[測定経営研究室]D.天然生森林調査における材積変動の研究(1)(2)

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(D) 天然生森林調査における材積変動の研究 (1)

A Study of sampling error percentages of various calculational techniques in forest inventory

Kenkichi Kinashi

1. Object of this study. There are many sampling methods in forest inventory. From simple method to complicated method we have more than ten. At the first glance, simple random, simple systematic, simple random with restricted two plots in each blocks, disproportional sampling in each stratum, proportional sampling in each stratum, subsampling random, subsampling systematic, cluster sampling randam, cluster sampling systematic, double sampling for stratification, double sampling, two occation sampling and etc. we have. Moreover, we have many conditions, many plot shapes and areas, many types of strip, various methods of Bitterlich system, various kinds of instrument, different types of forest and tree. This study is unable to cover all things, but tries only two or three cases. But it is important that we inform where sampling error in forest inventory comes mainly from.

2. Data of this study. Used data is a part of large forest inventory conducted by Obihiro National Forestry Bureau. The area is located south-west from Mt. Tomuraushi (2141.6m).
Rough shape is about 11Km×11Km. A set of plots is consisted with two rectangular plots, 20m×40m each, separated with distance 50m. Plot allocation was originally considered by Mr. Gan Nakashima based on various types of foliage on the aerial photographs.
Total number of the large plot is 80. Main speacies are Todomatsu(Abies Mayriana), Ezomatsu(Picea jezoensis), Akaezomatsu(Picea Glehnii), and broad-leaved tree included with Betula, Acer, Ulmus, Alnus, Populus and

Salix, etc. Almost natural stands age more than 100 years and they are stocked highly. There are scarcely so large, stocked forests in Japan recently.

3. Case study. Data are changed to volume(cubic meter)per ha.
Four strata;A:N > 80 per cent, B:80 > N > 50 per cent, C:80 > L > 50 per sent, D: L > 80 per cent, in which, A=soft wood stands, B=soft mixed with hard wood stands, C=hard mixed soft wood stands, D=hard wood stands.

(I) Random sampling separately from each stratum.

strata	sum $\sum x_1 + \sum x_2$	size n	mean $\frac{\sum x_1 + \sum x_2}{n}$	variance Δ^2	error $\frac{\Delta}{\sqrt{n}}$	error per cent
A	16872.83	52	324.48	10822.6781	14.43	4.45
B	19710.76	62	317.92	9582.4193	12.43	3.91
C	6893.09	26	265.12	8569.5956	18.15	6.85
D	3724.60	18	206.92	8383.5720	21.58	10.43
Simple random from aggrigate						
	47202.28	158	298.75	11029.0124	8.35	2.80

(II) Representative sampling

strata	block sum $(X_1 + X_2)$	variance of sum $(X_1 - X_2)^2$	square root	error percent
A	16872.83	368530.1627	607.0669	3.60
B	19710.76	192779.0430	439.0661	2.23
C	6892.69	90019.7281	300.0329	4.35
D	3724.60	97644.6116	312.4814	8.39
Σ	47200.88	748973.5424	865.4325	1.83

(III) Cluster sampling in stratification

strata	sum $\sum \frac{x_1 + x_2}{2}$	size n	variance of sum $n\Delta^2$	root	error per cent
A	8436.49	26	191201.1101	437.27	5.18
B	9855.44	31	252206.9502	502.20	5.10
C	3446.39	13	91684.4867	302.79	8.79

D	1861.63	9	52620.2100	229.39	12.32
Σ	23599.95 (X2=47199.9)	79	587712.7569	766.6243	(1.62) 3.24

(Ⅳ) Cluster sampling separately

strata	mean $\Sigma(\frac{x_1+x_2}{2})/n$	variance Δ^2	standard error $\Delta/\sqrt{n}$	error percent
A	324.48	7353.8889	16.82	5.18
B	317.92	8135.7081	16.20	5.10
C	265.12	7052.6528	23.29	8.79
D	206.84	5846.69	25.48	12.32
Simple random from aggrigate,(sum of two plots) n=79				
	600.52 (1/2=300.26)	34801.9908	20.99	3.50

(Ⅴ) Correlation between A plot and B plot

strata	A	B	C	D
pair	26	31	13	9
r =	0.33	0.68	0.58	0.48

A plot : main plot

B plot : sub plot

(Ⅵ) Correlation between species, within plot

strata	A		B		C		D	
plot	A	B	A	B	A	B	A	B
pair	26	26	31	31	13	13	9	9
picea-abies	−0.44	−0.36	−0.21	−0.11	0.22		−0.28	
N − L	−0.29	−0.21	0.01	−0.17	0.14		0.17	

(Ⅶ) Stratified random sampling(based on one plot)

strata	sum of squares within strata $\overset{n}{S}\{(y-y_b)^2\}$	degree of freedom
A	551956.5842	51
B	584527.5793	61
C	214239.8901	25
D	142520.7245	17
Σ	1493244.7781	154

s^2 (within strata) $= \frac{1493244.7781}{154} = 9696.394662$

$\sqrt{ns^2} = \sqrt{1532030.356596} = 1237.752138$

error percent = 1237.752138/47201.28 = 2.62

(Ⅷ) Stratified cluster sampling(based on two-plot-sum/2)

strata	sum of squares within strata $\overset{n}{S}\{(y - y_b)^2\}$	degree of freedom
A	183847.2213	25
B	244071.2421	30
C	84631.8338	12
D	46773.5200	8
E	559323.8172	75

s^2 (within strata) $= \frac{559323.8172}{75} = 7457.650896$

$\sqrt{ns^2} = 767.563952$

error percent = 7457.650896/23599.95 = 3.25

4 . Consideration

Representative sampling(Ⅱ) abows the smallest error percent.

Cluster sampling shows larger error than simple random sampling.

(Ⅲ),(Ⅳ) > (Ⅰ). These may be shown as followings:

Error percent of various kind of sampling techniques

STRATA	(Ⅰ) Random Simple		(Ⅱ)Representative		(Ⅲ) Cluster	
	unrestricted	restricted	unrest.	rest.	unrest.	rest.
A		4.45		3.60		5.18
B		3.91		2.23		5.10
C		6.85		4.35		8.79
D		10.43		8.39		12.32
Σ	2.80	2.62		1.83	3.50	3.25

If correlation between pair plot is high, representative sampling may be excellent. Likeness may or may not decrese in various ecological behavior. We can not estimate it exactly, blocking, however, will supply some idea to us.(Dec. 23,1968)

天然生森林調査における材積変動の研究（2）

── えびの調査を中心として ──

（Hierachical classifications による分散分析）

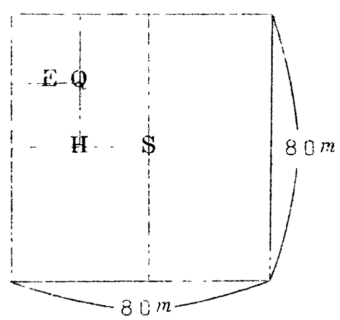
木　梨　謙　吉

熊本営林局えびの営林署川添国有林南九州天然生広葉樹林霧島国立公園栗野岳北側 80 m × 80 m Section 7個 但し80 mづつ南により南北線1,020 m山ろくより山頂に向つて設定した。

（樹種は暖帯生広葉樹イス、カゴノキ、タブ、サカキ、カシ、シイ、ツバキ、ユズリハ、サザンカ、シキミ、ヤブニッケイを主としミズキ、サクラ、カエデ、ミズメなどを混え、1E20 cm以上測定、50～100 cmのもの点在。）

森林調査に必要な20 m × 20 mを基本plotとして、その材積をHiarachical Classificationsにより分散分析を行いRepresentative Samplingに必要なBlockの大きさ決定の資料とする。

Section の分割は下図の通りすなわち、たてに折半してHalf，それをよこに切つてQuarter，さらにたてに折半してEight 最後によこに切つてPlot とする。



S：80 m × 80 m
H：40 m × 80 m
Q：20 m × 40 m
E：20 m × 20 m

plot #	$y_{shqh\alpha}$	Y_{shqh}	Y_{shq}	Y_{sh}	Y_s	Y
4 L 2	10.772	17.892	35.970	83.062	174.478	1056.791
3 L 2	7.120					
4 L 1	9.569	18.078				
3 L 1	8.509					
2 L 2	4.438	23.696	49.092			
1 L 2	19.258					
2 L 1	13.538	25.396				
1 L 1	11.858					
4 R 1	7.657	12.042	35.311	89.416		
3 R 1	4385					
4 R 2	14.245	23.269				
3 R 2	9024					
2 R 1	12.125	24.476	54105			
1 R 1	12.351					
2 R 2	13.400	29.629				
1 R 2	16.229					

Section No. 1 について示すと上表のとおりである。材積は㎥、Yはgroupとなる。

グループ数と観測個数（ base plot 数 ）については、

	Eight	Quarter	Half	Section	Total
Number of	n	$N_q = nk$	$N_h = nkq$	$Ns = nkqh$	$N = nkqhS$
groups	2	4	8	16	112
Number of	$K = kQ$	$Q = qH$	$H = hS$	S	1
observations	56	28	14	7	1

ここに　n＝k＝g＝h＝ 2 、それは半分づつ切つていつたからである。

分散分析は、

Source	df	ssg	msg	F
Section groups	S−1＝6	Bs−c	s^2_S	s^2_S / s^2_H
Half groups	H−S＝7	BH−Bs	s^2_H	s^2_H / s^2_Q

Quarter groups	Q−H=14	BQ−BH	s^2_Q	s^2_Q / s^2_E
Eight groups	K−Q=28	BE−BQ	s^2_E	s^2_E / s^2_W
Error	N−K=56	A−BE	s^2_W	
Total	N−1=111	A−C		

として取り扱つかつた。

$$A = \sum_s\sum_h\sum_q\sum_k\sum_\alpha y^2_{shqk\alpha} = 12579.1641$$

$$BE = \sum_s\sum_h\sum_q\sum_k \left(\frac{Y^2_{shqk}}{n}\right) = 11385.8528$$

$$BQ = \sum_s\sum_h\sum_q \left(\frac{Y^2_{shq}}{N_q}\right) = 10781.7767$$

$$BH = \sum_s\sum_h \left(\frac{Y^2_{sh}}{N_h}\right) = 10623.1325$$

$$BS = \sum_s \left(\frac{Y^2_s}{N_s}\right) = 10230.6254$$

$$C = \frac{Y^2}{N} = \frac{(1056.791)^2}{112} = 9971.4870$$

その期待値は一般には

$$E\{A\} = E\{\sum\sum\sum\sum\sum y^2\} = N\mu^2 + N\sigma^2_s + N\sigma^2_h + N\sigma^2_q + N\sigma^2_k + N\sigma^2_E$$

$$E\{BE\} = E\{\sum\sum\sum\sum \frac{Y^2_{shqk}}{n}\} = N\mu^2 + N\sigma^2_s + N\sigma^2_h + N\sigma^2_q + N\sigma^2_k + K\sigma^2_E$$

$$E\{BQ\} = E\{\sum\sum\sum \frac{Y^2_{shq}}{N_q}\} = N\mu^2 + N\sigma^2_s + N\sigma^2_h + N\sigma^2_q + \sum\frac{n^2}{N_q}\sigma^2_k + Q\sigma^2_E$$

$$E\{BH\} = E\{\sum\sum \frac{Y^2_{sh}}{N_h}\} = N\mu^2 + N\sigma^2_s + N\sigma^2_h + \sum\frac{N_q^2}{N_h}\sigma^2_q + \sum\frac{n^2}{N_h}\sigma^2_k + H\sigma^2_E$$

$$E\{Bs\} = E\{\sum \frac{Y^2_s}{N_s}\} = N\mu^2 + N\sigma^2_s + \sum\frac{N_h^2}{N_s}\sigma^2_q + \sum\frac{n^2}{N_s}\sigma^2_k + S\sigma^2_E$$

$$E\{C\} = E\{\frac{Y^2}{N}\} = N\mu^2 + \sum\frac{N_s^2}{N}\sigma^2_s + \sum\frac{N_h^2}{N}\sigma^2_h + \sum\frac{N_q^2}{N}\sigma^2_q + \sum\frac{n^2}{N}\sigma^2_k + \sigma^2_E$$

$E\{ssq_S\} = E\{Bs\} - E\{C\}$ であるから σ^2_k, σ^2_q, σ^2_h, σ^2_s の coefficients は

$$\sum\frac{n^2}{N_s} - \sum\frac{n^2}{N} = \frac{n^2kqhS}{nkqh} - \frac{n^2kqhS}{nkqhS} = Sn - n = n(S-1)$$

$$\sum\frac{Nq^2}{Ns}-\sum\frac{Nq^2}{N}=\frac{Sn^2k^2qh}{nkqh}-\frac{n^2k^2qhS}{nkqhS}=Snk-nk=nk(S-1)$$

$$\sum\frac{Nh^2}{Ns}-\sum\frac{Nh^2}{N}=\frac{n^2k^2q^2hS}{nkqh}-\frac{n^2k^2q^2hS}{nkqhS}=Snkq-nkq=nkq(S-1)$$

$$N-\sum\frac{Ns^2}{N}=nkqhS-\frac{n^2k^2q^2h^2S}{nkqhS}=Snkqh-nkqh=nkqh(S-1)$$

従って

$$E\{\frac{ssqS}{S-1}\}=\sigma_E^2+n\sigma_k^2+nk(\sigma_q^2)+nkq\ \sigma_h^2+nkqh\sigma_s^2$$

同様にして

$$E\{\frac{ssqH}{H-S}\}=\sigma_E^2+n\sigma_k^2+nk\sigma_q^2+nkq\ \sigma_h^2$$

$$E\{\frac{ssqQ}{Q-H}\}=\sigma_E^2+n\sigma_k^2+nk\sigma_q^2$$

$$E\{\frac{ssqK}{K-Q}\}=\sigma_E^2+n\sigma_k^2$$

$$E\{\frac{ssqW}{N-K}\}=\sigma_E^2$$

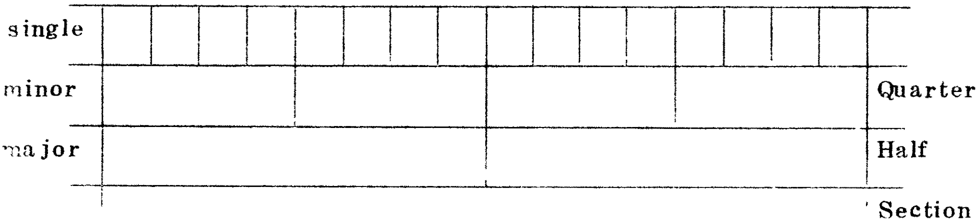
以上から分散分析の結果を検討すると、まず全体についての分散分析は

Source	SS	df	MS	
Between Section	259.1384	6	43.1897	$\sigma_E^2+2\sigma_h^2+4\sigma_q^2+8\sigma_h^2+16\sigma_s^2$
Between Half, within Section	392.5071	7	56.0724	$\sigma_E^2+2\sigma_k^2+4\sigma_q^2+8\sigma_h^2$
Between Quarter, within Half	158.6442	14	11.3317	$\sigma_E^2+2\sigma_k^2+4\sigma_q^2$
Between Eight, within Quarter	604.0761	28	21.5741	$\sigma_E^2+2\sigma_k^2$
Within Eight (Error)	1193.3113	56	21.3091	σ_E^2
Total	2607.6771	111		

$$\frac{SM^2}{SQ^2}=\frac{56.0724}{11.3317}=4.9483^{**}$$

$$\frac{SH^2}{SE^2}=\frac{56.0724}{21.3091}=2.6314^{*}$$

からみてEight(20m×40m)、Quarter(40m×40m)の効果はみとめられず Half(40m×80m)はError項に対し5%の有意である。したがつてもし$\sigma_k^2=\sigma_q^2=0$とみとて$\sigma_h^2 \neq 0$として Quarterをminor，Halfをmajor groupとみたて、



分散分析をすると

Source	SS	df	MS	F
Between major(half)(BH−C)	651.6455	13	50.1266	2.34*
Between minor (quarter) within major(BQ−BH)	158.6442	14	11.3317	
Within minor quarter(A−BQ)	1797.3874	84	21.3975	
Total (A−C)	2607.6771	111		

となり理論的にてはHalfをBlockとして各Block毎2plotをとるRepresentative sampling いこのような林分ては適当であろう。今majorをSectionとしminorをQuarterとすると、この分散分析は下表の通りで有意である。

source	SS	df	MS	F
Between Section(Bs−C)	259.1384	6	43.1897	2.018
Between Quarter,within Section(BQ−Bs)	551.1514	21	26.2453	
Within Quarter(A−BQ)	1797.3874	84	21.3975	
Total	2607.6772	111		

以上のことから、森林が川添国有林のような天然生林の場合は全体を40m×80mのBlockに切り、その中から2個の20m×20m plotをとり、2つのplot材積の差の2乗の和を用いて、

Block Sum $\sum'(X_1+X_2)$

その分散 $\sum(X_1-X_2)^2$

ら $V[\sum'(X_1+X_2)]=\sum'[(X_1-X_2)^2](\frac{3}{4})$

としそのD.F.はBlock個数となる。全体的には25%の抽出となるので未開発林調査ではもっとBlockを大きくするためには調査費用との比較考察が必要となるであろう。

天然生林（九州・広葉樹）の材積変動を前掲分散分析表から算出すると

		CV
80m×80m	Between Section	69.6%
40m×80m	Between Half, within Section	79.4%
40m×40m	Between Quarter, within Half	35.7%
40m×20m	Between Eight, within Quarter	49.2%
20m×20m	Between plot, within Eight	48.9%
20m×20m	Between plot, within Total	51.4%

又20m×20m plot baseでの平均値の分布巾は次図の通りである。

（7月31日, 1969）

Volume Distributions due to Different plot Size, volumebase 2 0 m×2 0 m, Ebino Natural broad leaved Forest (㎥単位)