森林経営のための連続調査法としての4地上調査法の比較

誌名	日本林學會誌 = Journal of the Japanese Forestry Society
ISSN	0021485X
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巻/号	77巻6号
掲載ページ	p. 573-580
発行年月	1995年11月

日林誌 77(6)'95 573～580

論 文

Comparison among Four Ground-Survey Methods as a Continuous Forest Inventory System for Forest Management

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NAKAJIMA, N. Y., YOSHIDA, S. and IMANAGA, M.: **Comparison among four ground-survey methods as a continuous forest inventory system for forest management. J. Jpn. For. Soc. 77: 573～580, 1995** The objective of this study was to compare the accuracy of four ground-survey methods, which are: the point sampling method (PS), the line sampling method (LS), the circular plot method (CP), and the concentric circular plot method (CCP), as a continuous forest inventory system for forest management. This work was conducted by using the data of a sugi (*Cryptomeria japonica* D. DON) stand 43 years old, on the Shiragadake Experimental Forest in Kagoshima, Japan. For PS and LS the basal area factor 2 was used. For the LS, the line length was 11 m, and the stems of both sides of the line were selected. For CP, the radius was 7 m, corresponding to 0.015 ha; for CCP, radii were 6 and 11 m, corresponding to 0.011 and 0.038 ha respectively. Sampling intensity was 30 samples, and the systematic sampling process was applied 10 times with each method. For the number of stems per ha and the mean diameter, CP presented the least sampling error, followed by CCP; for basal area and volume per ha, PS showed the least sampling error, followed by CCP. The differences in sampling errors among these methods, however, can be considered non-significant. Therefore, the best method should not be selected only on the basis of the sampling errors.

ネルソン ナカジマ・吉田茂二郎・今永正明：**森林経営のための連続調査法としての4地上調査法の比較 日林誌 77: 573～580, 1995** 森林経営のために行う継続的な森林調査法を想定したとき，実際に行う地上調査の精度の比較を行った。比較した四つの方法はポイントサンプリング (PS)，ラインサンプリング (LP)，円形プロット法 (CP) と二重円プロット法 (CCP) である。利用した資料は鹿児島県白鹿岳国有林の43年生のスギ人工林のものである。PSとLS法では断面積定数2を，LS法ではライン長を11mで，ライン両側の測定を行った。CP法では半径7m (0.015 ha) で，CCP法では半径は6m (0.011 ha) と11m (0.038 ha) であった。系統的に抽出したプロットの数は30個で，一つの方法を10回繰り返した。その結果，ha当り立木本数と平均直径の推定ではCP法が，そしてha当り断面積と同材積ではPS法がサンプリング誤差が最小値を示した。ただし，4方法におけるサンプリング誤差の差は小さく，これだけでは最適な方法を決める基準にはならない。

I. Introduction

It is known that the efficiency of any forest inventory depends on the sampling process, methods of measurement, and sampling method, that is, size and type or shape of the plots. As the sampling intensity is dependent on the degree of precision required, and the costs increase almost linearly with the number of samples, the sampling intensity should keep a balance between precision and cost.

In Japan, the next forest inventory system is just at the planning stage (Forestry Agency, 1994), and the details of ground-survey methods have not been defined yet.

The purpose of this work was to compare the four ground-survey methods: namely, point sampling method (PS), line sampling method (LS), circular plot method (CP), and concentric circular plot method (CCP), for use in the continuous forest inventory system (CFI). NISHIZAWA (1972) summarized the ground-

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survey methods for the sampling process in PS and LS as plotless sampling and CP as plot sampling. The investigation of CCP, which is adopted in Switzerland as the CFI, also was added to this study.

The objective of CFI is the monitoring of the forest evolution over time, and thus performing successive surveys on the ground, in the same population within a designated time interval. This permits the evaluation of the dynamic character of the population as well as the collection of indispensable basic information for the support of forest management, such as forest structure, growing stock, increment, site index, and yield estimation.

II. Materials and Methods

1. Study area

The study area is situated at Minamimata, Takanabe Town in Kagoshima Prefecture, at latitude 31 degrees 43 min north and longitude 130 degrees 50 min east.

The total area is 43.84 ha bounded with mountains, and the altitudes at the lowest and highest elevations are 400 and 600 m, respectively.

The soil was derived from sandstone and clay-slate of a mesozoic formation, and was covered with volcanic soil and sand. The soil depth varies from place to place, and in general this area does not present good conditions for tree growth.

In the year 1907, after the broadleaved trees had been cut down, a sugi (*Cryptomeria japonica* D. DON) forest was planted. In 1950, Shiragadake Experimental Forest was established, and a forest survey was conducted out by Dr. K. KINASHI and other researchers from Kyushu University. In addition to sugi, pines (*Pinus* spp.) and diverse species of broadleaved trees had grown up through natural regeneration, becoming a mixed forest. The study area was restricted to 27.57 ha; that is two-thirds of the entire Experimental Forest.

2. Methodology of forest survey (KINASHI, 1953)

In the survey of the forest, the total area was divided into 4,083 plots of 10×10 m each, and a stake was driven on one corner of each plot. These stakes were utilized as reference points in the measurement of individual trees with diameters at breast heights of at least 4 cm (dbh≧4 cm). The data collected were tree location coordinates, dbh, species, and the heights of sample trees. The measurements of diameters were made using a diameter tape, grouping 1 cm. The height of the tree nearest the corner stake was measured with a Weise hypsometer. A square consisting of 64 plots (80×80 m) was denoted a complete block, with plots numbered from 01 to 64.

Only complete blocks, situated between Nos. 2 and 7 horizontal-lines (Fig. 1) were utilized. The data of individual tree utilized in this study (dbh, tree height, species, and tree location coordinates) were surveyed by Dr. K. KINASHI, Dr. M. NISHIZAWA and Dr. K. TAKATA in 1950. The scheme of the survey plots is shown in the Fig. 1 (for more details see KINASHI, 1953).

1) Height equation, stem volume, and stand parameter calculations

The volumes of individual stems were obtained according to diameter classes, height classes, and respective species from the Japanese Forestry Volume Table (Forestry Agency, 1970).

The total height (h) was estimated by the following fitted equation:

$$h=1.20+[\text{dbh}/(2.02+0.18\times\text{dbh})]^2$$

(MITSUYASU, 1993), and we calculated the actual values (parameters) of stand variables.

3. Sampling process and ground-survey methods

A systematic sampling process was adopted to define the sampling point locations: the first sampling point was selected at random in the first block, and then the following sampling points were selected systematically; that is, they had the same sampling point as the first one in the first block. In Fig. 1 an example is denoted. The sampling size was 30 samples for each method, so that the desired sampling error of volume per ha is close to 10%. The number of repetitions was 10 times for each method. The four ground-survey methods (PS, LS, CP, and CCP) were compared in this study.

The PS was used as the reference method; the average number of stems at each point first was counted

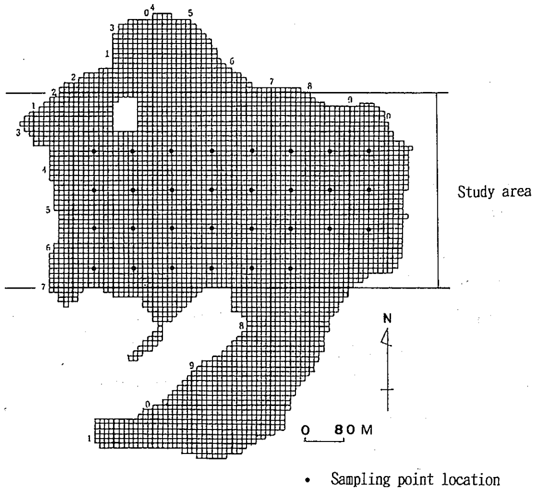

Fig. 1. Scheme of survey plots (Source: KINASHI, 1953)

and the other three methods then were adjusted to have the same number of stems as for the PS.

1) Point sampling method (PS)

This method consists of counting the trees whose diameters (dbh) are equal to or larger than the sighting angle, making a rotation of 360 degrees. The tree selections are made with the probability proportional to the basal area. In this study the basal area factor (BAF) 2 was chosen, because in the case of BAF 4 few trees would be included in each point sample, consequently increasing the sampling error.

The formulae utilized to estimate the variables were (NISHIZAWA, 1972):

$$dm = \mathrm{SUM}(d_i/g_i)/\mathrm{SUM}(1/g_i),$$
$$hm = \mathrm{SUM}(h_i/g_i)/\mathrm{SUM}(1/g_i),$$
$$N = k \times \mathrm{SUM}(1/g_i),$$
$$G = k \times n, \text{ and}$$
$$V = k \times \mathrm{SUM}(v_i/g_i),$$

where: dm, Mean dbh (cm); hm, Mean total height (m); N, Number of stems per ha; G, Basal area per ha (m^2/ha); V, Volume per ha (m^3/ha); k, Basal area factor; n, Number of stems counted per sample; d_i, Diameter of the i-th counted stem (cm); g_i, Basal area of the i-th counted stem (m^2); h_i, Total height of the i-th counted stem (m); and v_i, Volume of the i-th counted stem (m^3).

2) Line sampling method (LS)

In this method, a line with a constant length is set on a plot, and all trees whose dbhs are equal to or larger than the sighting angle are included in the sample. The trees are sampled with the probability proportional to the diameter. In this method, the basal area factor 2 was utilized. The line length was 11 m, and the sample trees from both sides of the line were selected. The formulae used to estimate the variables were (NISHIZAWA, 1972):

$$dm = n/\mathrm{SUM}(1/d_i),$$
$$hm = \mathrm{SUM}(h_i/d_i)/\mathrm{SUM}(1/d_i),$$
$$N = (2 \times \mathrm{SQR}(k) \times 100^2/L) \times \mathrm{SUM}(1/d_i),$$
$$G = (\pi \times \mathrm{SQR}(k)/2 \times L) \times \mathrm{SUM}(d_i), \text{ and}$$
$$V = (2 \times \mathrm{SQR}(k) \times 100^2/L) \times \mathrm{SUM}(v_i/d_i)$$

where: SQR, Square root; and L, Line length. (Other terms are as described for PS).

3) Circular plot method (CP)

The shape of the sample plot is circular with a constant radius. In this method, all trees with dbh≧4 cm inside the plot are selected. The trees on the plot border are counted if the center of the tree is located inside the plot. In this study, the radius was 7 m, corresponding to 0.0154 ha. The formulae used to estimate the variables were (NISHIZAWA, 1972):

$$dm = \mathrm{SUM}(d_i)/n,$$
$$hm = \mathrm{SUM}(h_i)/n,$$
$$N = n/a,$$
$$G = \mathrm{SUM}(g_i)/a, \text{ and}$$
$$V = \mathrm{SUM}(v_i)/a$$

where: a, Circular plot area (ha) (Other terms are as described for PS).

4) Concentric circular plot method (CCP)

In the CCP, two concentric circles are used. The radius of the larger circle was 11 m, corresponding to 0.0380 ha, and the smaller circle was 6 m, corresponding to 0.0113 ha. The criterion for sampling trees were the same as those for CP. In the smaller circle, all trees between 4≦dbh<26 cm were selected, and in the larger circle all trees with dbh≧26cm. The formulae used to estimate the variable values were (SCHIMID-HAAS *et al*. 1993) :

$$dm=\{[\mathrm{SUM}(d_i)/a_1]+[\mathrm{SUM}(d_j)/a_2]\}/N,$$
$$hm=\{[\mathrm{SUM}(h_i)/a_1]+[\mathrm{SUM}(h_j)/a_2]\}/N,$$
$$N=(n_1/a_1+n_2/a_2),$$
$$G=[\mathrm{SUM}(g_i)/a_1+\mathrm{SUM}(g_j)/a_2], \text{ and}$$
$$V=[\mathrm{SUM}(v_i)/a_1+\mathrm{SUM}(v_j)/a_2]$$

where: a_1, Area of smaller circular plot (ha) ; a_2, Area of larger circular plot (ha) ; n_1, Number of stems counted on smaller circular plot; n_2, Number of stems counted on larger circular plot; d_i, Diameter of the i-th counted stem on smaller circular plot (cm) ; d_j, Diameter of the j-th counted stem on larger circular plot (cm) ; h_i, Total height of the i-th counted stem on smaller circular plot (m) ; h_j, Total height of the j-th counted stem on larger circular plot (m) ; g_i, Basal area of the i-th counted stem on smaller circular plot (m^2) ; g_j, Basal area of the j-th counted stem on larger circular plot (m^2) ; v_i, Volume of the i-th counted stem on smaller circular plot (m^3) ; and v_j, Volume of the j-th counted stem on larger circular plot (m^3).

4. Statistic formulae

The statistic analyses were conducted by utilizing the following formulae (PELLICO-NETTO and BRENA, 1993) :

$$xm=\mathrm{SUM}(x_i)/n,$$
$$s^2=\mathrm{SUM}(x_i-xm)^2/(n-1),$$
$$s=\mathrm{SQR}(s^2),$$
$$s_{xm}=s/\mathrm{SQR}(n),$$
$$cv=(s/xm)\times 100,$$
$$se=[(t\times s_{xm})/xm]\times 100, \text{ and}$$
$$ci=xm\pm t\times s_{xm}$$

where: xm, Mean of variable x; x_i, Value of each variable x; n, Number of sample-plots; s^2, Variance; s, Standard deviation; SQR, Square root; s_{xm}, Standard error; cv, Coefficient of variation; se, Sampling error as percentage; t, Student table value [$t_{(0.05,29)}=1.70$]; and ci, confidence interval.

In the four methods, the population was considered infinite.

III. Results and Discussion

1. Stand parameters

The total area and the number of trees utilized in this study were 27.57 ha and 39,633 trees, respectively. After processing these data, the following parameters were obtained: Mean number of stems(N), 1,437 stems/ha; Mean diameter(dm), 19.4 cm; Mean total height(hm), 13.1 m; Mean basal area(G), 47.9 m^2/ha; and Mean volume(V), 345.8 m^3/ha.

2. Comparison among the four ground-survey methods

The number of stems in each repetition and the overall mean number for each method are presented in Table 1.

Figures 2 and 3 show, for each of the four ground-survey methods, the estimated variable values and the sampling errors, respectively, for the number of stems per ha (N/ha), mean diameter (dm), basal area per ha(G/ha), and volume per ha(V/ha).

Table 1. Mean number of stems in each method

Rep.	PS	LS	CP	CCP
1	23	20	20	21
2	23	20	21	22
3	23	22	22	23
4	23	20	21	22
5	23	20	21	22
6	23	21	21	23
7	24	20	19	21
8	24	21	22	22
9	22	20	21	21
10	25	21	20	22
Mean	23	21	21	22

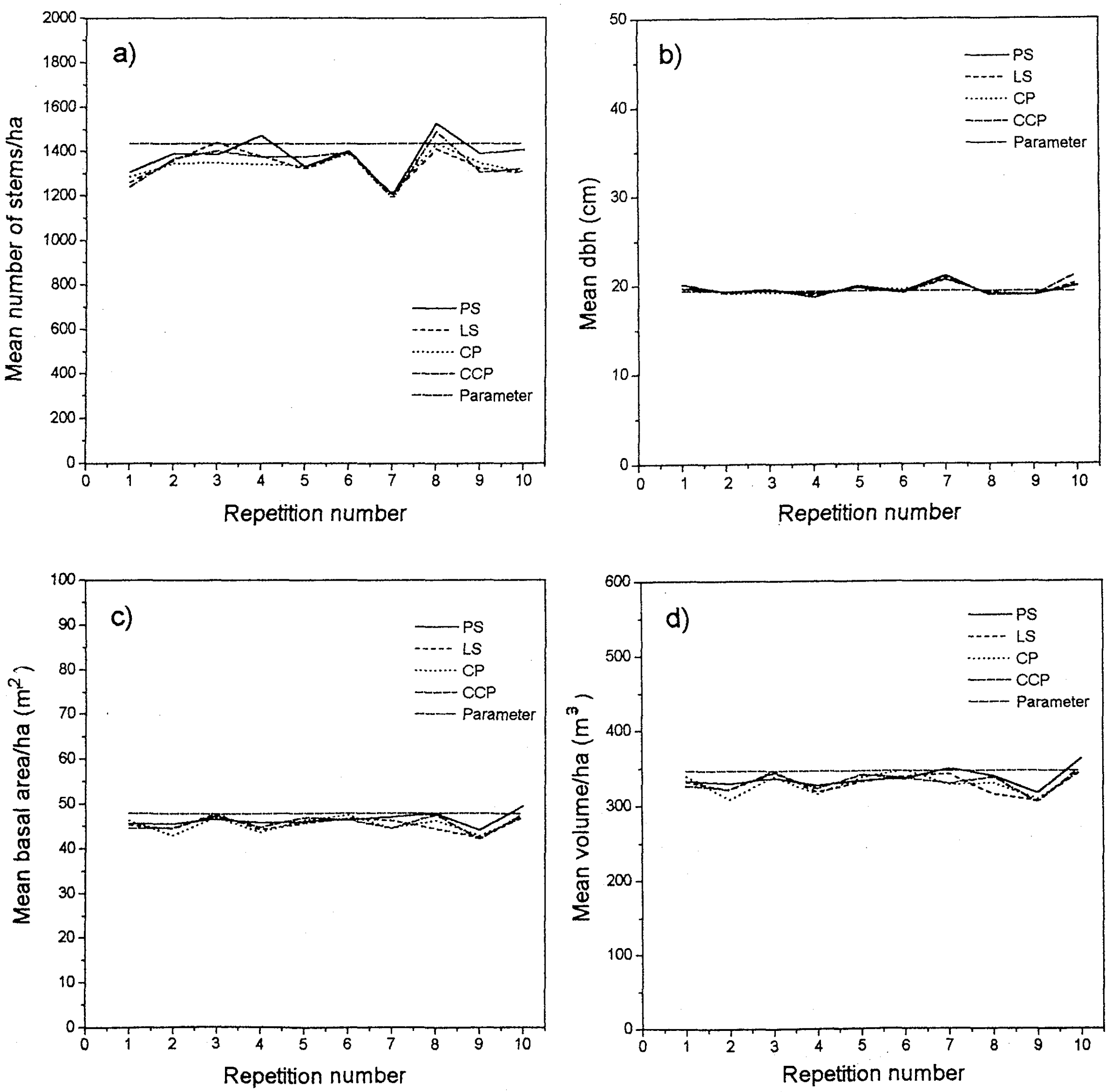

Fig. 2. Comparison of estimated variable values among the four methods
a), For number of stems/ha; b), For mean diameter; c), For basal area/ha; d), For volume/ha.

Compared with the stand parameters, all four methods underestimated values, except for mean diameter estimations. PS had the closest approximation of the stand parameters for each of the four variables. However, there were no marked differences among the four methods for any estimated stand variable or sampling error. Therefore, the selection of the most appropriate method should be based on other factors such as survey costs, and so forth.

Table 2 shows the mean of estimated variable values from 10 repetitions, as well as the results of statistic analyses for each method.

For the number of stems per ha, CP resulted in the least error, followed by CCP, LS, and PS. According to LOETSCH *et al.* (1973), CP may be regarded as sampling with probabilities proportional to frequency. Hence, the number of stems is more effectively estimated than by PS.

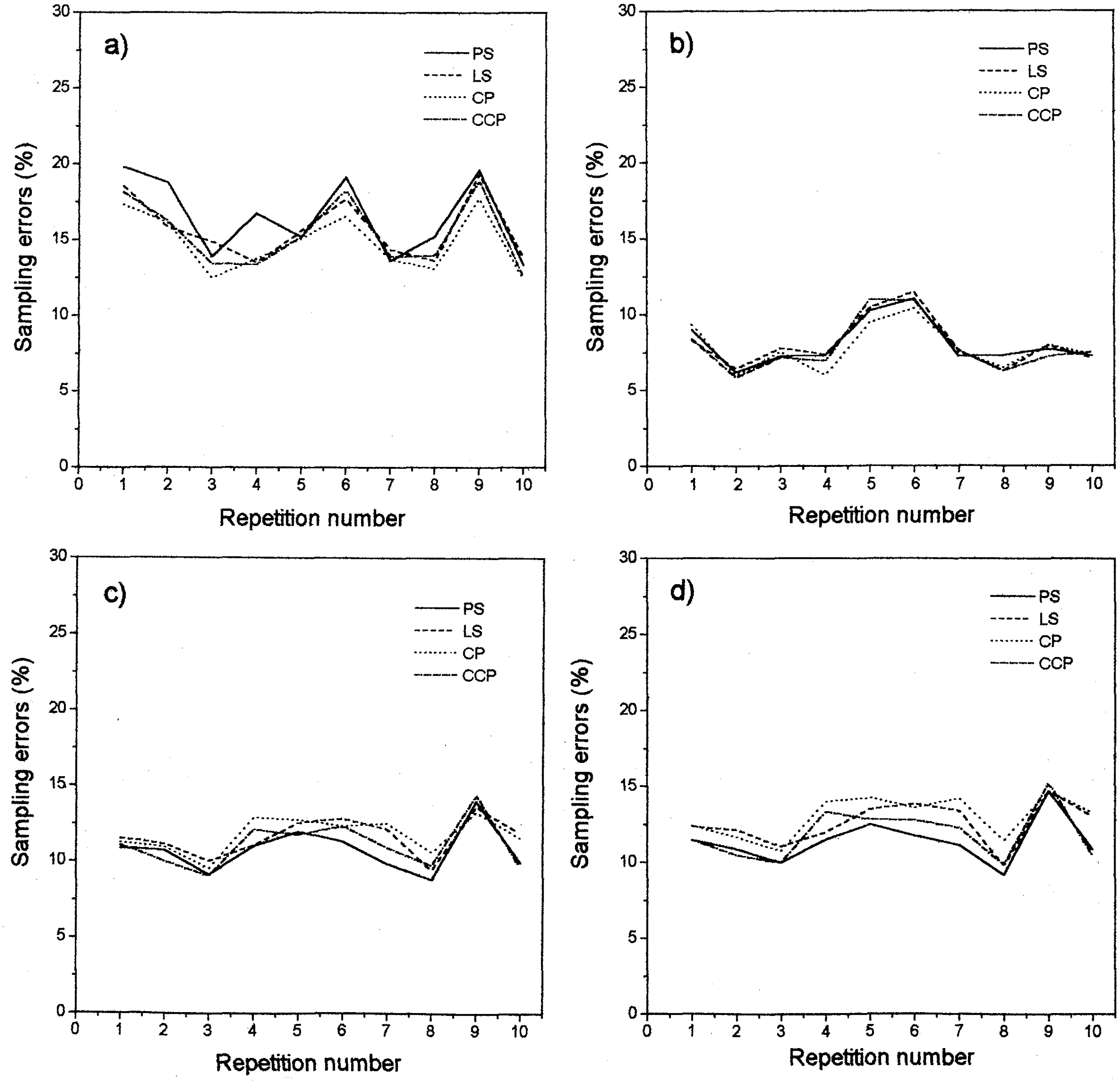

Fig. 3. Comparison of sampling errors among the four methods

a), For number of stems/ha; b), For mean diameter; c), For basal area/ha; d), For volume/ha.

For mean diameter, CP also was slightly superior to CCP, which in turn was slightly superior to PS and LS.

For basal area and volume of stand per ha, PS resulted in the least error, followed by CCP, LS, and CP. LOETSCH *et al.*(1973) note that, because, the sampling probabilities are proportional to the basal area of trees for PS, the total basal area is estimated more effectively than in plot sampling. This result is in accordance with their statement. In spite of plotless sampling like PS, LS did not provide so little error of estimation because the sampling is proportional to the diameter.

YOSHIDA (1991) compared these four methods in a 55-year-old sugi stand and obtained the following results: for the number of stems per ha: CP presented the least error, followed by LS, CCP, and PS. The least error for mean diameter was seen for LS, followed by CP, CCP, and PS, and that for volume per ha also was seen for LS, followed by CP, PS, and CCP. MAHRER and VOLLENWEIDER (1983) conducted the same comparison in Switzerland and obtained the following results: for number of stems, the least sampling error

Table 2. Estimated variables and statistic analyses for each method

Statistic analyses	PS	LS	CP	CCP
For number of stems (parameter N=1437 stems/ha):				
Mean num. of stem/ha	1383	1341	1344	1348
Standard deviation	737.16	678.33	640.99	667.75
Standard error	134.59	123.84	117.03	121.92
Coefficient of variation	53.25	50.63	47.74	49.63
Sampling error	16.53	15.72	14.82	15.40
Confidence interval*	(1154～1612)	(1130～1552)	(1145～1543)	(1141～1555)
For diameter (parameter dm=19.4 cm):				
Mean diameter (cm)	19.55	19.60	19.57	19.60
Standard deviation	5.06	5.09	4.91	4.97
Standard error	0.92	0.93	0.90	0.91
Coefficient of variation	25.89	25.97	25.05	25.34
Sampling error	8.03	8.06	7.78	7.86
Confidence interval*	(18.0～21.1)	(18.0～21.2)	(18.0～21.1)	(18.1～21.1)
For basal area (parameter G=47.9 m^2/ha):				
Mean basal area/ha (m^2)	46.54	45.52	45.50	45.75
Standard deviation	16.11	17.05	17.23	16.32
Standard error	2.94	3.11	3.15	2.98
Coefficient of variation	34.71	37.47	37.93	35.82
Sampling error	10.78	11.63	11.77	11.12
Confidence interval*	(41.5～51.5)	(40.2～50.8)	(40.2～50.9)	(40.7～50.8)
For volume (parameter V=345.8 m^3/ha):				
Mean volume/ha (m^3)	335.42	328.93	328.71	330.55
Standard deviation	122.63	133.12	137.57	125.68
Standard error	22.39	24.30	25.12	22.95
Coefficient of variation	36.65	40.46	41.87	38.16
Sampling error	11.38	12.56	13.00	11.85
Confidence interval*	(297.4～373.5)	(287.6～370.3)	(286.0～371.4)	(291.5～369.6)

* Lower and upper limits.

was seen for CCP, followed by CP, LS, and PS. For volume, the least error again was seen for CCP, but followed by LS, PS, and CP. However, in their studies there was a lack of equality for the number of stems per sampling point (in average) among the four methods.

IV. Conclusions

This comparative study of the four ground-survey methods revealed that the accuracy of each method varied according to the estimated variable: for estimation of the number of stems per ha and mean diameter, CP presented the least error, followed by CCP; and for basal area and volume per ha, PS presented the least error, also followed by CCP, under the study area conditions. However, there were no marked differences among the four methods for any estimated stand variable. Therefore, the selection of the most appropriate ground-survey method for the forest management should be based on cost, which directly relates to the amount of time spent in plot establishment and data surveys.

The choice of the ground-survey method as well as the amount of the time required for each method depend on the individual stand conditions such as stand structure, topography, undergrowth, and so forth.

This study was made to focus only on comparing the accuracies of estimated variables by the four methods. In our next study, we intend to compare the accuracy of growth estimations and the amount of time spent in plot establishment and data surveys by the same four methods. Based on those results, we hope then to be able to select the most appropriate ground-survey method for use as the continuous forest inventory system for forest management.

Acknowledgements

The authors thank Professors Dr. Kenkichi KINASHI and Dr. Masahisa NISHIZAWA (posthumous), from Kyushu University for providing data; Prof. Dr. Koji MATSUSHITA (Kyoto Univ.), Engineer Naomasa MITSUYASU and Miss Yoko NAKASHIMA for their valuable cooperation.

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(Received January 24, 1995)