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The Estimation of Growing Stock by Systematic Line-Plot Sampling and Stand Growth by Increment Core Survey of the State Forest in Águas de Santa Bárbara, São Paulo †

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The state forest in São Paulo, Águas de Santa Barbara, are mostly covered by pine plantation. Since all of these forest are the first plantation, there is still no establishment of the estimation method for their growing stock and growth of forest stand. Forest inventory by sampling has never been conducted yet. In this study, the systematic line-plot sampling, which is an effective method for the estimation of growing stock, has been experimentally applied on a stand of 1 Talhao (25 ha). Further, for the growth of forest stand estimation, the increment core survey was also conducted. In studies area, 35 plots of 0.04 ha has been investigated, and for the growth of forest stand estimation 105 stem of sample trees have been measured. The survey was conducted by a team consists of 4 persons, during 5 days. As the result, the estimated values for the mean and total number of trees, and for the mean and total volume (per 1 Talhao) are as follows. (1) Number of trees ; (i) per ha for $t_{.05}$: 937.5 i37.1, for $t_{.01}$: 937.5f49.9. (ii) Per 1 Talhao for $t_{.05}$: 23438±927, for $t_{.01}$: 23438±1248. (2) Volume(m^3) ; (i) Per ha for $t_{.05}$: 153.93±22.39, for $t_{.01}$:153.93±30.15. (ii) Per 1 Talhao for $t_{.05}$: 3848.3t559.6, for $t_{.01}$: 3848.3±753.7. Further, the plot sampling error for number of trees and volume are equal to 3.95 % and 14.54 %, respectively. The coefficient of variation for number of trees and volume are equal to 11.86 % and 43.37 % respectively. Regarding the growth of forest stand, it was found that the growth of forest stand per ha to be 14.3718 m^3, and the per 1 Talhao is equal to 359.2946 m^3. The corresponding growth percent of forest stand is equal to 9.27 %. The total time spent for the measurement of 32 plots, as presented in Table 2, was amount to 851 minutes, where 1 plot at average takes 26.6 minutes.

INTRODUCTION

The accurate estimated values for number of trees, growing stock and growth of forest stand is a very important factor to be applied as the basic information for the forest treatment activities, cutting, marketing planning and forest management planning.

As for the methods for the survey of growing stock in forest stand as well as the growth of forest stand, there are several methods like the survey of every tree, the

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survey of the standard area, the sampling survey, etc. Generally, the purposes of the forest survey are divided into : (A) survey for the aquisition, sale, etc. of forest land, (B) survey for cutting or sale, etc., (C) survey for the management plan, (D) large scale survey to grasp natural resources, etc., and (E) special survey for the change in tree species, the determination of forest area, and to grasp the damaged area due to plant diseases, insects, calamity by wind or fire, etc.

As for the survey method of case (B), São Paulo forest board provided a sample section of 1 ha (100 m x 100 m) in a part of 1 Talhão (500 m x 500 m = 25 ha) in Águas de Santa Barbara state forest. Then the whole in a sample section were cut and measured, whereby the estimation for the whole area was made from the result. Since this method required much labour and expense, the field test of systematic line-plot sampling was conducted, which was one of sampling method, and effective for both purposes of (B) and (C) above. Besides, the estimation on the growth of forest stand was also executed by increment core measurement. Thus it was examined whether the above survey could be supplied to the forest content in the field, and at the same time the training of the survey method was carried out.

MATERIALS AND METHODS

1. Survey plan

1) Subject area of survey

Talhão No. 8 in Águas de Santa Barbara state forest in São Paulo state was selected as the subject area. This locates in the almost center of the state forest, with its area of 25 ha (500 m x 500 m). The tree species is *Pinus elliottii*, planted 1961-1962, 20 years age at the time of survey (1982). The number of trees planted is 4400/ha (1.5 m x 1.5 m), and thinning was carried out by 50 % (2200 trees, 21 m^3) at first in 1970, and by 50 % (1100 trees, 56 m^3) at the second time in 1978. Since a part of the forest suffered the calamity of fire in 1979, and there are paticularly some damp area in the forest, so the state growth is not so good. The lay of the land is almost flat.

2) Survey programme

(1) Programme for systematic line-plot sampling

In the programme for the estimation of growing stock by systematic line-plot sampling, (a) Area of forest stand to be surveyed : A= 500 m x 500 m=25 ha, (b) Coefficient of variation of forest stand : C =30%, (c) Aimed accuracy (allowable error ratio) : e= 10 %, (d) Plot area : a=0.04 ha. On the basis of the above, the following were set.

① Number of sampling in the survey plot :

$$n = \frac{4C^2A}{e^2A+4aC^2} = \frac{4\times(30)^2\times 25}{(10)^2\times 25+4\times 0.04\times(30)^2} = 34.039 \fallingdotseq 34$$

② Sampling error of plot sampling :

$$e = 2C\sqrt{\frac{A-na}{nA}} = 2\times 30\sqrt{\frac{25-34\times 0.04}{34\times 35}} = 10.006 \fallingdotseq 10.01(\%)$$

③ Sampling ratio of plot :

$$p = \frac{n}{N} \times 100 = \frac{na}{A} \times 100 = \frac{34 \times 0.04}{25} \times 100 = 5.44\ (\%)$$

④ Distance of plot sampling :

$$d \doteqdot \sqrt{\frac{A}{n}} \times 100 = \sqrt{\frac{25}{34}} \times 100 = 85.749 \fallingdotseq 85\ (\mathrm{m})$$

⑤ Radius in case of circle Plot :

$$r = \sqrt{\frac{a\ (\mathrm{m}^2)}{\pi}} = \sqrt{\frac{400}{3.14159}} = 11.2838 \fallingdotseq 11.28\ (\mathrm{m})$$

When the number of sampling in a plot is less than the calculated number (34), it may cause to lessen the accuracy. Therefore, to prevent low accuracy, it is desirable to take less distance than the calculated sampling distance (d), resulting the increase in the number (n). This is because only 85 m of distance was taken instead of the

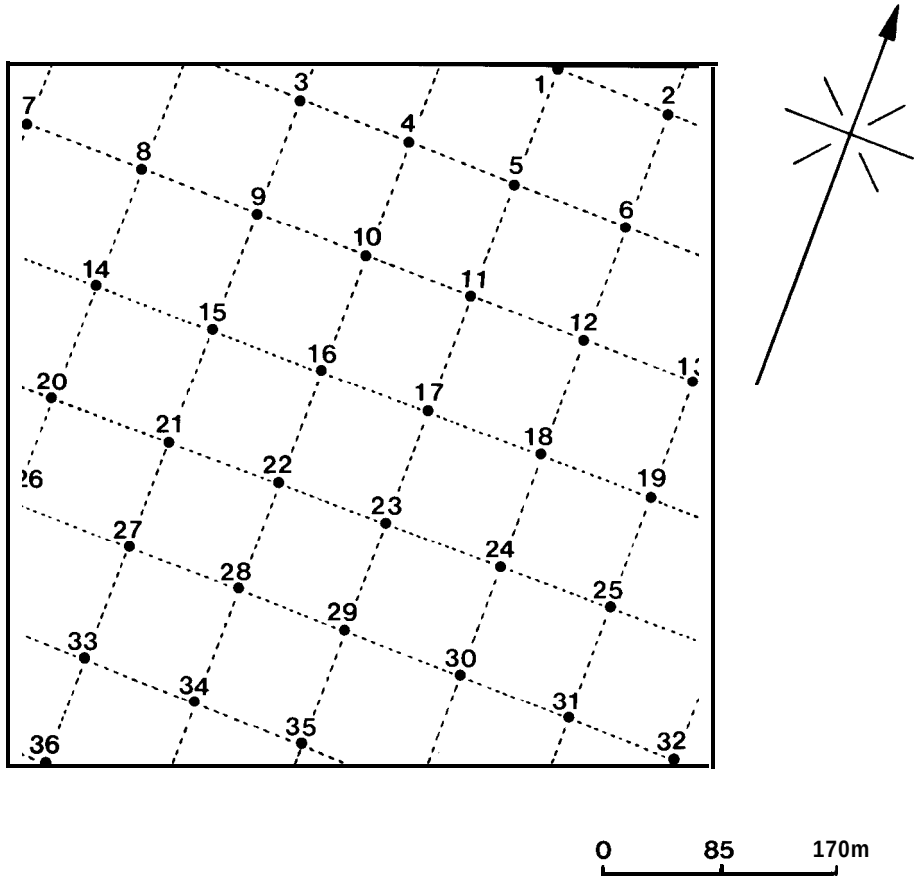


Fig. 1. **Plot setting position** (Talhão **No. 8).**

calculated distance $d = 85.749$ m in this example. Thus, the actual number of sampling became to be 31 as shown in Fig. 1. Further, the plot area a = 0.04 ha means 20 m × 20 m when it is a square plot area. However, in a actual case, as a circle plot is simpler in sectioning and setting than a square plot, and saves time, we adopted a circle plot, with its calculated radius of 11.28 m.

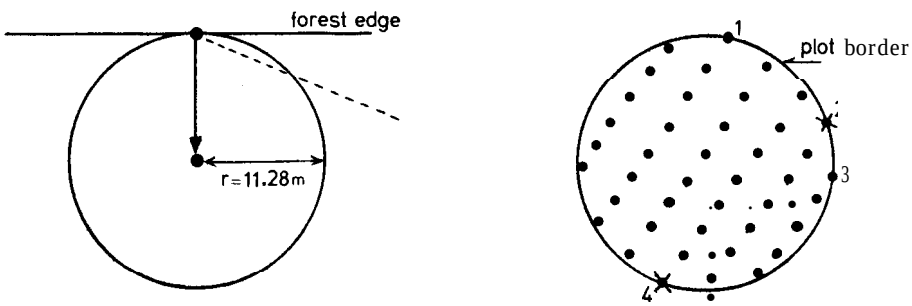
Fig. 1 illustrates on a plan, that 36 survey plots were set on the surveyd forest stand Talhão No. 8. The direction of sampling is, on basis of northern magnetic pole N, in direction of east-west and north-south. Plot No. 2 is the starting point. From the north-eastern end of forest section, the starting point extends 50 m southward (measured on the plan view) along the edge of the forest. From that point, it enters 30 m westward (also measured on the plan view) into the forest section in right angle, then the point is made to become the center of plot. Fig. 2 shows a case (i) when the plot center falls in the edge of forest, and treatment of trees (ii) in the border of plot.

(2) Programme for increment core survey

The increment core survey for the estimation of the growth of forest stand was carried out by select 3 sample trees of tree number 1, 11, and 21 every plot, take out the core (growth core) for last 10 years at the breast height (1.3 m) by increment borer, and measure the growth in millimeter. In addition, the thickness of bark at the same position was measured by a bark gauge in millimeter at the same time. In order to prevent the variation in the taken out direction, the direction toward the center of plot was always maintained for measurement.

(3) Equipment and field book

The following equipment and a field book were used in the survey on the forest stand based on the above programme. ① Equipment : a pocket compass, a tripod, a measuring rope (100 m), a calliper (65 cm), a hypsometer (Spiegel relascope), tape (20 m), chalk, an increment borer, a bark gauge; a scale (30 cm). ② Field book : a field book, which was made as with the from shown in Table 1, was used for the every tree survey within the plot and the increment core survey (The filling example sows a part of Plot No. 1). Every remarks on each plot were written in different pages in the field



(i) When plot center falls on forest edge, the center is removed for the survey.

(ii) Treatment when a tree is located on plot border.

Fig. 2. Treatment of plot center on forest edge and a tree on plot border.

book. Core, bark and *CD* were to be written only on the sample trees. By the way, volume (v) was to be written at the indoor work after the survey.

Table 1. Plot survey field book and its filling up example (A part of plot No. 1).

No. 1-1

Plot No. : 1, Talhão No. : 8, Data : 08--11--1982

No.	*DAP* (cm)	*H* (m)	*v* (m^3)	Core (mm)	Casca (mm)	*CD* (m)	Nota
1	20.7	16.2	(0.274)	28.0	15.0	2.90	
2	14.6	13.5	(0.122)				Ponta bifurcado
3	21.3	15.5	(0.274)				
4	16.4	15.8	(0.162)				
5	17.7	15.3	(0.188)				
6	21.5	15.5	(0.300)				Ponta bifurcado
7	18.8	16.3	(0.225)				Ponta sêca
8	18.5	16.5	(0.242)				
9	23.7	18.0	(0.408)				
10	16.0	15.7	(0.162)				
11	18.1	16.7	(0.218)	28.0	12.0	3.40	
12	17.6	15.7	(0.203)				
13	20.8	17.0	(0.294)				
14	15.1	17.5	(0.163)				
15	17.0	16.7	(0.193)				
16	16.3	14.5	(0.150)				
17	21.1	17.0	(0.294)				
18	20.8	17.0	(0.294)				
19	15.9	16.2	(0.162)				
20	20.7	16.5	(0.294)				
21	19.1	17.5	(0.258)	23.0	18.0	2.70	
22	19.8	16.7	(0.267)				Ponta bifurcado
23	17.6	15.8	(0.203)				

2. Field survey

1) Measurement with a measuring line and setting of plot section

Measuring line for plot setting was conducted with a pocket compass. In this case, when the center of plot falls outside the forest edge even a little, the plot will be discarded. On the contrary, when it falls inside, the plot will be surveyed. If it falls just on the edge, that makes 0.5 plot, therefore, in this case the first plot will be measured, while the second plot will be discarded, and thus this will be regarded as 0.5 plot. In this example, since Plot No. 1 and Plot No. 26 were applicable, while Plot No. 26 was discarded.

When the center of plot is determined, a circular plot with its radius r= 11.28 m was marked out and set. In this case, by using a tape of a length of 20 meters, trees within the plot will be marked a circle, while trees outside the plot will be marked $\times$, indicating the border of a plot. In this way, taking the center as its center of the circular plot, when the marking as above completes to go around the center, the marking out of a plot is completed. Hence, the trees on the border of a plot will be counted at 0.5, i. e. the first tree will be measured, while the second will be discarded.

2) Every tree measurement within a plot and increment core survey

In the every tree survey within a plot, a diameter at breast height (DAP) was measured at 1.3 m height with bark (Corn casca) with a calliper in centimeter to one-tenth of the unit, and the height (H) was measured with a Spiegel relascope to 0.1 m in precision. Further, any forked or dead-top trees were indicated in the colum of Nota. Dead trees were omitted. In this way, 35 plots were measured.

In a increment core survey, out of sample trees (3 trees were taken from every plot), the core taken for last 10 years, i.e. for 10 years growth from outside, was measured in millimeters, and the bark was also measured with a bark gauge in millimeters. The reason why Tree No. 1, 11, and 21 were systematically selected as sample trees was intended to prevent any possible concentration on small diameter trees or large. The number of data thus collected (sample trees) was 35 plot x 3 = 105. On these sample trees, the crown diameter (CD) also was measured in 0.1 m as reference.

3) Schedule of survey

The field survey is divided broadly into 4 categories of a measure line measurement, plot-section setting, every-tree survey, and increment core survey. The length of the period required for the survey for each item may differ depending on the state of forest section, land configulation, the survey team members and their skill etc. However, if the schedule of survey, i. e. the length of the survey period, is fixed, that will be a good reference in future, in case similar survey is planned and conducted. Therefore, in parallel with the survey on forest sections, schedule examination was practised, the result of which was shown in Table 2.

From the results in Table 2, for 32 plots as the subjects of summing for 4 survey items (33 plots only for the measure-line measurement) the total hours required for survey (Xx), the average time per plot ($\bar{x}$), and standard deviation (SD) (all in minutes) were as indicated the last column in the Table 2. From these data, the ratio of each item period against the total required time were 21.62 % for the measure-line measurement, 16.57 % for the plot section setting, 34.67 % for the every tree survey and 27.14 % for the increment core survey, respectively. Further, it seemed that in the project

Table 2. Results of survey procedures.

Date	Plot No.	Measurement with a measuring line (85m)	Setting of plot section	Every tree survey	Increment core survey	Total	Remarks (persons)	Date	Plot No.	Measurement with a measuring line (85m)	Setting of plot section	Every tree survey	Increment core survey	Total	Remarks (persons)
		min.	min.	min.	min.	min.				min.	min.	min.	min.	min.	
11.19	6	10	5	12	8	35	4	11.24	24	5	4	9	6	24	4
〃	12	7	4	11	11	33	〃	〃	23	5	4	7	8	24	〃
〃	13	6	5	11	11	33	〃	〃	22	5	4	8	6	23	〃
11.20	11	5	5	9	8	27	〃	〃	21	5	5	9	6	25	〃
〃	10	4	4	8	10	26	〃	〃	20	7	5	9	6	27	〃
〃	9	5	4	13	8	30	〃	〃	30	5	4	9	5	23	〃
〃	8	7	5	10	8	30	〃	〃	29	5	4	9	7	25	〃
〃	7	7	4	11	6	28	〃	〃	28	5	3	9	6	23	〃
〃	4	6	6	11	7	30	〃	11.25	27	5	3	7	6	21	〃
〃	3	6	4	8	9	27	〃	〃	26	(5)	—	—	—	—	(discarded)
11.23	14	7	4	14	9	34	〃	〃	33	4	4	8	6	22	4
〃	15	7	4	7	8	26	〃	〃	36	6	4	9	6	25	〃
〃	16	4	4	9	6	23	〃	〃	34	6	6	9	8	29	〃
〃	17	5	4	8	6	23	〃	〃	35	6	5	6	8	25	〃
〃	18	7	5	12	7	31	5								
〃	19	7	5	7	6	25	〃	n		33	32	32	32	32	
〃	25	5	5	9	6	25	〃	$\sum x$		189	141	295	231	851	
〃	31	5	5	7	7	24	〃	$\bar{x}$		5.727	4.406	9.129	7.219	26.594	
11.24	32	5	4	10	6	25	4	SD		1.2317	0.7121	1.8792	1.5395	3.7058	

survey schedule per day, in case of a team consisting of 4 members, the schedule from 7-8 plots to about 10 plots would be carried out as the staff personnel become well acquainted in the task.

RESULTS

1. Summarization of number of trees and volume by plot

As the result of the field survey conducted in the above methods, the number of plots actually measured was 35. On these 35 plots, the volume was calculated for each plot, by the following formula of total tree volume with bark that was made on basis of 100 sample trees of *Pinus elliottii* in the same Águas de Santa Barbara state;

$$V = 0.00674609 - 0.00012281\ D^2 + 0.00004552\ D^2H$$

The volumes were summed up for each plot, and shown in Table 3. Besides volume (V), regarding diameter at breast height *(DAP)* and height *(H)*, the total values and the mean values per tree *(D, H* and $\bar{v}$) were calculated and shown in Table 3.

2. **Estimation on number of trees and volume**

The results of the estimation on number of tree and volume were, from Table 3, as follows. In this case, the forest stand as the subject of the survey was *Pinus elliottii* only. Therefore, the estimation was also limited to one species of *Pinus elliottii.*

1) Estimation on the number of trees

① Average number per plot :

$$\bar{x} = \frac{\sum (x)}{n} = 37.5 \text{ (trees)}$$

② Variance :

$$V(\bar{x}) = s^2_{\bar{x}} = \frac{\sum (x - \bar{x})^2}{n(n-1)} \cdot \frac{N-n}{N} = 0.5273$$

③ Standard error :

$$SE(\bar{x}) = \sqrt{s^2_{\bar{x}}} = 0.7261$$

④ Standard error ratio :

$$e(\bar{x}) = \frac{SE(\bar{x})}{\bar{x}} \times 100 = 1.93\ (\%)$$

⑤ Estimation on the number of trees per ha :

$$X_{(ha)} = \frac{1}{a}\{\bar{x} \pm t \cdot SE(\bar{x})\}$$

if $n-1=34$, then $t_{.05}=2.042, t_{.01}=2.750$ hence,

for $t_{.05}$, $X_{(ha)} = 937.5 \pm 37.1$ (trees)

[range of estimation : 900.4-974.6 (trees)]

for $t_{.01}, X_{(ha)} = 937.5 \pm 49.9$ (trees)

(range of estimation : 887.6-987.4 (trees)]

Table 3. Over-all table of trees and volume of each plot.

No.	Plot No.	Number of trees (x)	*DAP*		*H*		Volume (y)	
			Total	*D*	Total	*H*	Total	$\bar{v}$
				cm		m		m^3
1	1	38	724.8	19.1	616.3	16.2	9.0055	0.2370
2	2	32	504.3	15.8	417.7	13.1	4.3121	0.1348
3	3	42	567.7	13.5	482.8	11.5	3.9612	0.0943
4	4	33	444.5	13.5	382.2	11.6	2.7746	0.0841
5	5	40	619.9	15.5	491.1	12.3	4.7256	0.1181
6	6	43	553.1	12.9	431.3	10.0	2.8823	0.0670
7	7	42	769.7	18.3	707.0	16.8	9.7568	0.2323
8	8	37	693.3	18.7	599.0	16.2	8.6412	0.2335
9	9	37	355.2	9.6	253.9	6.9	1.1387	0.0308
10	10	28	357.5	12.8	289.2	10.3	1.9646	0.0702
11	11	38	489.7	12.9	361.3	9.5	2.4080	0.0634
12	12	34	551.6	16.2	469.1	13.8	5.2163	0.1534
13	13	40	485.7	12.1	359.6	9.0	2.1026	0.0526
14	14	36	682.5	19.0	586.7	16.3	8.5499	0.2375
15	15	33	496.6	15.0	394.3	11.9	3.7037	0.1122
16	16	41	660.5	16.1	589.3	14.4	6.1271	0.1494
17	17	38	511.1	13.5	414.0	10.9	2.9889	0.0787
18	18	36	565.0	15.7	469.6	13.0	4.7552	0.1321
19	19	38	527.5	13.9	457.0	12.0	3.7418	0.0985
20	20	41	720.1	17.6	651.5	15.9	8.1471	0.1987
21	21	34	620.4	18.2	530.2	15.6	7.1329	0.2098
22	22	38	638.1	16.8	544.6	14.3	6.2640	0.1648
23	23	28	506.1	18.1	440.0	15.7	5.7903	0.2068
24	24	38	625.0	16.4	561.4	14.8	6.2245	0.1638
25	25	38	640.6	16.9	557.5	14.7	6.4746	0.1704
26	27	34	588.7	17.3	529.3	15.6	6.5124	0.1915
27	28	43	759.0	17.7	666.3	15.5	8.4760	0.1971
28	29	43	779.9	18.1	682.2	15.9	9.0016	0.2093
29	30	43	790.3	18.4	729.6	17.0	10.0839	0.2345
30	31	36	644.6	17.9	604.1	16.8	8.2750	0.2299
31	32	37	656.9	17.8	614.3	16.6	7.9184	0.2140
32	33	43	772.6	18.0	692.1	16.1	8.3135	0.1933
33	34	44	816.9	18.6	728.9	16.6	10.3237	0.2346
34	35	28	586.7	21.0	484.5	17.3	8.6458	0.3087
35	36	40	749.6	18.7	650.2	16.3	9.1647	0.2291
Σ	35	1314	–	–	–	–	215.5045	

⑥ Estimation on the number of trees per the subject area of survey (25 ha) :

$$X_{(25ha)} = \frac{A}{a}[\bar{x} \pm t \cdot SE\ (x))$$

for $t_{.05}$, $X_{(25ha)}$ = 23438 ± 927 (trees)

[range of estimation : 22511-24365 (trees)]

for $t_{.01}$, $X_{(25ha)}$ = 23438 ± 1248 (trees)

[range of estimation : 22190-24686 (trees)]

⑦ Error ratio of plot sampling :

$$E(x) = \frac{t \cdot \sqrt{V(\bar{x})}}{\bar{x}} \times 100 = 3.95\ (\%)$$

⑧ Coefficient of variation :

$$CV\ (x) = \frac{\sqrt{s^2_x}}{\bar{x}} \times 100 = 11.86\ (\%)$$

2) Estimation of volume

① Average volume per plot :

$$\bar{y} = \frac{\sum (y)}{n} = 6.1573\ (m^3)$$

② Variance :

$$V(\bar{y}) = s^2_{\bar{y}} = \frac{\sum (y-\bar{y})^2}{n\ (n-1)} \cdot \frac{N-n}{N} = 0.19231$$

③ Standard error :

$$SE\ (\bar{y}) = \sqrt{s^2_{\bar{y}}} = 0.4385$$

④ Standard error ratio :

$$e\ (\bar{y}) = \frac{SE\ (\bar{y})}{\bar{y}} \times 100 = 7.12\ (\%)$$

⑤ Estimation on volume per ha :

$$Y_{(ha)} = \frac{1}{a}[\bar{y} \pm t \cdot SE\ (\bar{y})]$$

for $t_{.05}$, $Y_{(ha)}$ = 153.93 ± 22.39 (m^3)

[range of estimation : 131.55-176.32 (m^3)]

for $t_{.01}$, $Y_{(ha)}$ = 153.93 ± 30.15 (m^3)

[range of estimation : 123.79-184.08 (m^3))

⑥ Estimation on volume per the subject area of survey (25 ha) :

$$Y_{(25ha)} = \frac{A}{a}[\bar{y} \pm t \cdot SE(\bar{y})]$$

for $t_{.05}, Y_{(25ha)} = 3848.3 \pm 559.6\ (m^3)$

[range of estimation : *3288.7-4407.9* (m^3)]

for $t_{.01}, Y_{(25ha)} = 3848.3 \pm 753.7\ (m^3)$

[range of estimation : *3094.6-4602.0* (m^3)]

⑦ Sampling error of plot sampling:

$$E(\bar{y}) = \frac{t \cdot \sqrt{V(\bar{y})}}{\bar{y}} \times 100 = 14.54\ (\%)$$

⑧ Coefficient of variation :

$$CV(y) = \frac{\sqrt{S^2_y}}{\bar{y}} \times 100 = 43.37\ (\%)$$

3. **Frequency distribution of the** number of trees by grade of diameter

To make the frequency distribution of the number of trees by grade of diameter is not only a good reference to know how many trees of a certain diameter are growing, but also furnishes basic data for calculation of commercial volume relating to the tree height, and data for the labor plan of cutting and lumbering, for a plant site, and for a carry-out plan. This time, mainly intending to use as materials for the next estimation on the growth of forest stand, as shown in Table 4, we calculated diameters by grade per plot, from the data of every tree survey in 35 plots in the field survey. We grouped trees with diameter every two centimeters, like 2, 4, 6, …… 24, 26, 28. Since the diameter was measured in millimeter, for example, the group of 10 cm diameter would include 9.0-10.9 cm, and 12 cm diameter would include 11.0-12.9 cm, like that.

4. Estimation on forest stand growth

The estimation on the forest stand growth was made by the increment core survey which was conducted in parallel with the plot survey. Using 105 samples of cores, this was carried out in the following way.

1) Calculation of diameter growth

The diameter growth for each of 105 samples is calculated at first, then the diameter growth as a whole will be calculated by the diameter growth regression formula.

① Under bark diameter :

$$d = D\text{-}2b$$

where, D : diameter with bark, b : thickness of bark

② Under bark diameter of the middle part for a determined period :

$x = d - 1L$

where, L : length of core for 10 years

③ Under bark average diameter growth :

$y = 2L / 10$

④ Diameter with bark at the determined period middle part :

$X = K \cdot x$

Table 4. Distribution of frequency of number of trees by diameter grade of each plot,

Plot No.	Grade of diameter (cm)														Total
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	
1							1	6	13	11	4	2	1		38
2						5	9	6	8	1	3	–	–		32
3		1	1	5	2	10	6	8	8	–	_	1	–		42
4	–	–	–	–	3	10	13	5	2	–			–		33
5	–	–	–	–	1	6	10	10	8	5	–	–	–	–	40
6	–	–	–	–	9	15	13	4	1	–	1	–	–	–	43
7							5	9	11	8	8	–	1	–	42
8	–	–	–	–	–	–	2	8	14	5	5	1	1	1	37
9	1	1	4	10	10	7	2	–	1	1	–	–	–	–	37
10	–	–		1	6	10	5	4	2	–	–	–	–	–	28
11				3	7	10	11	3	4	–	–	–	–	–	38
12	–	–	–	–	1	5	4	15	2	3	3	–	1		34
13		–	–	4	8	13	12	2	1	–	–	–	–		40
14	–	–	–	–	–	_	2	6	12	7	7	1	1		36
15	–	–	–	1	2	4	10	7	5	4	–	–		–	33
16	–	–	–	–	1	2	8	15	10	5	–	–	–	–	41
17		–	–	–	4	14	13	3	3	1	–	–	–		38
18	–	–	–		1	7	9	5	6	7	1	–			36
19	–	–	1	1	5	7	12	5	4	2	1	–			38
20	–	–	–	–	_	1	5	11	11	8	4	1	–	–	41
21							3	6	11	9	4	1	–	–	34
22	–	–	–	–	1	2	4	16	6	6	2	1	–	–	38
23	–	–	–	–	–	_	3	6	8	7	4	–	–	–	28
24	–	–	–	–	1	1	9	10	13	2	1	–	1	–	38
25	–	–	–	–	_	2	9	7	11	5	3	1	–	–	38
27	–	–	–	–	1	1	2	11	12	4	2	–	1	–	34
28	–	–	–	–	_	1	6	14	11	4	4	3			43
29						1	2	12	14	7	6	1			43
30	–	–	–	–	–	_	4	10	11	9	9	–			43
31	–	–	–	–	–	_	3	6	14	6	5	2	–	–	36
32		–	–		_	–	4	14	5	8	6	–	–		37
33	–	–	–	–	–	_	7	12	16	5	2	1		–	43
34	–	–	–	–	–	_	4	12	8	14	3	1	1	1	44
35	–	–	–			–	–	4	4	5	9	3	3		28
36			–		–	_	2	8	10	12	5	2	1		40
Total	1	2	6	25	63	134	214	280	280	171	102	22	12	2	1314
Ratio	0.08	0.15	0.46	1.90	4.80	10.20	16.29	21.31	21.31	13.01	7.76	1.67	0.91	0.15	100.00

⑤ Diameter with bark growth :

$$Y = K \cdot y$$

$$\text{where, } K = \frac{\sum (D)}{\sum (d)} = \frac{1785.6}{1463.0} = 1.220506$$

⑥ Diameter growth regression formula :

$$Y = 0.3052+0.0169X$$

2) Calculation of volume regression formula

Using the diameter growth regression formula as calculated above, the diametrer growth for each tree of every diameter grade is acquired. Then the value will be combined with the volume, where the volume for each diameter grade will be necessary as premises. The volume by each diameter grade was obtained, on basis of 105 sample trees, by the one-variable equation with a diameter as the independent variable, as follows.

$$V = 0.011804 - 0.0087790 + 0.001049D^2$$

3) Calculation of volume growth

After the calculation by the regression formula of diameter growth and volume is made, the volume growth by diameter grade is then calculated, and the result will be used to estimate the forest stand growth. The calculation method procedure is as follows.

① Grouping by diameter was made by every 2 cm in the range of diameters of sample trees (the 105 trees from which cores were taken).

② The volume per tree corresponding to each diameter (D), grouped by every 2 cm, was calculated by the volume formula as in the paragraph 2) in the previous section.

③ The difference in volume of different diameter grade, i. e. volume difference Δv is calculated. For example, Δv between 2 cm diameter and 4 cm is ;

$$\Delta v = 0.0045-0.0015 = 0.0030$$

and Δv between 4 cm diameter and 6 cm is ;

$$\Delta v = 0.0100-0.0045 = 0.0055$$

.....

④ Volume modified difference δv was calculated, based on the volume difference Δv. For example δv for 4 cm diameter is ;

$$\delta v = (0.0030+0.0055) / 2 = 0.0043$$

and for 6 cm diameter ;

$$\delta v = (0.0055+0.0085) / 2 = 0.0070$$

.....

⑤ Diameter growth Δd was calculated for each diameter grade by the diameter

Table 5. Calculation of growth of volume.

① Diameter at breast height D	② Volume per tree v	③ Difference of volume Δv	④ Difference of modified volume δv	⑤ Growth of diameter Δd	⑥ Growth of volume $v_{(K)}$ $(\delta v \cdot \Delta d/2)$	⑦ Number of tree N	⑧ Growth of total volume $V_{(K)}$ $(v_{(K)} \cdot N)$	⑨ Total volume V $(v \cdot N)$
cm	m^3	m^3	m^3	cm	m^3		m^3	m^3
2	0.0015		–		–	(1)	–	–
		0.0030						
4	0.0045		0.0043	0.3728	0.00080	2	0.0016	0.0090
		0.0055						
6	0.0100		0.0070	0.4066	0.00142	6	0.0085	0.0600
		0.0085						
8	0.0185		0.0113	0.4404	0.00249	25	0.0623	0.4625
		0.0140						
10	0.0325		0.0195	0.4742	0.00462	63	0.2911	2.0475
		0.0250						
12	0.0575		0.0310	0.5080	0.00787	134	1.0646	7.7050
		0.0370						
14	0.0945		0.0412	0.5418	0.01116			
		0.0454				214	2.3882	20.2230
16	0.1399		0.0496	0.5756	0.01427	280	3.9956	39.1720
		0.0538						
18	0.1937		0.0580	0.6094	0.01767	280	4.9476	54.2360
		0.0621						
20	0.2558		0.0664	0.6432	0.02135	171	3.6509	43.7418
		0.0706						
22	0.3264		0.0784	0.6770	0.02532	102	2.5826	33.2928
		0.0789						
24	0.4053		0.0832	0.7108	0.02957	22	0.6506	8.9166
		0.0874						
26	0.4972		0.0916	0.7446	0.03410	12	0.4092	5.9124
		0.0957						
28	0.5884		0.0999	0.7784	0.03888	2	0.0778	1.1768
		0.1041						
30	0.6925		–		–			–
(a) Total (per surveyed area, 1.4ha)						1314	20.1205	216.9554
(b) Per unit area (lha)						939	14.3718	154.9681
(c) Per estimated survey subject area (A = 25ha)						23464	359.2946	3874.2035

growth regression formula in 1)-⑥ above.

⑥ Using thus obtained volume modified difference δv and the diameter growth Δd, the volume growth was calculated by $v_{(g)}=(\delta v \cdot \Delta d)/2$. The figure 2 in this formula is because 2 cm is used for diameter grading. If the grading is made by 1 cm, the above figure is 1. In addition, so far the above means the volume growth per a single tree.

⑦ The number of trees at each diameter grade, N is acquired by the frequency distribution table of number of trees by diameter grade per plot in Table 4, based on the materials of plot survey. Here, 2 cm diameter grade is omitted from the calculation of volume growth, since the number of trees is only one. However, in the ultimate calculation (Table 5, (a), (b), and (c)) the number of trees was also treated among the subject of calculation.

⑧ When the volume grade $v_{(g)}$ of ⑥ above is multiplied with the number of trees by diameter grade, N of ⑦, the total volume growth $V_{(g)}$ is obtained. This is the volume growth by diameter grade, which is estimated from the 105 sample trees, and the total value 20.1205 m^3 is the total tree volume per 1.4 ha of plot area (0.04 ha **x** 35 plots= 1.4 ha).

⑨ When the volume per tree by diameter grade, v times the number of trees by diameter grade, N make the volume by diameter grade, and the total value of 216.9554 m^3 is the total volume per 1.4 ha.

From Table 5, the volume growth per 1.4 ha of survey plot area is obtained as 20.1205 m^3. From this figure, the estimated volume of 14.3718 m^3 per unit area (1 ha) and 359.2946 m^3 per area subject to estimation on (25 ha) were obtained.

In addition, thus calculated volume showed the results of 216.9554 m^3 per 1.4 ha, 154.9681 m^3 per unit area (1 ha), and 3874.2035 m^3 per total area (25 ha). From these, the volume growth percentage *(P)* of this forest stand was figured as below.

$$p = \frac{20.1205}{216.9554} \times 100 = 9.27\ (\%)$$

DISCUSSION

1. Coefficient of variance of forest stand

Prior to the field survey, the coefficient of variance (CV) was assumed at 30 %. This is because the state of the forest stand is regarded lacking in uniformity, since there are certain difference in the growth of tree heights, diameters and so on, and further there are burned area by forest-fire and damp ground in a part of the forest. As the result, the number of plot survey, n was 34 (actually 35 plots were surveyd). However, the calculation after the survey, the coefficient *(CV)* was proved to be 43.37 %. So it can be said that this forest stand had average variance as artificial forest. Therefore, the required plot number for the survey in case of $CV = 43.37 \fallingdotseq 43\%$ would be $67.2 \fallingdotseq 67$ which is the sufficient number for aimed accuracy of 10 %. This value will be one of the reference materials in future survey programme.

2. Result of estimates on growing stock

The result of estimates on number of trees as well as volume were as in Table 6.

Table 6. List of estimation results of the number of trees and volume.

		Results of systematic line-plot sampling		Results based on the estimated volume production of a forest stand
		For $t_{.05}$	For $t_{.01}$	
Number of trees	Per 1ha	937.5± 37.1 (900.4-974.6)	937.5± 49.9 (887.6～987.4)	939
	Per 25ha	23438± 927 (22511-24365)	23438t 1248 (22190-24686)	23464
Volume (m^3)	Per 1ha	153.93± 22.39 (131.54～176.32)	153.93± 30.15 (123.78-184.08)	154.97
	Per 25ha	3848.3± 559.6 (3288.7-4407.9)	3848.3± 753.7 (3094. G-4602.0)	3874.20

Comparing these with the values on the number of trees and volume based on the estimate on the volume growth of forest stand, the results were both within the range of estimation based on the plot survey, showing a good coincidence. The sampling error ratio of plot sampling was 14.54 %.

It must be checked in future how the above estimates meet the actual forest stand. However, for the estimation on the growing stock in a forest of spacious area, since this survey method is simple in practice and easy in afterward calculation, it can be concluded as one of very efficient methods.

3. Result of estimates on plot stand growth

The result showed that the forest stand volume growth was 14.3718 m^3 per ha, and 359.2946 m^3 per 25 ha of the subject area of estimation, and the growth percentage ***P*** was 9.27 %. This percentage is not excellent. It is necessary to consider tree-species, by comparison with other species of pine trees.

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