of 0.960 is a high value. The average tree height column in the Forest Inventory Note were calculated using these values. In addition, these score values can be used when the average tree height is required for stands in areas near the survey area.

In the sample plots, the real values of average tree height, and the estimated values using these score values are shown in Table 2.6, and they prove the score values to be a highly accurate means of estimation.

Table 2.6 Real and estimated values in the sample plot (m)

Sample No.	Real values	Estimated values	Sample No	Real values	Estimated values	Sample No.	Real values	Estimated values
1	22.3	23.2	24	21.2	20 8	47	17.3	20.4
2	23.0	23.2	25	15 8	15.6	48	18 3	20 8
3	25.6	25 6	26	14 9	17.5	49	17.0	17 5
4	23.8	25.0	27	2 4	6 2	50	15.9	17.4
5	27.5	23.2	28	26 3	25 6	51	16 3	14 8
6	25 0	25 6	29	26 5	25.6	52	18 2	20 4
7	26 2	25 0	30	23 1	20 7	53	15.6	20 8
8	22 7	23 2	31	22 4	20 4	54	5 1	6 2
9	21 4	23.2	32	19.6	17.8	55	3.3	4 8
10	25.2	23.2	33	18 2	18 3	56	12 0	6 2
11	24 5	23.2	34	17.6	17.4	57	14.1	15 7
12	21.8	22 6	35	18 8	18 2	58	24 4	25 6
13	19.7	22 5	36	21.6	17.5	59	6 9	6 1
14	22.1	20 0	37	21 3	17.5	60	4 6	6 1
15	22 0	20.4	38	21 3	20.8	61	5 7	6 1
16	22.5	23.2	39	21 6	20 4	62	6 1	5 5
17	20.1	20 7	40	20.4	20.8	63	6 5	5 5
18	22 1	20 7	41	21 5	20 8	64	15.6	17.8
19	23.2	23.0	42	20.3	20 4	65	14 3	17.4
20	20 1	20.3	43	16 7	17.4	66	14 6	14.3
21	2 2	2 4	44	16 2	14 3	67	12 2	14 5
22	2 6	2 4	45	5 8	5 7	68	12 5	11.9
23	21.7	20 0	46	12 0	12.5	69	14.5	14 5

2.4.2 Estimation of basal area

The factors corelated to basal area, easily interpreted from aerial photographs, are tree age, number of stand per hectare, and crown density. However, in this case, due to picture reduction, there was a little problem in accurately interpreting the number of stand from the photographs. Therefore number of stand grade was arranged in units of 200 stands. Score values, multiple correlation coefficient, and simple correlation matrix are shown in Table 2.7.

From this multiple correlation coefficient high accurate estimation is expected. The figures in the basal area column of the Forest Inventory Note were obtained using this score values. In addition, these score values can be used when the basal area is required for stands in areas near the survey area. In the sample plots, the real values of basal area, and the estimated values using these score values are shown in Table 2.8, and they prove the score values to be a highly accurate means of estimation.

Table 2.7 Score value of basal area

Item	Category	Score	Score range
Tree age	0 ～ 2年	− 29.64	29.64
	3 ～ 5	− 21.19	
	6 ～ 8	− 3.74	
	9 ～ 11	− 0 38	
	12 ～ 14	− 0 50	
	15 ～ 17	− 0 36	
	18 ～	0 00	
Number of stand per HA.	0 ～ 400本	− 9.48	10 39
	401 ～ 600	− 10 39	
	601 ～ 800	− 7.27	
	801 ～ 1000	− 5 76	
	1001 ～ 1200	− 2 00	
	1201 ～	0.00	
Crown density	0 ～ 30 %	32.68	14 35
	31 ～ 50	35.88	
	51 ～ 70	37.94	
	71 ～ 90	40.61	
	91 ～ 100	47.03	

Multiple correlation 0 947

Simple correlation matrix

	Basal area	Tree age	No. of stand	Crown density
Basal area	1	0.658	− 0 067	0 809
Tree age	0 658	1	− 0.637	0 857
No. of stand	− 0 067	− 0.637	1	− 0.376
Crown density	0.809	0.857	− 0 376	1

Table 2.8 Real and estimated values in the sample plot (m^3 /ha)

Sample No	Real values	Estimated values	Sample No.	Real values	Estimated values	Sample No.	Real values	estimated values
1	30.35	29 86	24	38 13	34 35	47	29.44	30.17
2	39 15	32 99	25	28 97	35.57	48	26 37	32 84
3	32 31	31 14	26	37.87	37.56	49	28.25	31.80
4	38 41	36 64	27	2 04	9.49	50	31 60	37.56
5	33.21	30.78	28	30.67	30 22	51	23.50	28 23
6	27.53	31 14	29	31.05	30.22	52	32 77	30 17
7	36 81	36 64	30	29 77	32 84	53	36 77	38 11
8	27.54	29.86	31	27.50	27.05	54	4 54	4 22
9	29.27	29.86	32	39.08	40.23	55	11 16	8 93
10	31 04	29.86	33	37.40	40 23	56	20 05	11 49
11	30.85	29 86	34	46 03	38 24	57	38 47	33 50
12	32 13	40 91	35	37.37	35.57	58	29 41	30 22
13	46 79	44 68	36	32.73	31.80	59	10.23	11.49
14	40 08	44 53	37	40 44	31 80	60	2 75	5.73
15	26 33	31 68	38	34.69	32 84	61	9.42	9 49
16	33.91	34 49	39	34.26	30.17	62	14 26	14 69
17	32.75	34.35	40	31.74	34 35	63	12 88	14 69
18	34.05	34 35	41	37.23	34 35	64	37.48	40 23
19	27.47	29 86	42	36 78	34 35	65	37 69	37.56
20	47.97	46 67	43	40 60	37.56	66	24 06	23.81
21	1 40	3.04	44	23.31	23.81	67	30.03	32.20
22	4 67	3.04	45	14 36	11.49	68	27 68	30.14
23	52.41	44.53	46	28 61	26 38	69	31 09	28 44

2.5 Making Stereogrammes

Stereogrammes were useful in the interpretation of Caribbean Pine forest types in the survey and nearby areas. The stereogrammes were made for the 69 sample points of the survey area (Table 2 9)

The aerial photographs used were taken in 1978, and there is a two year discrepancy with the actual survey date, 1980. Therefore, it was necessary to back date the survey data by two years.

2.5.1 Average tree height

With regard to tree height, the growth rate varies according to the site index. In Fiji, site index curves were drawn for the Caribbean Pine according to each site index in the Seaqaqa area These are shown in Figure 2.6 in section 2.8. Each sample plots the values for tree age and average tree height were plotted on this graph and values for average tree height for two years earlier were obtained by back-dating two years along the site index curves.

2.5.2 Stand volume

The two year adjustment for stand volumes was obtained in the following way. In section 3.3, the stand volume, V was obtained from the stumpage per hectare, N, and average tree height, $\bar{H}$, by regression calculation. The formula is as follows:

$$\log (V/N) = -1.4759 + 1\ 7431\ \log \bar{H} - 0.4532 \log N$$

If the stumpage per pectare, N, has not changed over the two years, present stand volume can be made using the present average tree height, and the average tree height for two years earlier which has been estimated in section 2 5 1, and the growth rate over the two years can be defined as:

$$\frac{\text{Present stand volume} - \text{stand volume two years earlier}}{\text{present stand volume}}$$

Using this growth rate, the stand volumes obtained in the sample plot survey were altered to values for two years earlier.

2.5.3 Diameter breast height

The diameter breast height could not be estimated directly from the aerial photographs, so the sample plot survey results were used as they stood

2.5.4 Crown density

Crown density is not obtained by sample plot surveying, but is obtained from aerial photographs Therefore, it was not necessary to alter the data, and the values were used as they were.

With regard to sample plots 21 and 22, the planting year was 1978, and at the time the aerial photographs were taken. The planting had not yet been carried out, therefore, stereogrammes for these plots were not made

Table 2.10 shows the average tree height and stand volume for the present and for two years earlier of the sample plots.

Table 2.10 Average tree height and volume for the present and two years earlier

Sample No.	Average height		Stand volume		Sample No	Average height		Stand volume		Sample No	Average height		Stand volume	
	2 years earlier	Present	2 years earlier	Present		2 years earlier	Present	2 years earlier	Present		2 years earlier	Present	2 years earlier	Present
1	20.3	22.1	203.3	235.8	24	18 4	20.7	235 8	289 5	47	14 4	16 6	144 2	184 7
2	21.0	22.8	277.0	319 7	25	13 1	15.7	129.3	177.3	48	14 6	16 7	141 5	178 8
3	23 8	25 4	247.3	277.0	26	12.5	14 9	154.5	209 9	49	13.5	16 3	126 5	175 7
4	22.0	23.5	285.5	320 3	27	1.2	2 4	3.8	7 5	50	12 6	14 8	135 7	179 7
5	25 4	27.4	280.1	319 7	28	24.7	26 3	248 1	276 8	51	13 5	16 3	98.4	136 7
6	23.3	24.8	215.6	240 4	29	24 7	26 3	258.0	287.8	52	15.8	18 1	175 3	222 2
7	24 1	25 9	291.9	331 0	30	20 4	22 5	201 9	239.5	53	13.5	15.4	164.8	207.3
8	20.5	22 5	185 3	217.9	31	20.1	22 1	181.3	213.9	54	1 7	5.1	1.9	13 0
9	19.7	21 4	193.3	223.3	32	16 3	19.2	203.0	270 1	55	1 3	3 3	6 2	31 3
10	22 6	24 5	234 0	269 3	33	15.5	18 2	192 5	254 7	56	6 0	12 0	28.1	94.1
11	22 3	24 2	228 7	263.7	34	14 8	17.5	206 9	277.1	57	11 6	14 1	150 3	211.2
12	19 6	21 4	212 9	248 1	35	15 8	18 6	188 9	251.0	58	22 8	24 4	228 0	256 6
13	17 2	19.2	275.9	334 2	36	18.3	21 5	188 8	250 0	59	1 7	6 9	2 7	31.2
14	19 3	21.4	334 8	400.8	37	18 2	21 3	233.2	306 8	60	2 2	4 6	2 7	9.8
15	18.2	20 7	167.3	209 4	38	18 7	21 2	212 2	264.1	61	2 7	5.7	7.3	26 7
16	18 8	20 8	225.0	268 3	39	19 0	21 3	207.7	253.5	62	2 8	6 1	9 9	38 5
17	18 0	20.0	191 4	230 0	40	18 1	20.4	185 4	228 4	63	3 0	6 4	10 0	37.3
18	18 8	21.0	218.8	265 3	41	18 1	20.4	228 7	281 7	64	12 7	15 6	146 9	210 3
19	19 5	21.7	174 8	210 6	42	17.4	19 6	214.7	264 2	65	11.3	13.7	140 0	195 9
20	18.1	20.1	295 7	355 0	43	12 7	15 5	190.4	269 4	66	11 3	14 6	79 0	123.5
21	–	2.2	–	7.2	44	12 6	16 2	85 3	132.2	67	8 9	11.7	84.4	135 9
22	–	2 6	–	14.0	45	2 2	5 8	6 8	37.0	68	9.7	12 5	83.8	130 4
23	18.6	20 9	326 1	399.6	46	9.1	11.8	80.6	126 8	69	11.4	14 4	106 9	160 6

Table 2.9

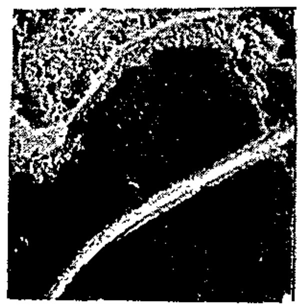
STANDARD INTERPRETATION CARD (STEREO GRAMME)

Location	Forest Age	Crown Density	Filing No.
Seaqaqa	15	D4	1

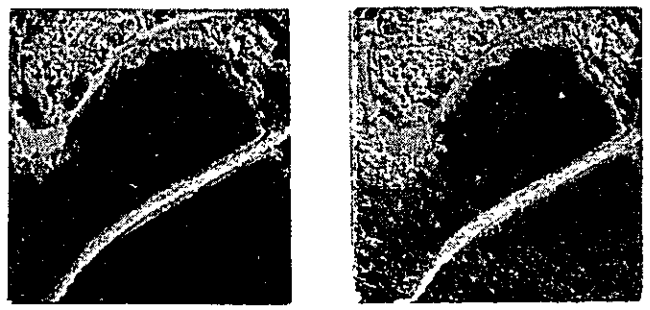
Plot No.	S − 1
Location	Seaqaqa
Compartment & Sub-Compartment	1 − a1 − 1
Planned by	J.I.C.A Fiji Government
Enforced by	J.F.T.A
Surveyed on	August, 1980
Plot Area	0.1 ha

Data of Field Survey				
Site Description		Forest Description		
Topography	flat	Species	P. var. caribaea	
Inclination	0°	Forest Age & (Planted Year)	15 (1963)	
Direction	——	Average Height	20.3 m	
Altitude	90 m	Average D.B.H	27.1 cm	
		Number of Trees	Plot	51
			per ha	510
		Volume	Plot	20.33 m³
			per ha	203.3 m³
		Crown Density	90 %	
		Basal Area	30.35 m²/ha	

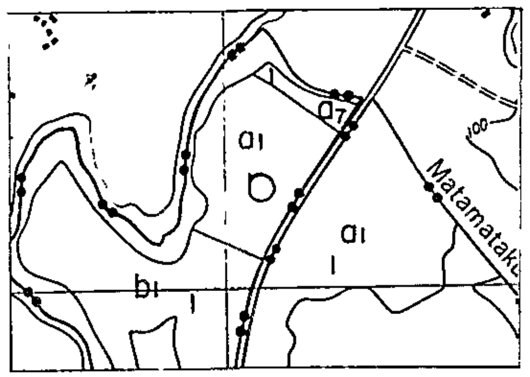
Aerial Photograph Index	
District Name	VANUA LEVU
Flyng Date	May ~ Jun, 1978
Scale of Photograph	1 : 20,000
Flyng Altitude	3,200 m
Focal Length	152.89 mm
Course No. & Photo No.	7 — 12, 13
Base Length	181 mm



Ground Photo



Stereo Photograph (Scale. 1 : 10,000)



Plot Location Map
(Scale. 1 : 10,000)

2.6 Aerial Photograph Stand Volume Table

The estimation of stand volume by the regression estimation method was already explained in section 2.1 Survey Method. While, generally, the regression estimation method uses the multiple regression calculation, in the survey it has been explained that estimation can also be made using Quantification (I). Amongst the factors which have a strong relationship with stand volume, and at the same time, can be measured from aerial photograph analysis or topographical maps, are tree age, stumpage per hectare, crown density and inclination. But average tree height is also considered to be a factor having a high relationship Average tree height was estimated accurately as explained in section 2.4 The calculation results from using these five factors are shown in Table 2 11.

Table 2.11 Score table of stand volume

Item	Category	Score	Range
Tree age	0 ~ 2	− 20 49	79.87
	3 ~ 5	− 6 59	
	6 ~ 8	10 30	
	9 ~ 11	59 38	
	12 ~ 14	35 67	
	15 ~ 17	4 97	
	18 ~	0 00	
Tree height	~ 6 m	− 215 53	217.72
	7 ~ 10	− 217 72	
	11 ~ 14	− 145 93	
	15 ~ 18	− 136 66	
	19 ~ 22	− 74 97	
	23 ~ 26	− 47.02	
	27 ~	0 00	
Number of Stand	0 ~ 400	− 20.30	35.22
	401 ~ 600	− 35 22	
	601 ~ 800	− 17.61	
	801 ~ 1000	− 24 76	
	1001 ~ 1200	0.46	
	1201 ~	0 00	
Crown density	0 ~ 30 %	− 153 38	153.38
	31 ~ 50	− 140 59	
	51 ~ 70	− 120.24	
	71 ~ 90	− 92 80	
	91 ~ 100	0 00	
Inclination	~ 9°	421.82	21.82
	10 ~ 19	400 00	
	20 ~	411 09	

Multiple correlation 0.972

Simple correlation matrix

	Stand volume	Tree age	Tree height	No. of stand	Crown density	Inclina- nation
Stand volume	1	0.829	0 871	− 0 308	0.899	− 0.401
Tree age	0.829	1	0 914	− 0.637	0.857	− 0 531
Tree height	0 871	0 914	1	− 0 601	0.845	− 0 490
No of stand	− 0 308	− 0.637	− 0.601	1	− 0 376	0 467
Crown density	0.899	0 857	0 845	− 0 376	1	− 0.395
Inclination	0 401	− 0 531	− 0 490	0 467	− 0 395	1

Inference from the value of the multiple correlation coefficient, the estimation can be made with a high degree of accuracy. Therefore, the volume per hectare column of the Forest Inventory Note, the estimated values calculated by this Score Table were used. In the sample plots the real values of stand volume, and the estimated values using the score values are shown in Table 2.12

Table 2.12 Real and estimated values in the sample plot

Sample No.	Real values	Estimat-ed values	Sample No.	Real values	Estimat-ed values	Sample No.	Real values	Estimat-ed values
1	235 8	223.8	24	289.5	265 0	47	184.7	183.0
2	319 7	269 4	25	177.3	203.0	48	178.8	210 4
3	277.0	261 7	26	209.9	224 3	49	175.7	199.5
4	320.3	339 6	27	7.5	25.0	50	179.7	202 5
5	319.7	313.7	28	276 8	246 8	51	136 7	164.5
6	240.4	261 7	29	287.8	293.8	52	222 2	183.0
7	331.0	339 6	30	239 5	278 2	53	207.3	228.5
8	217.9	251 8	31	213.9	227.1	54	13.0	6 9
9	223.3	223.8	32	270.1	291.6	55	31.3	12 5
10	269.3	251.8	33	254 7	229.9	56	94 1	94 1
11	263.7	251.8	34	277.1	252 2	57	211.2	184.4
12	248 1	305.2	35	251.0	275.7	58	256 6	246 8
13	334.2	330.5	36	250.0	261.2	59	31.2	22.3
14	400.8	361.2	37	306 8	261.2	60	9 8	0.0
15	209.4	237.5	38	264 1	272 1	61	26 7	25 0
16	268 3	262 2	39	253 5	244 7	62	38 5	48 4
17	230 0	243.1	40	228.4	265 0	63	37.3	46 2
18	265 3	243.1	41	281.7	265 0	64	210.3	229.9
19	210.6	229.9	42	264.2	265.0	65	195 9	193.2
20	355 0	351.8	43	269.4	202 5	66	123.5	118 2
21	7.2	10.6	44	132.2	118.2	67	135 9	166 4
22	14.0	10 6	45	37.0	46 3	68	130 4	146 1
23	399.6	361 2	46	126 8	110.1	69	160.6	150.5

* Score values of sample No. 60 is −0.3

In some cases, when it is desired to find the stand volume for areas near the survey area, using all five factors mentioned above is not possible. In these cases, where the inclination factor is missing, or where the factors for inclination for stumpage per hectare are missing, score values as given in Table 2.13. Single correlation coefficients of these factors have only a small effect on the estimated stand volume.

Table 2.13 Score values of stand volume (except inclination and number of stand

Item	Category	Score values (except inclination)	Score values (except inclination and number of stand)
Tree age	0 ~ 2	− 61 09	− 28 42
	3 ~ 5	− 43.69	− 19 48
	6 ~ 8	− 17.21	− 5.88
	9 ~ 11	27.77	60 82
	12 ~ 14	15 72	36 07
	15 ~ 17	− 5.31	3.51
	18 ~	0 00	0 00
Tree height	~ 6 m	− 208 69	− 189.68
	7 ~ 10	− 210.68	− 181 72
	11 ~ 14	− 142 60	− 115 12
	15 ~ 18	− 134 74	− 128.25
	19 ~ 22	− 72 38	− 74 41
	23 ~ 26	− 48 68	− 52 56
	27 ~	0 00	0 00
Number of stand	0 ~ 400	− 27.24	
	401 ~ 600	− 40.95	
	601 ~ 800	− 18 86	
	801 ~ 1000	− 24 31	
	1001 ~ 1200	1.16	
	1201 ~	0.00	
Crown density	0 ~ 30 %	280 38	228 70
	31 ~ 50	296 84	242 21
	51 ~ 70	319 79	272.59
	71 ~ 90	340 50	302 00
	91 ~ 100	419.35	397.64
Multiple correlation		0 969	0.965

2.7 Estimation of Growing Stock according to Forest Type and Total Growing Stock

The growing stock according to forest type is given in a separate Forest Inventory Note. This section presents computer compiled data on Caribbean Pine planting area, growing stock, and average growing stock per hectare for each compartment; and total area and total growing stock according to age group and compartment.

In the total survey area, the growing stock was 456,000 m^3 and the area was 1868.7 ha. Seaqaqa accounted for 401,000 m^3, 1571 76 ha., and Koroutani, 55,000 m^3, 296.94 ha With regard to area according to tree age, the overall results are shown in the below table and the results are detailed in Figure 2.1.

1 year old	2	3	4	5	6	7	8	9	10
0 ha	54 68	90 04	55.12	26 72	0	0	134 82	187.44	185 68
11 years old	12	13	14	15	16	17	18	19	20
231.00 ha	281 64	330 88	164 40	58 28	30.28	13.44	11.64	8.16	4 48

Fig. 2.1 Area according to tree age

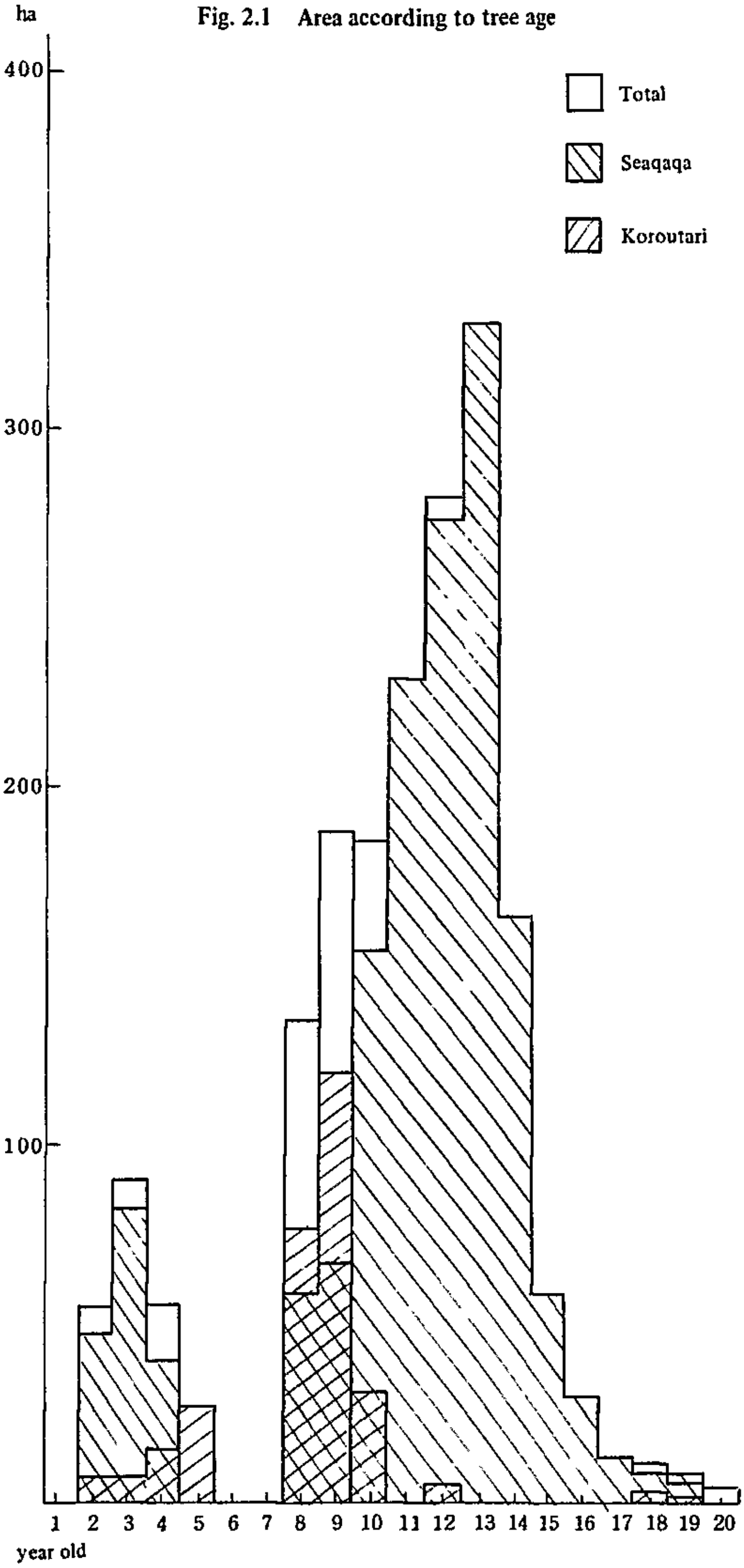


Fig. 2.2 Stand volume according to tree age (Semi log)

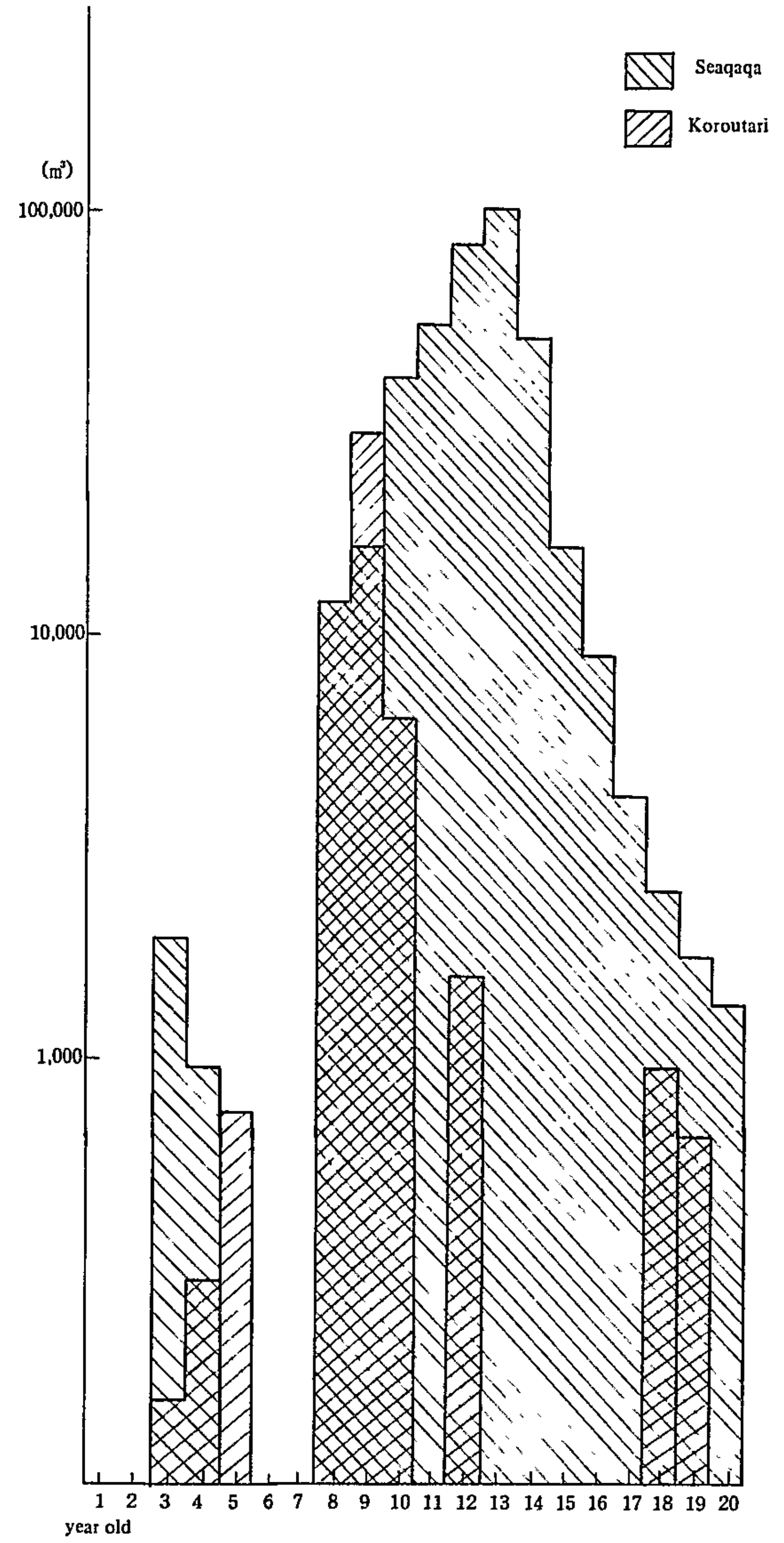


Table 2.14 Planted area stand volume and average volume per HA. according to each compertment

Seaqaqa								Koroutari			
Com-part-ment	Area (ha)	Volume (m^3)	Average volume (m^3/ha)	Com-part-ment	Area (ha)	Volume (m^3)	Average volume (m^3/ha)	Com-part-ment	Area (ha)	Volume (m^3)	Average volume (m^3/ha)
1	29.08	9,143	314	29	15 68	3,815	243	1	4 12	906	220
2	62.92	18,881	300	30	19.84	4,762	240	3	2.16	475	220
3	26 56	8,221	310	31	13.00	3,120	240	4	5.16	703	136
4	32.52	8,302	255	32	16 72	3,797	240	5	4 08	315	77
5	20.16	6,280	312	33	40.24	11,870	295	6	12 28	2,341	191
6	9 68	1,431	148	34	40.48	12,954	320	7	13.76	1,321	96
7	13.56	2,188	161	35	51.12	16,007	313	16	6 32	383	209
8	34.88	10,115	290	36	47.92	15,334	320	17	19.80	2,593	131
9	29.64	8,493	287	37	41.84	13,389	320	22	32 40	7,052	218
10	29.80	8,966	301	38	34.64	8,943	258	23	20.12	1,152	57
11	47.00	13,655	291	39	33.04	11,432	346	24	16 52	2,062	125
12	22 96	5,539	241	40	42.68	13,561	318	25	7.80	1,863	239
13	26 68	6,679	250	41	35.92	11,036	307	26	15.44	3,586	232
14	8.96	1,884	210	42	24 12	6,117	254	27	27.28	7,164	263
15	10.00	335	34	44	40.36	1,746	43	28	25.96	7,810	301
16	35.76	4,671	131	45	40.40	8,364	207	29	14 84	3,960	267
17	23.56	54	2	46	20 16	1,524	76	30	15 96	2,873	180
18	23.64	6,700	263	47	30 72	1,153	38	31	31.54	4,494	142
19	20.72	6,532	315	48	24 92	811	33	32	21.40	2,843	133
20	41.16	12,708	309	49	18.16	4,358	240				
21	0 56	184	329	50	44 72	13,800	309				
22	28 68	7,216	252	51	63.68	15,925	250				
23	24 92	5,735	230	53	35 96	11,456	319				
24	19.84	4,819	243	54	23.12	6,995	303				
25	9.24	1,903	206	55	24 96	7,659	307				
26	23.08	5,570	241	56	42.24	14,122	334				
27	27.16	5,357	197								
28	22.40	5,469	244								
				Total	1,571.76	401,080	255	Total	296 94	54,896	185

With regard to growing stock according to tree age is given in the following table, and the results detailed in Figure 2.2.

1 year old	2	3	4	5	6	7	8	9	10
0 ㎥	0	2,094	1,252	752	0	0	24,348	47,303	47,201
11 yearsold	12	13	14	15	16	17	18	19	20
54,817㎥	87,514	102,715	50,122	16,298	9,043	4,258	3,464	2,430	1,365

Table 2.15 Area, stand volume according to compertment and tree age

	com-part-ment		1 year old	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	16	18	19	20
Seaqaga	1	area															9.28		7.00	8 32		4 48
		volume															3,062		2,220	2,496		1,365
	2	area												15.32		4 24	6 64	30.28	6 44			
		volume												4.318		1,357	2,125	9,043	2,038			
	3	area													10 60	9 00	6 96					
		volume													3.392	2,880	1,949					
	4	area												9.92			22 60					
		volume												2,678			5,624					
	5	area													15 48		4.68					
		volume													5,016		1,264					
	6	area		1.28	2 88						5.52											
		volume		0	144						1,287											
	7	area		2 44	1.52						9.60											
		volume		0	76						2,112											
	8	area		'											34 88							
		volume													10,115							
	9	area													15.56	14 08						
		volume													4,331	4,162						
	10	area													17.12	12.68						
		volume													4,782	4,184						
	11	area														46 40					0.60	
		volume														13,493					162	
	12	area											14 84				8.12					
		volume											3,265				2,274					
	13	area									26 68											
		volume									6,679											
	14	area		1.00	0.52						7.44											
		volume		0	10						1,874											
	15	area			10.00																	
		volume			335																	
	16	area		2.00	15 68						18 08											
		volume		0	314						4,357											
	17	area		20.84	2.72																	
		volume		0	54																	

	compartment		1 year old	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Seaqaqa	18	area											1 52		22 12							
		volume											285		6,415							
	19	area													17.20	3.52						
		volume													5,504	1,028						
	20	area														35.96					5 20	
		volume														11,148					1,560	
	21	area										0 40									0.16	
		volume										136									48	
	22	area											28.68									
		volume											7,216									
	23	area											24 92									
		volume											5,735									
	24	area											19 84									
		volume											4,879									
	25	area											9 24									
		volume											1,903									
	26	area											23.08									
		volume											5,570									
	27	area			0.84	5.08							21.24									
		volume			42	254							5,061									
	28	area											22.40									
		volume											5,469									
	29	area											15.68									
		volume											3,815									
	30	area											19.84									
		volume											4,762									
	31	area											13.00									
		volume											3,120									
	32	area											16 72									
		volume											3,797									
	33	area		1.72												38.52						
		volume		0												11,870						
	34	area												8.68	31 80							
		volume												2,778	10,176							

	compartment		1 year old	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Seaqaqa	35	area												51.12								
		volume												16,007								
	36	area													47.92							
		volume													15,334							
	37	area													41.84							
		volume													13,389							
	38	area										34 64										
		volume										8,943										
	39	area										21.48		11 56								
		volume										7,733		3,699								
	40	area													42.68							
		volume													13,561							
	41	area								2 24					33.68							
		volume								336					10,700							
	42	area										15.76		8.36								
		volume										3,686		2,431								
	44	area		3.92	31.08					5.36												
		volume		0	622					1,124												
	45	area		2.68						37.72												
		volume		0						8,364												
	46	area		3.32	11.68					5.16												
		volume		0	234					1,290												
	47	area			5.32	22 04				3.36												
		volume			107	441				605												
	48	area		7.88		12.76				4 28												
		volume		0		255				556												
	49	area										18 16										
		volume										4.358										
	50	area												44 72								
		volume												13,800								
	51	area										63.68										
		volume										15,925										
	53	area												35.96								
		volume												11,456								

	compartment		1 year old	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Seaqaqa	54	area												23.12								
		volume												6,995								
	55	area												24.96								
		volume												7,659								
	56	area												42.24								
		volume												14,122								
	Total	area	0	47 08	82 24	39.88	0	0	0	58.12	67.32	154 12	231 00	275.96	330.88	164 40	58 28	30.28	13.44	8 32	5.96	4 48
		volume	0	0	1,938	950	0	0	0	12,275	16,309	40,781	54,817	85,943	102,715	50,122	16,298	9,043	4,258	2,496	1,770	1,365
Koroutari	1	area										4 12										
		volume										906										
	3	area										2.16										
		volume										475										
	4	area				2 00						3.16										
		volume				50						653										
	5	area				2.60						1.48										
		volume				19						296										
	6	area			0.80							5.80		5.68								
		volume			16							754		1,571								
	7	area		7.60								6 16										
		volume		0								1,321										
	16	area			5 04							1 28										
		volume			101							282										
	17	area			1.96	8 24						7.40									2 20	
		volume			39	161						1,733									660	
	22	area				2 40					28.96									1.04		
		volume				72					6,678									302		
	23	area					17.84													2.28		
		volume					486													666		
	24	area					8 88				7.64											
		volume					266				1,796											
	25	area								7.80												
		volume								1,863												
	26	area									15.44											
		volume									3,586											

	compartment		1 year old	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Koroutari	27	area									27.28											
		volume									7,164											
	28	area									25.96											
		volume									7,810											
	29	area									14.84											
		volume									3,960											
	30	area								15.96												
		volume								2,873												
	31	area								31.54												
		volume								4,494												
	32	area								21.40												
		volume								2,843												
	Total	area	0	7 6	7.8	15.24	26.72	0	0	76 7	120.12	31 56	0	5.68	0	0	0	0	0	3.32	2.20	0
		volume	0	0	156	302	752	0	0	12,073	30,994	6,420	0	1.571	0	0	0	0	0	968	660	0

Figure 2.1 shows the large area of 11 – 13 year old stands, and there are no stands 6 – 7 years old. If a Normal Age Class Distribution aim, to give stand continuity, these findings must be given consideration in making future forest plans.

Next, the estimated quantity of saw-timber obtainable from the present stands is presented here. The minimum standard stumpage for usable saw-timber in Fiji is 2.4m x 23 cm (central diameter). Therefore the aim is to produce D.B.H 24 cm, or more, and 30 cm or more, and calculations were made to establish the volumes for these D.B.H. To this end, first, in the 69 sample plots in the survey area, the ratio of stumpage volume for D.B.H 24 cm and over, and 30 cm and over, to the total volume was measured. The deviation function was obtained by regression calculation on tree age in the sample plots and this ratio, and using this coefficient, the stumpage volume for D.B.H. 24 cm and over, and 30 cm and over was estimated from the present volume according to tree age. Figure 2.3 shows the relationship between the percentage volume and tree age for D.B.H. equal or greater than 24 cm. The regression line was drawn excluding data for tree age 7 years and under. Figure 2.4. shows the percentage volume for D.B.H equal or greater than 30 cm, and the regression line was drawn excluding data for tree age 8 years and under. From these two regression relationships, the percentage volumes according to tree age, for D.B.H. equal or greater then 24 cm, and equal or greater than 30 cm, can be obtained, and these are given in the table below.

tree age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
over 24cm	0	0	0	0	0	0	34	40	46	52	57	63	69	74	80	86	92	97	100
over 30cm	0	0	0	0	0	0	0	0	6	12	19	25	32	38	45	52	58	65	71

(%)

Table 2.16 Volume that can be used as saw-timber according to tree age.

Tree age	D.B.D. 24cm over		D.B.H. 30cm over	
	Seaqaqa	Koroutari	Seaqaqa	Koroutari
8	4,174 (㎥)	4,105 (㎥)	(㎥)	(㎥)
9	6,524	12,398		
10	18,759	2,953	2,447	385
11	28,505	0	6,578	0
12	48,988	895	16,329	298
13	64,710	0	25,679	0
14	34,584	0	16,039	0
15	12,061	0	6,193	0
16	7,234	0	4,069	0
17	3,662	0	2,214	0
18	2,296	891	1,448	561
19	1,717	640	1,151	429
20	1,365	0	969	0
Total	234,579	21,882	83,116	1,673
Sum total	256,461		84,789	

Fig. 2.3 Relationship between the percentage volume and tree age for D.B.H. equal or greater than 24cm

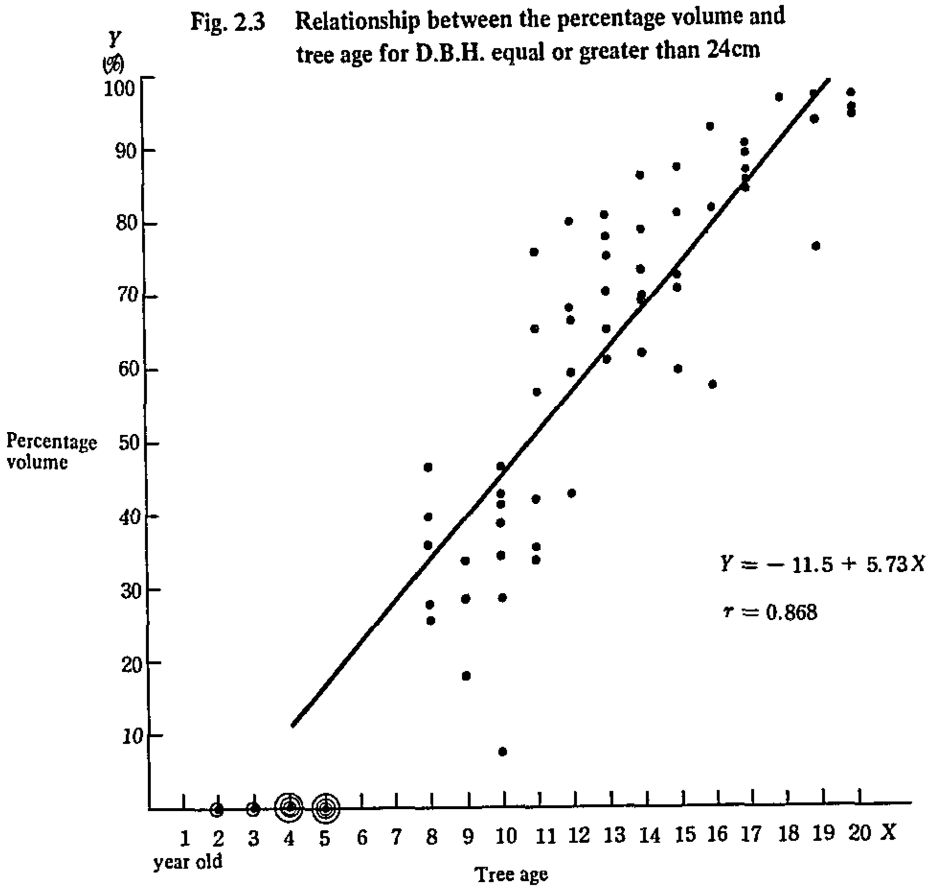


Fig. 2.4 Relationship between the percentage volume and tree age for D.B.H. over 30 cm

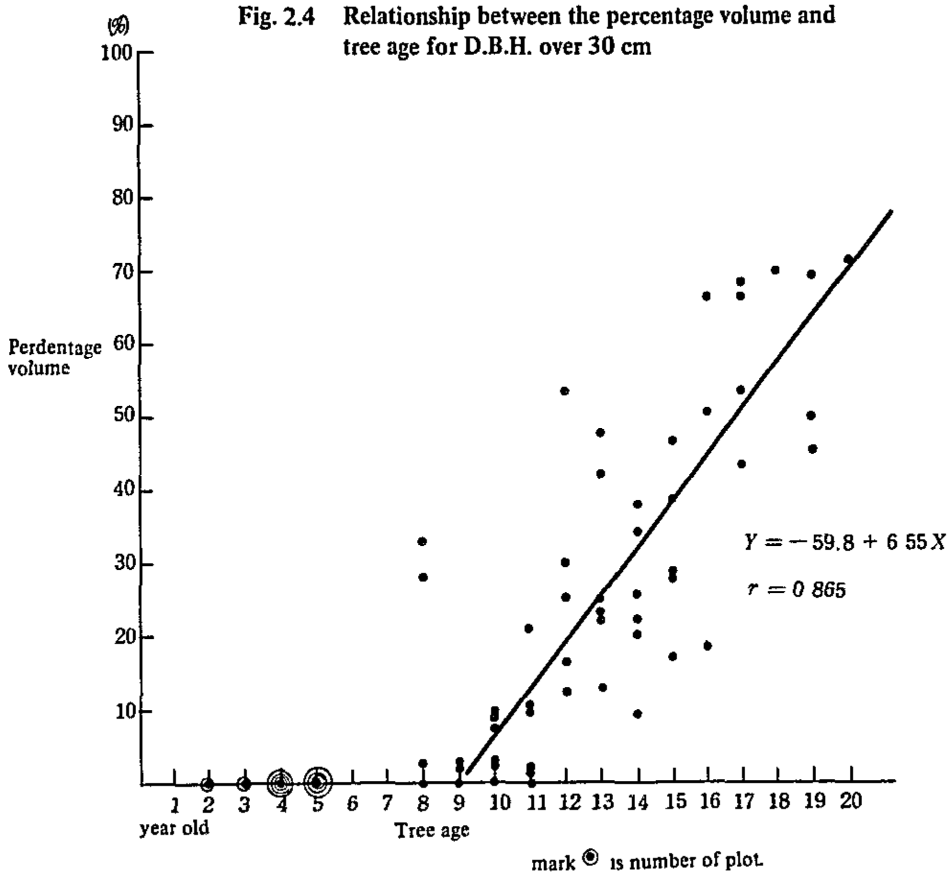


Fig. 2.5

Stand volume under D.B.H. 24 cm	24 cm ~ 30 cm	30 cm over
199000 m^3 (43.7 %)	172000 m^3 (37.7 %)	85000m^3 (18.6 %)

10 20 30 40 50 60 70 80 90 100%

The volume that can be used as saw-timber can be calculated by multiplying these percentage volumes (%) by the total volume according to tree age as shown in Table 2.15, and the results obtained are given in Table 2.16.

Figure 2.5 shows the breakdown of stand composition volumes for the total survey area, according to the above-mentioned results.

The Commonwealth Forestry Institute suggest that, for pulp use, Caribbean Pine in Fiji should have a diameter of 3 inches or more, and the proportion of usable volume to total volume can be expressed by the following formula:

$$V(\text{ft}^3\ 3''\ \text{and over}) = -0.45 + 0.9359\ TV\ (\text{total volume ft}^3)$$

$$\downarrow$$

$$V(\text{m}^3) = -0.01274 + 0.9359\ TV\ (\text{m}^3)$$

Thus, the amount of timber for pulp in the present volume, is estimated to be 375,301 m^3 out of a total volume of 401,080 m^3 in Seaqaqa, and 50,441 m^3 out of a total volume of 54,896 m^3 in Koroutari.

2.8 Making the Forest Inventory Note

Each of the details in the Forest Inventory Note were calculated by computer, and are given below. The total area and volume was calculated for every variety and every compartment, starting a new page of printout for each.

1) As each new forest plan is added to the Fiji government stock map, it is labelled alphabetically, so that within one compartment there may occur sub-compartments bearing the same alphabetic label. Therefore, in order to distinguish them, a number was added, ex. a-1, a-2.
2) Where there are different tree heights, or crown densities, within the same sub-compartment, it is divided into forest type.
3) Areas for sub-compartments and forest types are measured from the stock maps created by the survey and are given in hectares to two decimal places.
4) All tree types are Caribbean Pine, but as this includes var. caribaea, var. hondurensis, var. cuban and var. bahamensis, and these varieties may be mixed, the following codes are used:

   var. caribaea .... PC
   var. hondurensis .... PH
   var. cuban .... PCU
   var. bahamensis .... PB
   broad leaved tree .... B
   caribaea, hondurensis mixed .... PCH
   caribaea, broad leaved tree mixed .... PC.B
   caribaea, hondurensis, broad leaved tree mixed .... PCH.B
   caribaea, cuban mixed .... PCCU

5) Average tree height was obtained from score values shown in section 2.4, and are given in whole numbers.
6) Crown density was estimated to the nearest 10% from aerial photographs
7) The number of trees per hectare was estimated to the nearest hundred from aerial photographs.
8) Volume per hectare was obtained from score values shown in section 2.6, and are given to the nearest 10 m^3.
9) Total volume was obtained by multiplying the area by the volume per hectare.
10) Altitude was taken from the stock maps drawn up by the survey, and are given to the nearest 10 m.
11) The direction of dip was taken from the stock maps drawn up by the survey, and there are nine directions: N, NE, E, SE, S, SW, W, NW, and FLAT.
12) The inclination was taken from the stock maps drawn up by the survey, and are given to the nearest whole degree.
13) The topography was taken from the stock maps drawn up by the survey, and they are referred to as CONV., CONC., PAR.S and FLAT.
14) Soil water content was estimated from aerial photographs, and are indicated as DRY, MID, and WET.
15) The site index was obtained according to tree age and average tree height at the time of the survey, from the Caribbean Pine site index curves (See Figure 2.6) drawn up from the Seaqaqa area by the Fiji government.
16) Basal area was obtained from score values shown in section 2.4.

Figure 2.7 shows an example of the Forest Inventory Note.

Fig. 2-6 PINUS CARIBAEA MODIFIED SITE INDEX CURVES (SEAQAQA PLANTATION)

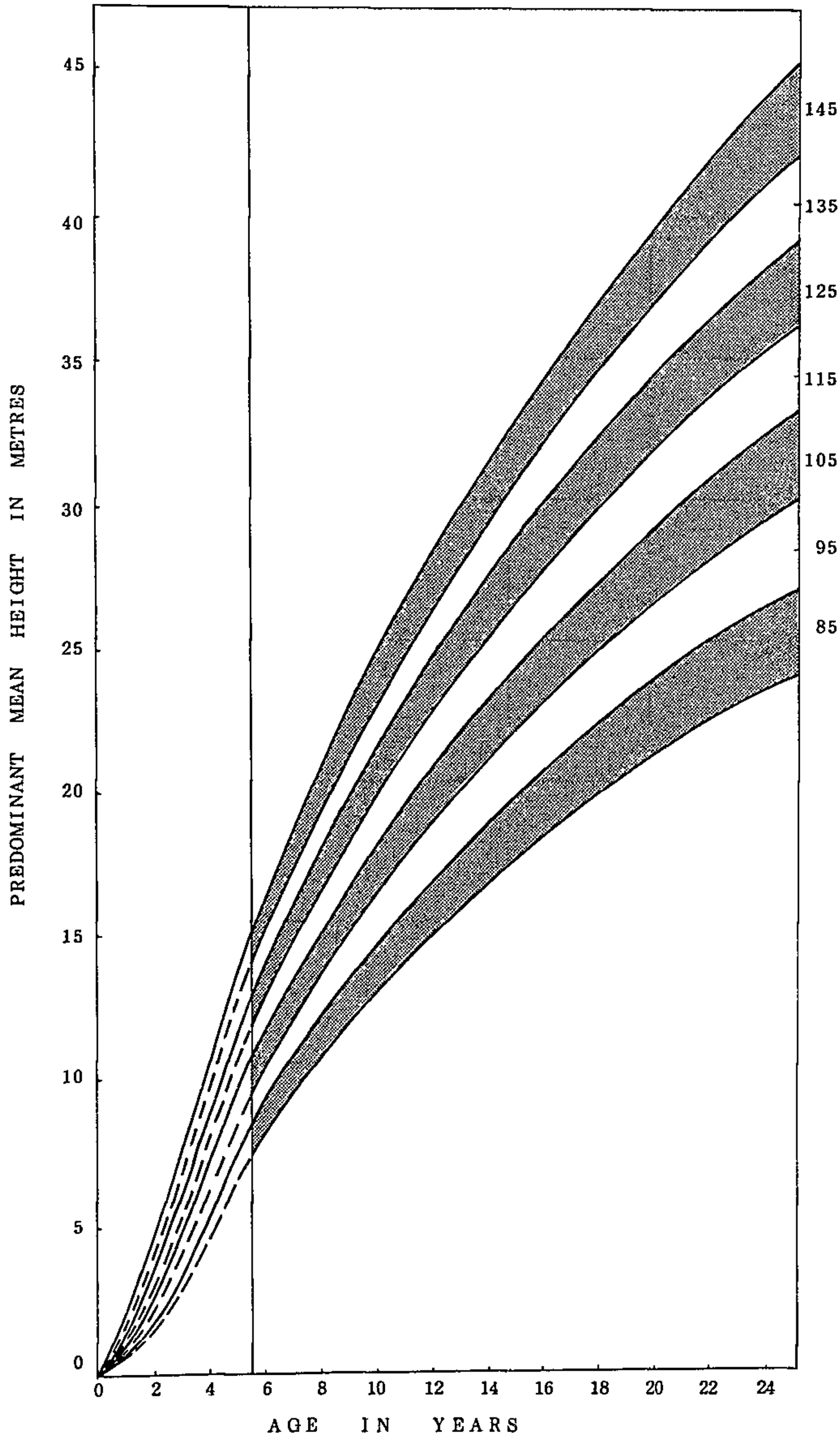


Fig. 2-7 Forest inventory note

FOREST INVENTORY NOTE

* * LOCATION SEAQAQA * *

* * COMPARTMENT 1 * *

SUB COMP.	FOREST TYPE NO.	AREA (HA)	PLANT YEAR	SPP.	AV. HEIGHT (M)	CROWN DENS. (%)	NUM. OF TREES (/HA)	VOL. (M↑3/HA)	TOTAL VOL. (M↑3)	ALTITUDE (M)	DIRECTION	INCLINATION (°)	TOPOGRAPHY	SOIL HUMIDITY	SITE INDEX	BASAL AREA (M↑2/HA)	NOTE
	FOREST DESCRPTION										SITE DESCRIPTION						
A 1	1	2.96	1963	PCH	21	90	500	330	977	90	FLAT	0	FLAT	MID	85	30	
A 2	1	1.28	1963	PC	20	70	600	260	333	90	FLAT	0	FLAT	MID	85	27	
A 3	1	2.40	1960	PC	23	80	500	300	720	90	FLAT	0	FLAT	MID	85	30	
A 4	1	2.36	1963	PC	21	80	400	340	802	90	FLAT	0	FLAT	MID	85	31	
A 5	1	2.08	1960	PC	23	80	400	310	645	100	NW	8	PAR.S	MID	85	31	
A 6	1	8.32	1962	PCH	23	90	500	300	2496	90	FLAT	3	FLAT	MID	95	30	
A 7	1	.40	1963	PCH	20	70	400	270	108	90	FLAT	0	FLAT	MID	85	28	
B 1	1	4.84	1965	PCH	21	80	600	330	1597	90	FLAT	0	FLAT	MID	95	30	
B 2	1	4.44	1965	PCH	21	80	500	330	1465	90	FLAT	0	FLAT	MID	95	30	

TOTAL AREA 29.08HA

TOTAL VOLUME 9143M↑3

	AREA(HA)	VOLUME(M↑3)
P.CARIBAEA	8.12	2500
P.HONDURENSIS	0	0
P.CUBAN	0	0
P.BAHAMAENSIS	0	0
BROAD REAF	0	0
P.C,B	0	0
P.C,P.H	20.96	6643
P.H,B	0	0
P.C,P.H,B	0	0
P.C,P.CU	0	0
P.C,P.B	0	0

3. GUIDE TO THINNING

3.1 Study of thinning methods.

The purpose of thinning is to adjust the stand density to match the purpose of production, by suitable control of crown closure between canopy closure and final cutting in forest of uniform type. The four factors which affect the choice of thinning method are:

1. Maximization of stand yield (final cutting and thinning total)
2. Healthy growth of the stand during the growth period.
3. Matching of timber produced to the standard required according to use.
4. Ease and cost of thinning operation.

The choice of thinning method must take all the factors into account.

The first step in choosing the thinning method is to consider the special ecological characteristics of the exploitable stand. This requires an examination of the relationships between stumpage per unit area, trunk volume, average tree height and average diameter breast height in the existing stand. In Japan, as a method of expressing the stand composition, a Stand Density Control Diagram is used. A simple explanation of this diagram is given here.

Where the forest tree height is constant, the relationship between the number of trees per unit area and the volume can expressed by the following formula:

$$1/V = A + B/N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where V = Volume per unit area.

N = Number of trees per unit area.

A, B = Fixed values.

This is called Y–D Effect (Yield Density Effect).

Figure 3.1 is an example showing the Y–D Effect for each tree height class. The fixed values, A and B, can be obtained by the method of least squares for each height category from sampling. Where there are sufficient samples, the relationship for each tree height shows the smooth curves indicated in the figure, whereas small samples will produce a wide scatter. Therefore, A and B are expressed as deviation functions according to tree height, and b_1, b_2, b_3, b_4, as in (2) and (3) were obtained by the method of least squares, and smoothing was achieved.

$$A = b_1 H^{b_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$B = b_3 H^{b_4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where H = average upper class tree height.

The relationship between volume per unit area, number of trees per unit area, and tree height can be obtained by substituting formulae (2) and (3) into formula (1), which then becomes formula (4) as below.

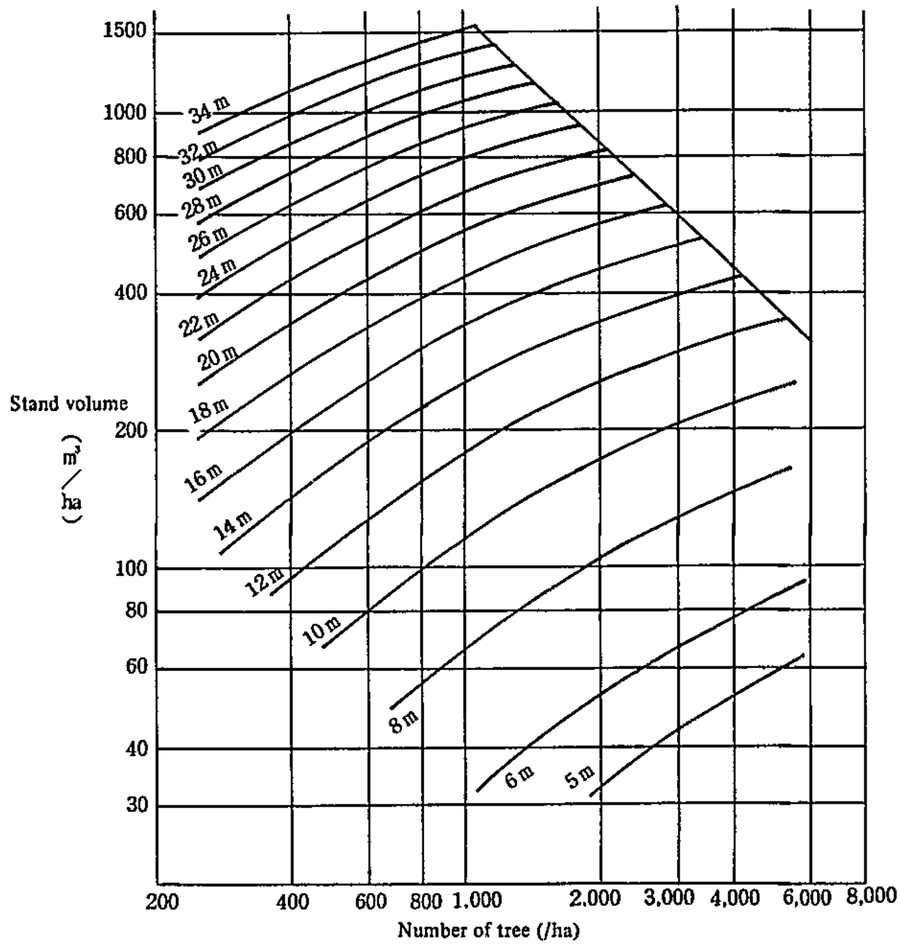
$$1/V = A + B/N = b_1 H^{b_2} + b_3 H^{b_4}/N$$

$$V = (b_1 H^{b_2} + b_3 H^{b_4}/N)^{-1} \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

On the other hand, the relationship between form height of stand, HF, average upper class tree height, H, and number of trees per hectare, N, is known from experience to be expressed by the following formula

$$HF = C_1 + C_2 H + C_3 \frac{\sqrt{N \cdot H}}{100} \quad \ldots\ldots\ldots\ldots \quad (5)$$

Fig. 3.1 Y-D effect



From the sample, using the method of least squares, values of C_1, C_2 and C_3 can be obtained. Basal area, G, can be obtained from V/HF, so G can be obtained by substituting appropriate values for H and N in formulae (4) and (5) The average basal area diameter can be calculated from

$$\bar{D}_g = 200\sqrt{G/(\pi \cdot N)}$$

Furthermore, the relationship between the average basal area diameter and number of trees per hectare, tree height, average diameter, $\bar{D}$, is known from experience to be expressed by the formula:

$$\bar{D} = d_1 + d_2 \cdot \bar{D}_g + d_3 \cdot \sqrt{N \cdot H/100} \quad \ldots\ldots\ldots \quad (6)$$

and by the method least squares d_1, d_2, d_3 can be obtained. The average diameter, $\bar{D}$, eventually becomes a function of H and N, and for appropriate values of H and N, $\bar{D}$ can be calculated.

Thus, trunk volume per hectare, number of trees per hectare, average tree height and average diamenter in the exploitable stand can be shown as a functional relationship. If the stand is left to grow without thinning, competition between individuals starts, and natural thinning occurs. The following method is used to obtain the point at which natural thinning occurs.

In each sample a functional relationship exists between number of trees per hectare, volume per hectare and average tree height. There are differences between closely spaced

and well spaced stands, and these conditons can be described by the competitive ratio, as shown in the following formula (7):

$$R_c = b_3 H^{b_4} \cdot V/N \quad \ldots\ldots \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

where R_c = competitive ratio.

This R_c can be calculated for every sample, but the value of R_c is smallest for closely spaced stands If the area is left without thinning, the ratio reaches a critical value, according to the each growing stage, which represents the limit of acceptable competition in the exploitable stands.

In the Stand Density Control Diagram, there are lines representing natural thinning curve, which indicates that a number of trees will die off as a result of natural thinning, when thinning operations are not carried out. The yield rate curve indicates the condition of highest density.

On the Stand Density Control Diagram, basal area, G, can be drawn, according to the formula:

$$G = (\bar{D}/2)^2 \cdot \pi \cdot N$$

where $\pi = 3.1416$

The appropriate average breast height can be obtained from diameter, $\bar{D}$, and the number of trees per hectare.

This Stand Density Control Diagram explains the ecological condition of the stand, and the thinning method should be chosen using this diagram, and with due consideration to the earlier mentioned factors 1–4.

3.2 Current thinning method in Fiji.

In Fiji, for thinning guidance, the following criteria have been composed.

1) Thinning prescription for Caribbean Pine.

For stands having reasonably good growing cinditions (site grade 120), details as shown in Table 3.1 are used as a standard prescription However, these figures are rough averages and are not meant to be strictly adhered to. The relationship between tree age, predominant mean height, and basal area differs from stand to stand. Therefore, it was decided to carry out actual thinning according to the graph shown in Figure 3.2. On this graph, the top curved line indicates the maximum basal area for each predominant mean height, and thinning must be carried out where basal areas exceed this level. The middle curve runs between the upper and lower lines and indicates the optimum basal area before thinning. The lower curve indicates basal area after thinning and this represents the lower limit below which the basal area must not fall. For example, if a stand with a basal area of 30 m^2/ha and a predominant mean height of 18 m. has a diameter growth rate greater than its height growth rate, then it can be plotted as shown by dotted line(1) in the figure. If this line crosses into the area above the middle curve, thinning is acceptable. If, however, it crosses the upper line, thinning becomes essential. Suppose that at the predominant mean height of 22 m low class thinning is carried out, then the basal area drops, as indicated by the dotted line. The thinning amount should allow the basal area to remain above the lower curved line. Thinning of this kind should be repeated so that the basal area remains between the upper and lower curved lines. As a seperate example, where the height growth rate is greater than the diameter growth rate, it can be represented on the graph as dotted line(2), and thinning is needed less frequently. This method is a field method and the values obtained from the graph are shown in Table 3.2.

Table 3-1

	Predominant mean height (m)	Average age (years)	Basal area		Average stems/ /HA after thinning
			before thinning	after thinning	
1st	18 m	9	33 m²/ha	28 m²/ha	840 /ha
2nd	24	13	36	31.5	600
3rd	29	17	37	33	400
4th	(34)	(21)	(37.5)	(34.5)	(290)

Fig. 3.2 Current thinning method

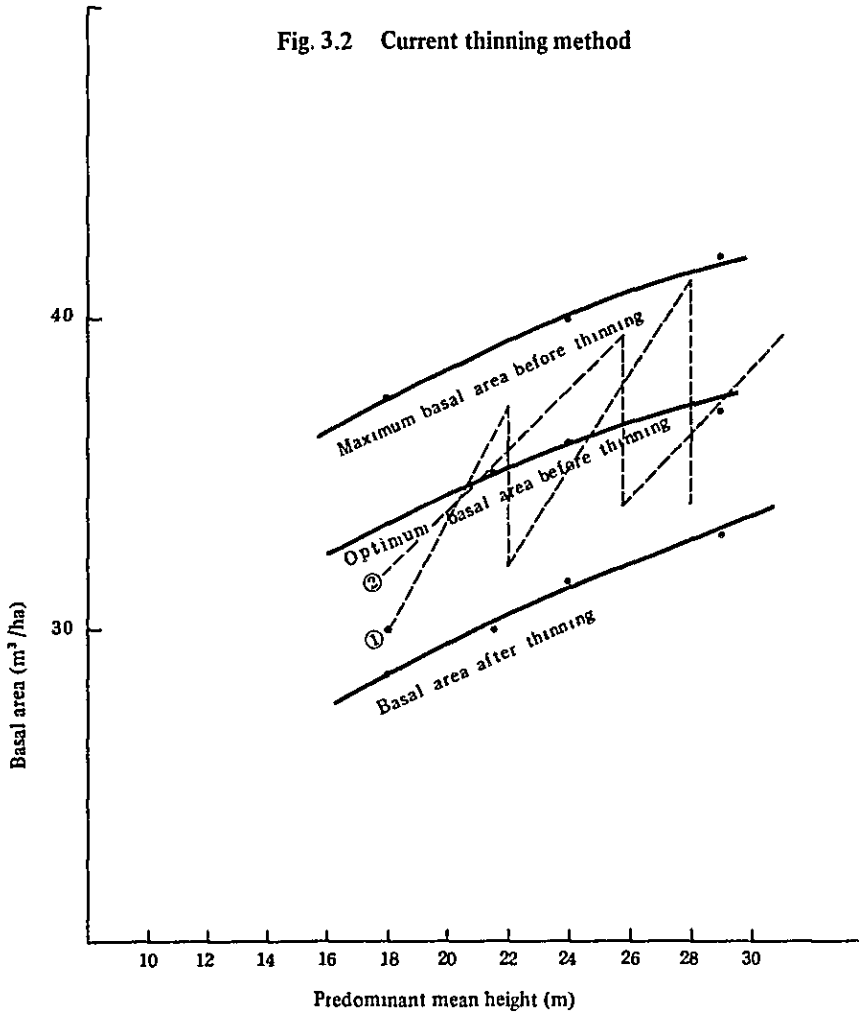


Table 3-2

Predominant mean height	Optimum basal area (before thinning)	Maximum Ba. (before thinning)	Basal area after thinning
18m(17 ~19m)	33.0 m²/ha	37.5 m²/ha	28.5 m²/ha
21 (19.1~22)	35.0	38.5	30.0
24 (22.1~26)	36.0	40.0	31.5
29 (26.1~32)	37.0	42.0	33.0

Based on these criteria, the most effective means of thinning is explained in "Thinning Procedures On Caribbean Pine Plantation". For the stand on which thinning is proposed, the predominant mean height is estimated from the permanant sample plot. If there is no permanent sample plot in the stand, select eight points scattered over the stand, and within the surrounding 3 ft x 6 ft area of each point, the highest tree should be taken as the predominant mean height. Then three pilot are set out at representative places in the stand. The diameter breastheight is measured, and the basal area calculated. The thinning amount can then be decided. Trees for thinning are then selected in the pilot plot, and in a surrounding area amounting to five times the size of the pilot plot. Within this area a check plot is set up, and from basal area measurements the amount of thinning is checked. By repeating this procedure, trees for thinning are selected in the exploitable stand.

The above is an outline of the current thinning method, but due to costs and labour requirements, it is difficult to execute satisfactorily. In fact, when walking around the stand, it is apparent from the white paint marks indicating trees to be thinned that delays in thinning are occuring.

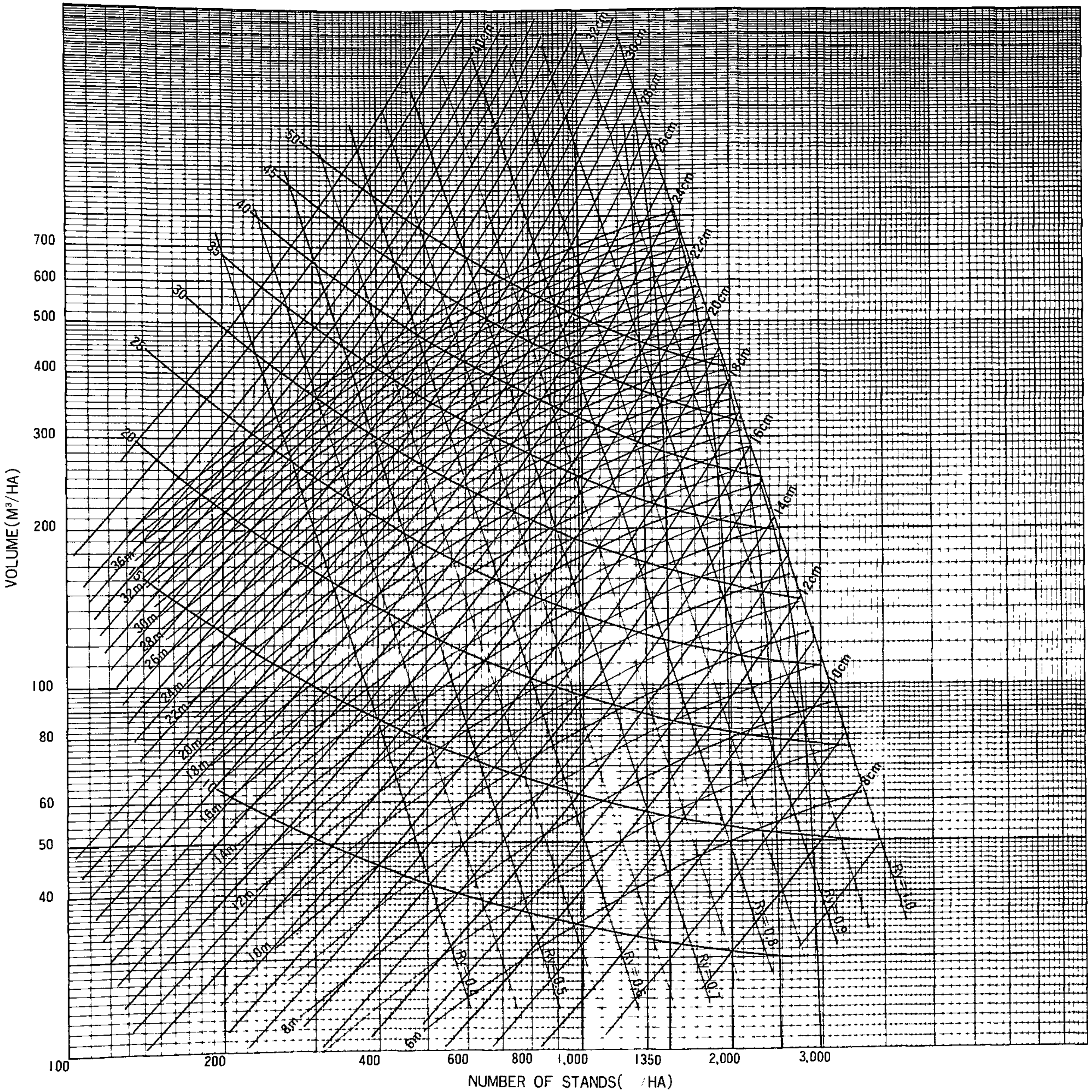
3.3 Stand Density Control Diagram.

We calculated four regression equation, they based on the re ults obtained from the survey of 69 sample plots. They show below. And by dividing the deveations between actual and estimated values by the standard error, decisions could be made to abandon sample plots from which the results proved highly irregular. However, none of the sample plots produced such irregular results, and all 69 plots were approved. The regression coefficients and multiple correlation coefficient of the four kinds of regression calculations are as follows:

$HF = 1.7799 + 0.2792H - 0.0352\dfrac{\sqrt{N \cdot H}}{100}$	Multiple correlation coefficient	0.9570
$\bar{D} = -0.3580 + 1.0011\bar{D}_g - 0.0332\dfrac{\sqrt{N \cdot H}}{100}$	"	0.9972
$\bar{H} = 0.2569 + 0.9942H - 0.0888\dfrac{\sqrt{N \cdot H}}{100}$	"	0.9962
$\log v = -1.4759 + 1.7431 \log H - 0.4532 \log N$	"	0.9843

where HF = Form height of stand.
H = Upper class tree height.
N = Number of stads per hectare.
$\bar{D}$ = Average D.B.H.
$\bar{D}_g$ = Average basal area diameter.
$\bar{H}$ = Average tree height.
v = Average single tree volume.

The results of the regression calculation $1/V = A + B/N$ (Y–D Effect) according to height category are shown in next Figure.



STAND DENSITY CONTROL DIAGRAM OF PINUS CARIBAEA (SEAQAQA, KOROUTARI PLANTATION)

INDEX	
⁄ (line)	average height curve
/	average D.B.H. curve
\	yield rate curve
|	natural thinning curve
‾ (line)	basal area curve

Table 3.3 A, B of Y-D effect according to tree height

Height class (m)	Number of plot	A	B
1 ~ 2.9	3	−0.03715	215.46115
3 ~ 4 9	2	−0.47038	492.27902
5 ~ 6.9	6	−0.03627	84 76315
7 ~ 8 9	0	−	−
9 ~ 10 9	0	−	−
11 ~ 12 9	4	0 01984	−12.50509
13 ~ 14.9	5	0 00316	2.34311
15 ~ 16.9	7	0.00277	2.36060
17 ~ 18.9	7	0 00235	1.92809
19 ~ 20.9	6	0.00077	2.85491
21 ~ 22.9	16	0 00148	1.68918
23 ~ 24.9	6	0.00177	1.06092
25 ~ 26.9	6	0.00145	0.94123

(Height class 7 – 8.9m and 9 – 10 9m are not able to calculate with no sample)

The values of b_1, b_2, b_3, b_4 in the deviation functions $A = b_1 H^{b_2}, B = b_3 H^{b_4}$, obtained by regression calculation are as follows

$b_1 = 0.104683$
$b_2 = -0.366508$
$b_3 = 142.720201$
$b_4 = -1\ 478392$

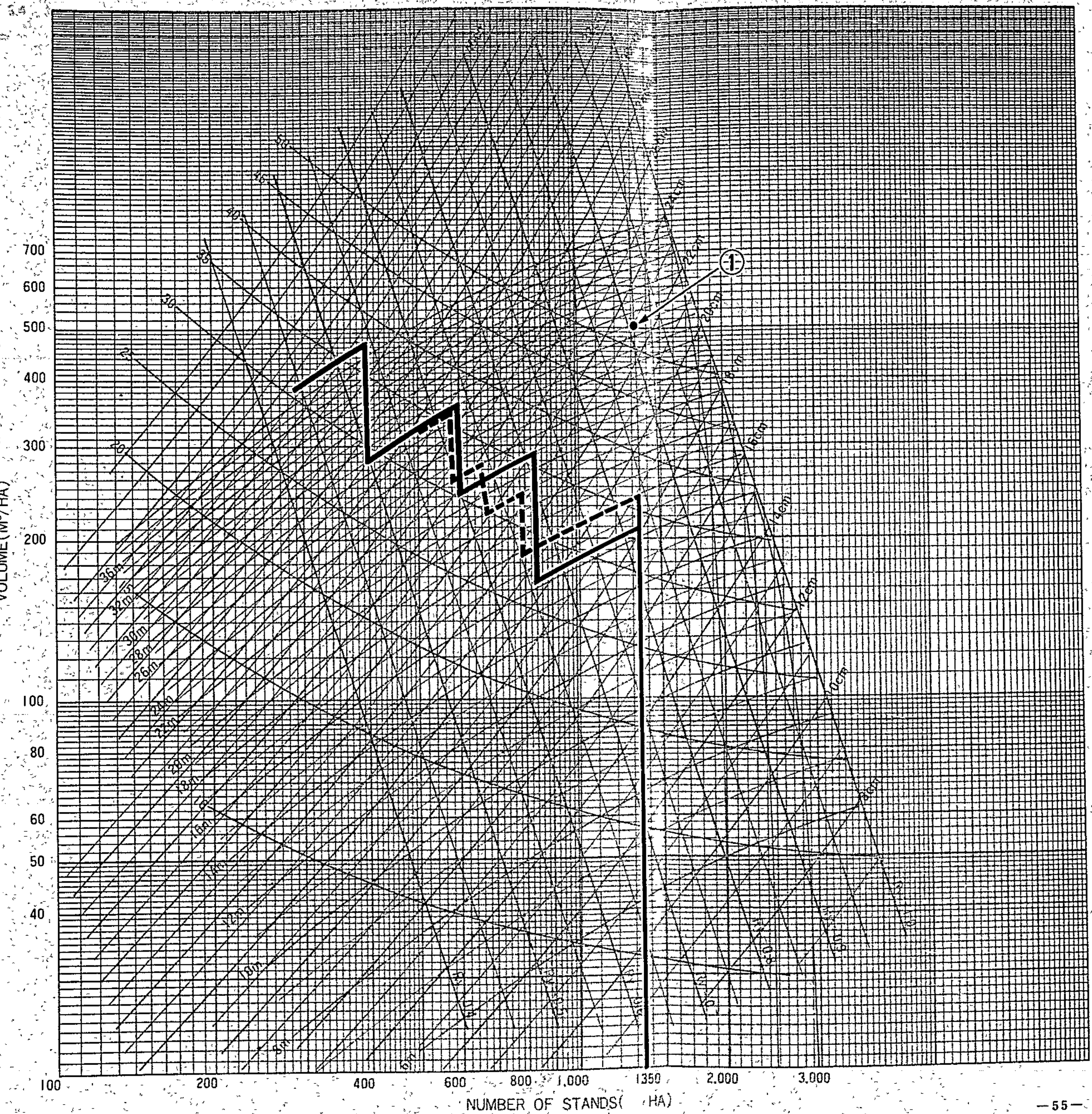
In formula (4) in section 3.1, in order to minimize the total square deviation between estimated and actual volumes, the values of b_1, b_2, b_3, b_4 were improved using Marquardt's algorithm* and the results are as follows:

* D W. Marquardt, An algorithm for least squares estimation of non-linear parameters. J. Coc. Indust. Appl. Math. Vol 11 No 2

$b_1 = 0.129018$
$b_2 = -1.389128$
$b_3 = 444.5$
$b_4 = 1.856444$

Using these fixed values, the Stand Density Control Diagram was drawn up. Figure 3.3 shows the Stand Density Control Diagram for Caribbean Pine

Fig. 3-4


VOLUME (M³/HA)
700
600
500
400
300
200
100
80
60
50
40
100
200
400
600
800
1,000
1350
2,000
3,000
NUMBER OF STANDS(/HA)
①
24cm
22cm
20cm
18cm
16cm
14cm
12cm
10cm
8cm
36m
32m
30m
28m
26m
24m
22m
20m
18m
16m
14m
12m
10m
8m
6m
50
45
40
35
30
25
20

3.4 Study of optimum thinning amount.

The current thinning guidance for Fiji is plotted on a Stand Density Control Diagram. The continuous line in Figure 3.4 plots the results from Table 3.1 in section 3.2, and the dotted line plots those of Table 3.2. Suppose Table 3.1 to be case 1 and Table 3 2 to be case 2. In case 1 at the third thinning, the predominant mean height is 29 m, and in case 2 the same height is reached at the fourth thinning. If the fourth thinning for case 2 and the third thinning for case 1 are both carried out to give a stumpage per hectare of 400, the total thinning quantities, from first to third thinnings for case 1, and from first to fourth thinnings for case 2, can be compared. Table 3.4 shows the thinning amounts for cases 1 and 2. This shows that, in order to reach a stumpage per hectare of 400 and a volume of 280 m^3/ha, in case 1 the thinning quantity produced is 179 m^3/ha , and in case 2, the quantity if 145 m^3/ha If this level is to be attained in one thinning, it can be represented on the diagram as point (1) i.e. 1320 stumpage per hectare, and 510 m^3/ha., and the amount of thinning 220 m^3/ha It is clear from these three examples that in order to produce the maximum thinning quantity, the frequency of thinning operations should be reduced, and thinning carried out as late as the maximum density will allow. In other words, factor 1 in section 3.1, maximization of stand yield, involves the minimum number of thinning operations. In a thinning method employed in Japan, a value for the yield amount Ry is decided according to the use of the final cutting. In other words, in closely packed stands, timber with narrow annual ring and beautiful grain can be obtained, while in widely spaced stands, timber with wide annual ring and large diameter timber can be obtained, useful in boat-building These differences in closely packed and widely spaced stands are expressed by the yield ratio value (Ry) in Japan Yield ratio is a ratio of volume to maximum density and at the growing stage the yield ratio category must be chosen. For example, in forestry areas famous for closely packed stands thinning is carried out when the yield ratio is in the range 0.8–0.9, whereas in the forestry areas famous for widely spaced stands, thinning is carried out when the yield ratio is in the range 0.5–0.6. In Fiji, on the other hand, thinning is carried out in order to maintain a fixed range of basal area for any given predominant mean height. This is the biggest difference in thinning methods between Fiji and Japan.The Stand Density Control Diagram can use both thinning methods, but in Fiji one factor in deciding the thinning requirement is the predominant mean height, and the Stand Density Control Diagram does not show this. Therefore the average tree height can be used instead of the predominant mean height.

Factor (4) in section 3.1, ease and cost of thinning operation, involves the reduction of thinning operations to the minimum, and the greater the thinning quantity for one thinning operation, the lower the cost. Also the timber from thinning can then be produced in larger quantities, thus reducing the fixed cost element.

Factor (2) in section 3.1, healthy growth of stand during the growing period, involves encouraging healthy growth, preventing blight, insect damage and weather damage, by controlling the density of the stand to maintain the optimum density. In order to decide what sort of stand density is most suitable, the relationship between the abnormal tree ratio and stand density in the sample plot survey is shown in Figure 3.5. The numbers in the figure represent tree height As an explanation of this graph, the sample areas with greater number of trees per hectare have a greater number of abnormal trees. This indicates that the greater the stand density, the greater the number of abnormal trees. This is only to be expected. Where the number of trees per hectare is more than 1000, a smaller number of abnormal trees is found among trees of small average height, than among trees of greater average height. With regard to stands with less than 1000 trees per

Fig. 3.4 Thinning amounts for cases 1 and 2

	Case 1	Case 2
1st	4 5 m³	5 0
2nd	4 5	2 0
3rd	8 0	1 5
4th		6 0
Total	1 7 0	1 4 5

Fig. 3.5

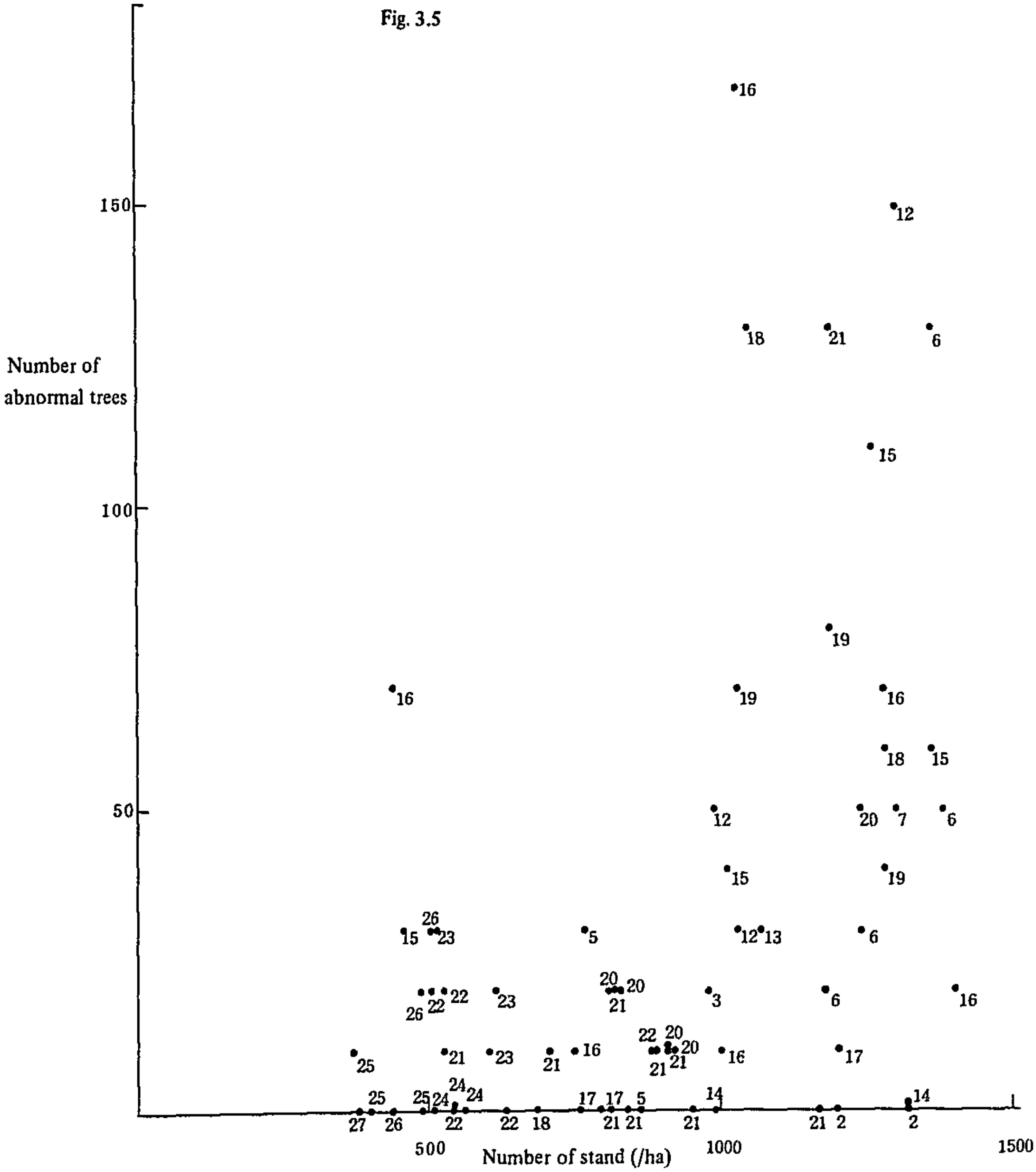
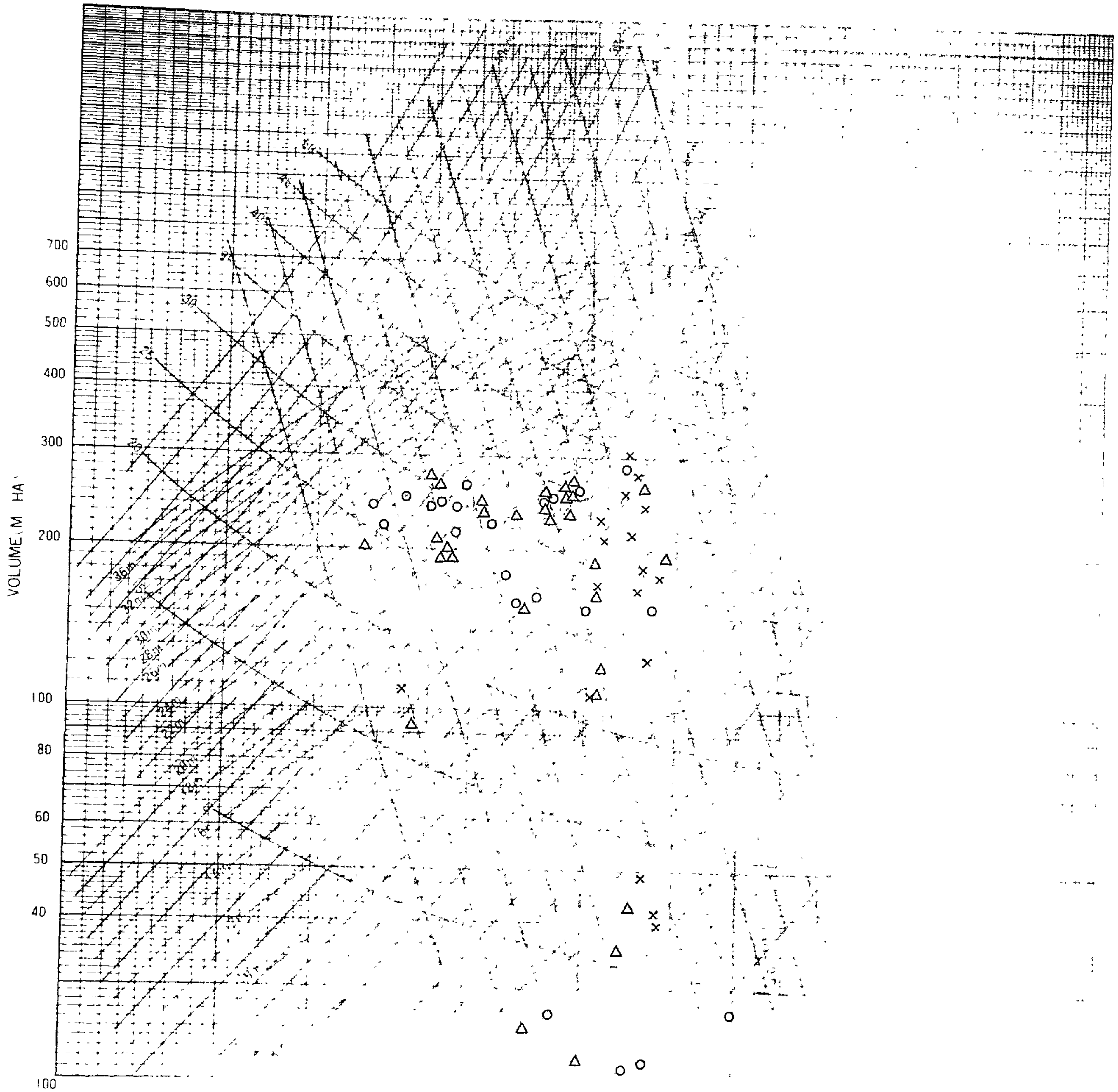


Fig. 3-6



hectare, the reverse is true; the greater the average height, the smaller the number of abnormal trees This indicates that for each stage of stand growth (height category), there is an optimum number of trees per hectare. When the relationship between average tree height, number of trees per hectare and number of abnormal trees is shown on the Stand Density Control Diagram, the result is as shown in Figure 3.6. In the figure, crosses (x) indicate over 50 abnormal trees per hectare, triangles (Δ) indicate 10–40 abnormal trees per hectare, and circles (O) indicate no abnormal trees It is clear that a large number of abnormal trees occur in stands having a large number of trees per hectare. Stands having a large number of trees per hectare are considered to produce a lot of trees that die out naturally through competition, but as mentioned in section 1.4.4., trees that die out naturally compose only 20% of all abnormal trees, thus it is estimated that cyclone damage is more widespread in stands having a large number of trees per hectare. Here, factor (3), matching of timber produced to the standard required according to use, is considered.

Table 3-5 Standard use for Caribbean Pine

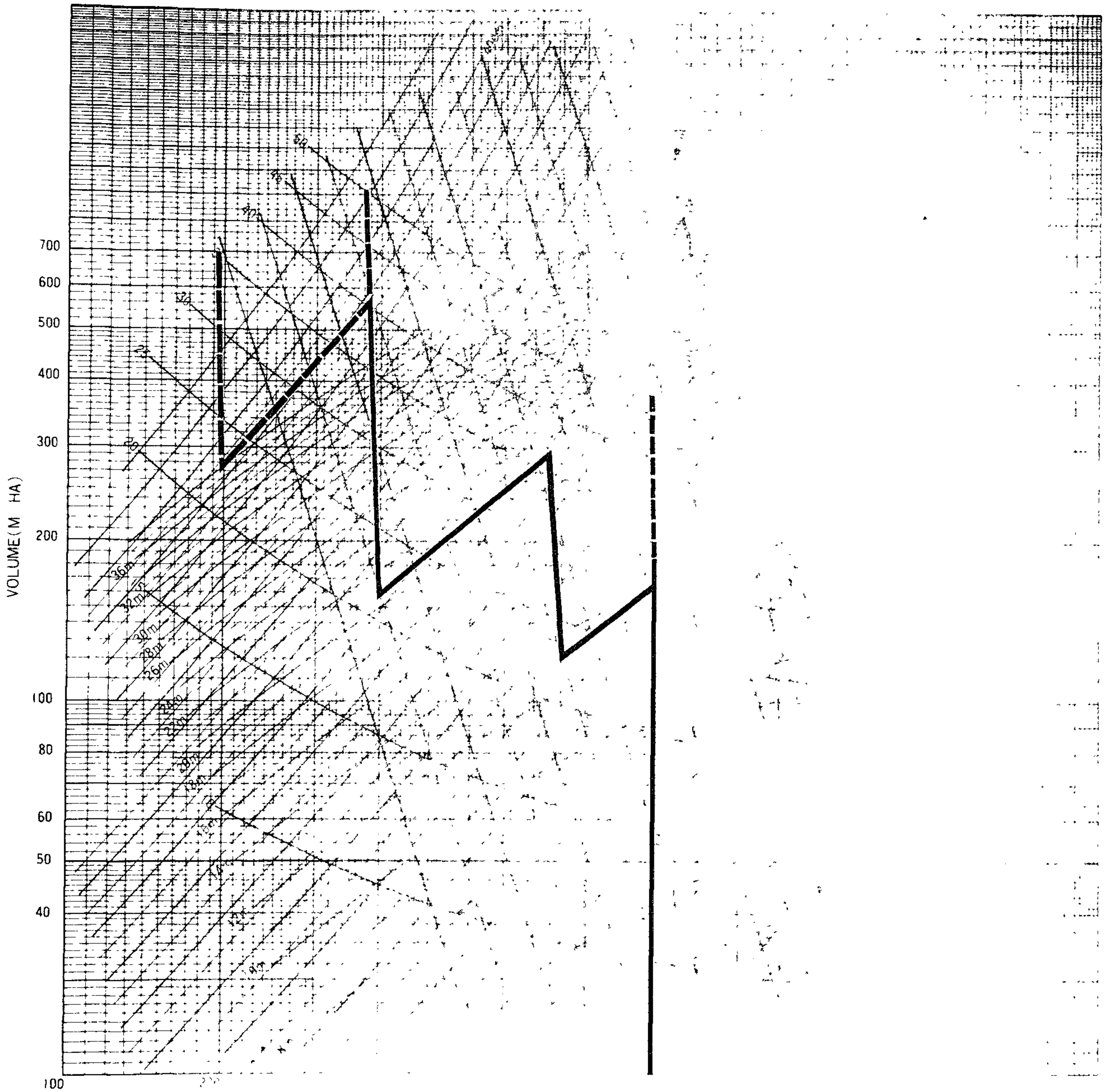
Use	Diameter	Length
Fence posts	1 0 cm<	1. 5 ～ 2. 0 m
Foundation	2 0 ～ 3 5 cm	1. 5 ～ 2. 0 m
House pillar	1 5 cm<	4. 0 ～ 6. 0 m
Fruit tree supports	1 5 ～ 2 0 cm	2. 5 ～ 4. 0 m
Telegraph pole	2 0 cm<	6. 0 ～ 8 5 m
Pulp	1 0 cm<	1. 5 m<

Table 3.5. shows the current standard use in Fiji for Caribbean Pine. And that is given in order of frequency of use. Of these, thinning timber can be used for fence posts, fruit tree supports, and pulp, etc. and these uses will probably require a minimum 14–16 cm stand diameter breast height including bark. Also the maximum diameter according to Table 3.5 is reckoned to be about 40 cms, but taking into account the opening of the plywood factory, the use value of very large diamenter trees (diameter breast height over 60 cm) is likely to be high.

The following is a summary of methods of satisfying the previously mentioned four factors individually.

1. In order to maximize the total stand yield, thinning should be carried out as infrequently as possible, and heavy thinning should be carried out at a time when the stand density is as high as can be allowed.
2. In order to maintain healthy growth of the stand during the growing periods, in the early stages the density can be high, but when the average height exceeds 14–15 m, the number of stumpage per hectare should be less than 1000.
3. In order to match the timber produced to the standard required according to use thinning should not be carried out until the diameter breast height of low class trees exceeds 14 cm With regard to large diameter trees, there is a limited number of uses for trees with diameters breast height in the range 40–60 cm, so these are not accepted.

Fig. 3-7


700
600
500
400
300
200
100
80
60
50
40
100
VOLUME (M HA)
36m
32m
30m
28m
26m

4. In order to economize on thinning costs, thinning should be carried out as infrequently as possible, and thinning quantities at any one time should be heavy.

By putting all these condtions together, the most suitable thinning line can be constructed and drawn on the Stand Density Control Diagram. Figure 3.7 shows the result, which indicates that, in order to obtain a diameter breast height of the thinning timber of about 14 cm. The first thinning should be carried out when the average diameter breast height is 17 cm, and should leave 900 trees per hectare after first thinning. The second thinning should be carried out when the average diameter breast height is 24 cm, to leave 400 trees per hectare after thinning. If the stand is required to have a diameter breast height of 38 cm at final cutting, no further thinning is required. However, if a diameter breast height of over 60 cm is required, a third thinning should be carried out when the average diameter is 38 cm, leaving 200 trees per hectare. This is shown in Table 3.6.

Table 3.6 Guide of optimum thinning

	Before thinning			After thinning			thinning volume
	average height.	number of stand	basal area	average height	number of stand	basal area	
1st	14 m	1,320	30 m²	13 m	900	33 m²	50 m³/ha
2nd	23	850	37	21	400	22	140

Furthermore, if pulp timber is to be produced, the stand should be left without thinning until the average tree height reaches 24 m. The cutting cycle for this situation is estimated from Figure 1.4 to be 18 years.

The choice of optimum thinning amount is a particularly difficult one. Although a thinning line can be produced on the Stand Density Control Diagram, because this diagram is obtained using the method of least squares, it may not match the individual stand; also this Stand Density Control Diagram was created from the results from 69 sample plots and cannot therefore be said to represent fully the stand composition. According to the site conditions, the time or amount of thinning will differ from stand to stand, but fortunatelly, in the Stand Density Control Diagram there is no tree age factor, and the stand average tree height is used as a measure to decide the thinning time.

If the thinning method used in Fiji is drawn on the Stand Density Control Diagram, taking into account the various conditions, it is shown to be an appropriate method. However, in relation to individual considerations, there is still room for improvement. One of these considerations is the cost of thinning, and it seems that a reduction in the number of thinning operations would be an improvement, with two thinning operations being sufficient. This would be more appropriate considering the present labour force.

As has already been said, the Stand Density Control Diagram is very useful in studies on thinning guidance, but it is also useful in explaining the average stand composition. For example, if the average diameter breast height is 22 cm, at 800 trees per hectare, it provides information on average tree height, being 18 m, volume, being 200 m^3/ha., and basal area, being 29 m^2/ha , etc. From the number of trees per hectare and average tree height, a yield quantity estimation is possible, and a yield estimation table can be drawn up.

Also, indivídaual stands can be monitored. In other words, by reading off the volume and average diameter breast height from the Stand Density Control Diagram with regard to the stand for which the average tree height and number of trees per hectare is known, and by comparison with the actual stand values, an indication is given regarding that stad's condition in relation to the norm

In Japan, the slope of Ry on the Stand Density Control Diagram is less steep for Pinus densiflora SIEB et ZUCC. than that for Caribbean Pine. This is because the number of trees planted per hectare is large, being 3000–4500 per hectare. With regard to Caribbean Pine in Fiji, as shown in Figure 1.7 and by the line of natural thinning on the Stand Density Control Diagram, competition begins to occur fairly late in the growing stages. In the earlier stages of growth, if the stand is well spaced, very fast diameter growth takes place and the annual ring is wide, and the timber becomes undersirably uneven.

The above thinning guidance was developed from data obtained from survey results over one month, and with reference to existing Japanese thinning methods.

With regard to Caribbean Pine, personnel in Fiji have a great deal of experience, and a large amount of data, so it is hoped that a system of thinning will be established, with reference to the method explained in this report, aided by the addition of new data.

4. OTHER

The following points regarding the planting number are suggested

The Caribbean Pine planting number currently used in Fiji is 1350/ha , the reasons for this figure being a saving on labour requirements for thinning, and planting rows being wide enough for machinery access However the annual ring indicates that at early stages of growth, the diameter growth rate is very high, and Figures 1 6 and 1 7 indicate a need to increase the planting number somewhat. In the future, new plantations can be created on mountain slopes, and, as the present record for planting on slopes is not very good, with problems of trunk bending and poor machinery access, for these reasons there is a need to reconsider the planting number.

The panorama from the fire tower in compartment 3

JICA