COMPLETE ENUMERATION FOREST INVENTORY VERSUS CLUSTER* SAMPLING METHOD APPLIED IN THE AMAZONIC RAIN FOREST.

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RESUMO

O objetivo desta pesquisa é comparar resultados obtidos através da enumeração completa com resultados de um inventário usando amostragem em conglomerado, sistematicamente distribuída na área inventariada de 3.012 hectares. A área deste estudo está localizada na Floresta Nacional de Tapajós, Município de Santarem, Estado do Pará.

A área total de 3.012 hectares foi topograficamente dividida em 36 blocos de trabalho, a maioria deles com superfície de 96 hectares, com dimensões de 800 x 1200 m, para facilitar o inventário sob enumeração completa. Foram medidos o diâmetro, altura comercial e as coordenadas X e Y de todas as árvores com DAP maior ou igual a 55 cm. Isto permitiu a construção de mapas para todos os blocos apresentando a distribuição espacial destas árvores, numa escala de 1:1000.

O volume total e o número de árvores obtidas da enumeração completa, distribuídos por classe de diâmetro e por espécie foram considerados como parâmetros verdadeiros da população. Assim foram comparados estes parâmetros com os seus respectivos valores estimados obtidos através da amostragem em conglomerados, para as principais espécies encontradas na área.

1. INTRODUCTION

Quantitative and qualitative information from forestry lands can be obtained through the measurement of all trees of the forest, or by measuring the trees in small compartments scattered over the area. The first case involves a complete enumeration or a hundred percent forestry inventory, while the second case refers to the use of sampling technic.

Although the complete enumeration inventory does not contain sampling errors, it envolves high costs when compared with use of sampling methods. For this reason it has been used almost only in small areas for research purposes, or in areas with timbers of large dimension and high commercial values.

Examples of complete enumeration forestry inventory in the Amazonic region are those carried out by EMBRAPA, in the Tapajós and by SUDAM in Curuá-Una.

These works carried out in small areas aiming mainly researches in the field of forestry explotation, gave data which have been used also for other important research (SUDAM, 1978; BARROS, 1980; SILVA, 1980).

Cluster sampling has been the technic most used in forestry inventories in the Brazilian Amazon because of the difficult access and large extension of these rain forests. Each cluster is formed by 4 sub-units in the form of a cross. A research developed by QUEIROZ, (1977) concluded that the coefficient of variation inter clusters in the form of a cross with 20 m of width stabilized when the area of each sub-unit was approximately 0,32 ha, and that the distance of each arm of the cross should be between 50 and 100 m.

In 1983 the Brasilian Institute for Forestry Development (IBDF) contracted the Foundation for Forestry Research (FUPEF) to carry out a complete enumeration forestry inventory and to map all trees with DBH greater or equal to 55 cm, in an exploitation area of 1000 hectares located in the National Forest of Tapajós, in the State of Para. The success of this work, encouraged the IBDF to contract the FUPEF again to carry out the same kind of inventory in another exploitation area of 3012 hectares located in the same National Forest. The data of this second survey were used for comparison in this paper.

Athougt it would be possible to compare results for all the 210 tree species found in this area, comparisons were made only for the most important com-

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mercial species, to restrict the size of this paper. Results for all species can be gotten from the original report presented to the IBDF.

2. MATERIALS AND METHODS

Location and characteristics of the area under study

The area in question belongs to the Tapajós National Forest, which is located along the santarem-Cuiaba road, in the county of Santarem, State of Para. Especifically this area is located in the plateau of the Tapajós River.

The soils of this area are characterized by the dominance of distrophic yellow latosoils with different texture, covered by a dense forest. According to Holdridge's (1967) classification, the life zone is that of the tropical rain forest, with small temperature variation during the year. The precipitation varies from 1750 to 2000 mm annually, presenting a rainy season and a drier season.

Division of the area

The whole area of 3012 ha was topographycally divided in small work compartments, called blocks, by using a theodolite. Most of the blocks have an area of 96 ha, with dimensions of 800 x 1200 m. FIGURE 1 shows this division in 36 blocks. Poles were set down on the ground every 50 m along the division lines to control distances.

Secondary trails were also opened every 100 m by using a compass to allow or facilitate the control of the full enumeration forest inventory and measurements of the coordinates x and y of every tree with DBH $\geq$ 55 cm. Thus the work was carried out strip by strip within every one the 36 blocks.

These trails were opened in the small dimension of the blocks, that is, every trail has 800 m length and a north-south direction.

Sampling

A part from the complete enumeration forestry inventory of all trees equal and above 55 cm of DBH, the IBDF asked for a sub sampling, to have in addition, information of the trees above 20 cm of DBH. Thus it was planned to set down a cluster sampling, systematically distributed in the center of every one block which fits a cluster with dimension as specified in the FIGURE 2. It was set down and measured 29 clusters.

This sub-sampling made possible the comparison between results obtained from the full enumeration forestry inventory and from the cluster sampling.

The sub-sampling was used as a way of controlling the full enumeration work, and was done only by the supervisor of the field crews.

Measurements

The following measurements were done in the complete enumeration work:

— Circunference at breast height or at the end of buttress, with a tape.
— Height from the ground or from the end of the buttresses until the first bifurcation, measured with Blum-Leis hipsometer.
— Coordinates x and y of every tree, with a tape of 50 m.
— Numeration of every tree with a numbered tag affixed on the stem of every tree.

Volume estimation

The volume estimation was made by the equation previously developed by SILVA (1980), who cubed 900 trees in this forest, distributed in all diameter classes. He tested several equations, but the most satisfactory results were obtained with the equation:

$$1_n V = -8{,}970w4 + 1.97011\ 1_n d + 0.738348\ 1_n h$$ where:

V = commercial volume without bark in m^3
d = diameter at breast height over bark in cm
h = commercial height in m.

List of compared species

The forest inventory resulted in 210 forest species in the area. The local IBDF

staff gave a list of 31 species which are the most important ones for local use and for export. There is not enough space for comparing all 210 species in this paper, thus it was decided to compare only the commercial tree species, as shown in the table 1.

Results and discussions

Twenty nine clusters were set down in every block wich fit a cluster with dimensions specified in the FIGURE 2; as each cluster has an area of 1,5 ha, the sample size is 43 ha. This means that the sample intensity was 1,43% of the total inventoried area of 3.012 ha.

The estimated inter cluster correlation coefficent of 0,12378 indicated that the inventoried area is homogeneous in volumetric terms. The complet enumeration forest inventory gave results to compare with those obtained from the cluster sampling forest inventory. TABLE 2 shows the main results coming from the 2 kinds of forest inventory, for the total of 210 tree species found in the area.

TABLE 2: Some Parameters from complete enumeration and from the cluster sampling forest inventory.

	Total Volume m^3	Number of trees	Average m^3/ha	Average trees/ha	Smapling error
True Parameter	292452,5	61661	97,1	20,5	—
Estimated Parameter	304569,8	63089	101,1	20,9	3,42%

The confidence interval for the mean is:

$$CI\ (90{,}6 \leq \mu \leq 103{,}6) = 95\%$$

Therefore the values for all species, when, compared, the estimated results, obtained from the applied sampling method with those obtained from the complete enumeration are very close, as shown, in TABLE 2. The estimated value is between the confidence interval, at 95% of probability. This means that the results obtained from the sampling method when all species are included prove very reliable. Meanwhile, if the same comparisons are made species by species the results are not reliable, at least not for all the species.

As prove of this argument TABLE 3 was prepared, containing volume under bark (V), and number of trees for the 30 commercially main species, obtained, booth from complete enumeration (true parameter) and from cluster sampling (estimated parameter). Deviation in percent was calculated by

$$\frac{(\text{TRUE VALUE} - \text{ESTIMATED VALUE})\ 100}{\text{TRUE VALUE}}$$

From the 30 listed species it can be seen that only Andiroba, Aroeira, Castanha do Pará, Louro vermelho, and Piquia presented deviation of less than 20%. From these 5 species, the first 3 are among the 5 species most numerous within TABLE 3. It was expected that the results from sampling of the most frequent species should be close to their true obtained from the complete enumeration. This expectation was not confirmed for "Maçaranduba and Jarana" which are among the most frequent species in the inventoried area. Both species seem to be homogeneonsly spread over the area, thus the fact that they did not appear in the sample was a question of sampling.

TABLE 3 shows that the results from cluster sampling were underestimated for 19 species, and overestimated for 11 species. The estimated volumes of the species "Jutai, Marupa, and Piquiarana" were much higher than theirs observed values, but they do not have a high frequency.

TABLE 4 presents results for all tree species by diameter class. This table is placed in this paper only for observation how reliable are the estimates by diameter class.

4. CONCLUSIONS

The total volume and number of trees for all species obtained from the cluster sampling were very close to their true values. Thus the estimates for the total are reliable.

The same parameters when compared at species level were not reliable. It was expected that these estimated parameters should be approximate from their true values, but this was not confirmed, at least for all the compared species.

Informations on volume and number of trees by diameter class were reliable when refers to the total of species, but not when these estimates are given at specie level.

5. SUMMARY

The objective of this paper is to compare results obtained from a complete enumeration forest inventory with results obtained from a cluster sampling method systematically distributed over the inventoried area. The area of this study is located in the Tapajós National Forest, in the tropical rain forest of the Braziliam Amazon.

The whole area of 3.012 hectares was topographically divided in 36 blocks, most of them with an area of 96 hectares, with dimensions of 800 m x 1200 m to facilitate the full enumeration forest inventory. The DBH, commercial height and the coordinates x and y were measured and ploted every tree above 55 cm of DBH, resulting in several maps containing the spatial distribution of these trees at a scale of 1:1000.

The total volume and number of trees obtained from the complete enumeration forest inventory distributed by diameter classes and by species were considered as the true parameter of the population. Thus the estimates of the same parameter obtained through the cluster sampling were compared with their true value. These comparisons will be made only for the principal species found in the area.

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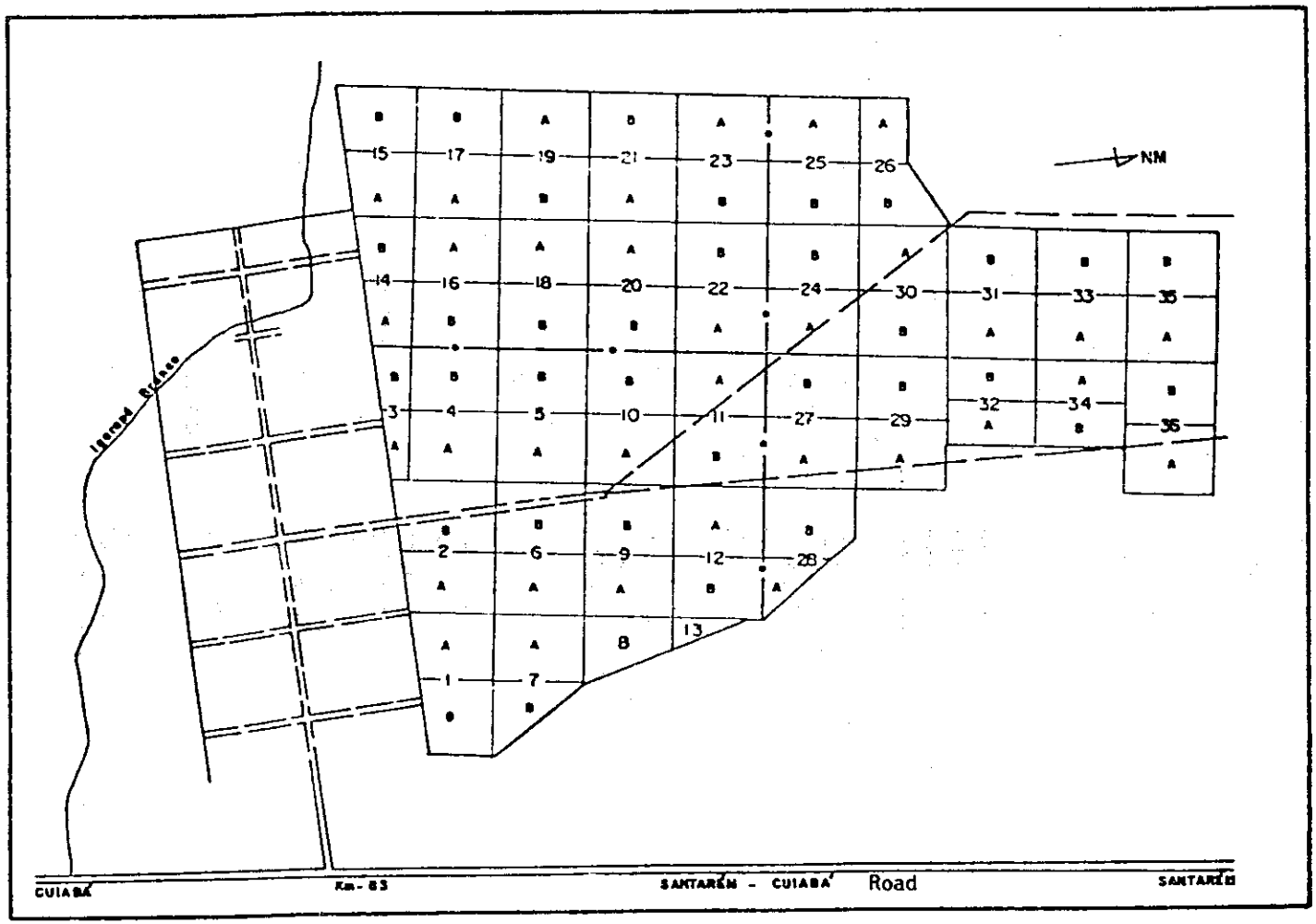

FIGURE 1: Division of the exploitation area in 36 work blocks.

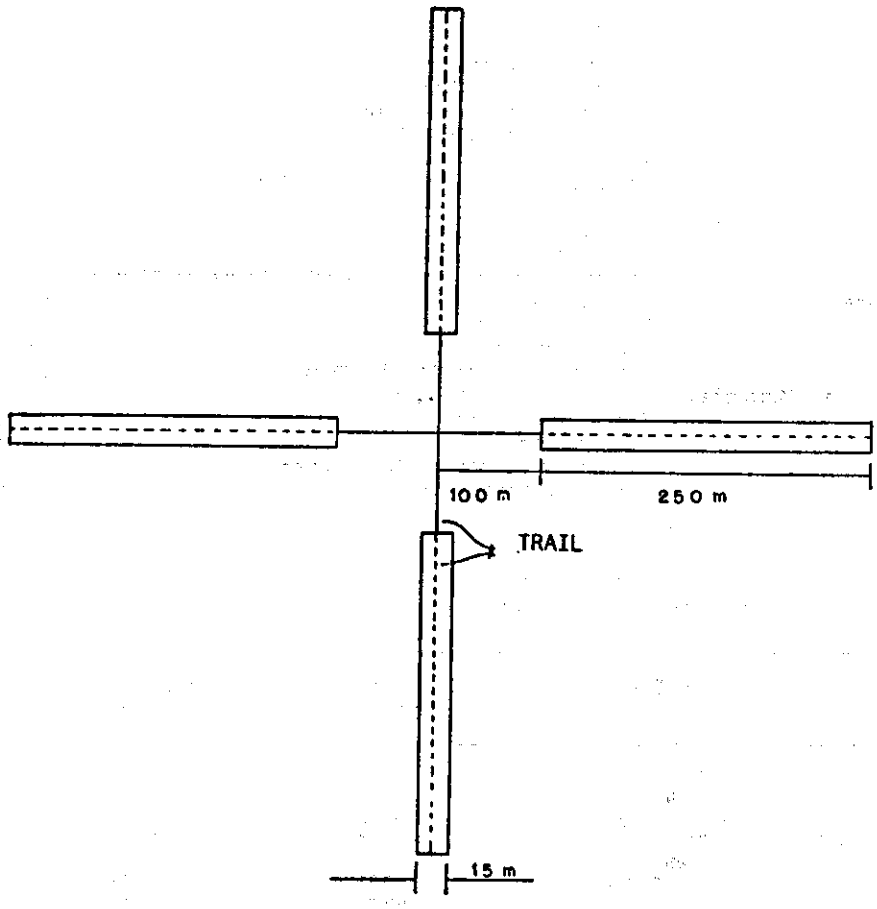

FIGURE 2: Form of the used sampling units (clusters) located on the center of each block.

TABLE 1: List of the commercial forestry species

Common name	Scientific name	Family
Andiroba	*Carapa guianensis* Aubl.	Meliaceae
Angelim-da-mata	*Hymenolobium excelsum* Benth.	Leguminosae
Angelim-rajado	*Pithecelobium racemosum* Ducke	Leguminosae
Aroeira (Muiracatiara)	*Astronomium* spp	Anacardiaceae
Castanha-do-pará (Castanheira)	*Bertholletia excelsa* Humbe e Bonpl	Lecythidaceae
Cedro	*Cedrela* sp	Meliaceae
Cedrorana	*Cedrelinga catenaeformis* Ducke	Leguminosae
Cumaru	*Dipteryx odorata* (Aubl. Willd)	Leguminosae
Freijó-branco	*Cordia bicolor* A. DC.	Boraginaceae
Jacareúba	*Callophyllum brasiliensae* Camb.	Guttiferae
Jarana	*Holopyxidium jarana* Ducke	Lecythidaceae
Jutaí	*Hymenaea intermedia* Ducke	Leguminosae
Jutaí-açu	*Hymenaea cf courbaril* L.	Leguminosae
Jutaí-mirim	*Hymenaea parvifolia* Huber	Leguminosae
Jutaí-pororoca	*Dialium guianensis* D. C.	Leguminosae
Louro-amarelo	*Aniba* sp	Lauraceae
Louro-vermelho	*Nectandra rubra* (mecz) C. K. Allen	Lauraceae
Maçaranduba	*Manilkara huberi* Ducke	Sapotaceae
Maparajuba	*Manilkara amazonica* Hub.	Sapotaceae
Marupá	*Simaruba amara* Aubl.	Simarubaceae
Morototó	*Didymopanax morototoni* (Aubl.) Decne et Planch	Araliaceae
Pau-d'arco-amarelo	*Tabebuia serratifolia* Rolfe	Bignoniaceae
Pau-d'arco-roxo	*Tabebuia violaceae* Hub.	Bignoniaceae
Piquiá	*Caryocar nillosum* Aubl.	Caryocaraceae
Piquiarana	*Caryocar glabrum* (Aubl.) Pers	Caryocaraceae
Quaruba-verdadeira (Quaruba)	*Vochysia maxima* Ducke	Vochysiaceae
Quarubarana	*Erisma uncinatum* Warm	Vochysiaceae
Sucupira-amarela	*Vatairea sericea* Ducke	Leguminosae
Sucupira-preta (Sucupira)	*Diplotropis purpurea* (Rich) Amsh	Leguminosae
Tatajuba	*Bagasa guianensis* Aubl.	Moraceae

TABLE 3: Volume under bark and number of trees for several tree species obtained from complete enumeration and from cluster sampling forest inventory.

Common name	Variables	True Parameter	Estimated Parameter	Deviation %
ANDIROBA	V_{ub}	11720,27	13916,19	— 18,74
	N.of. TREES	3602	4006	— 11,22
ANGELIM-DA-MATA	V_{ub}	1403,94	468,13	+ 66,66
	N.of. TREES	181	66	+ 63,54
ANGELIM-RAJADO	V_{ub}	189,65	0,00	+ 100,00
	N.of. TREES	21	00	+ 100,00
AROEIRA (Muiracatiaria)	V_{ub}	6860,41	7873,10	— 14,76
	N.of. TREES	1144	1225	— 7,08
CASTANHA-DO-PARÁ	V_{ub}	8799,47	9930,82	— 12,86
	N.of. TREES	906	1296	— 43,05
CEDRO	V_{ub}	1342,22	1022,52	+ 23,82
	N.of. TREES	237	198	+ 16,46
CEDRORAMA	V_{ub}	15,40	0,00	+ 100,00
	N.of. TREES	05	00	+ 100,00
CUMARU	V_{ub}	1619,71	949,02	+ 41,41
	N.of. TREES	302	198	+ 34,44

FREIJO-BRANCO	V ub	805,83	1003,26	— 24,50
	N.of. TREES	241	202	+ 16,18
JACAREUBA	V ub	7,60	0,00	+ 100,00
	N.of. TREES	02	00	+ 100,00
JARAMA	V ub	11407,87	0,00	+ 100,00
	N.of. TREES	2574	00	+ 100,00
JUTAÍ	V ub	279,27	6784,56	— 2.329,39
	N.of. TREES	79	740	— 836,71
JUTAÍ-AÇU	V ub	6053,56	672,70	+ 88,89
	N.of. TREES	727	132	+ 81,84
JUTAÍ-MIRIM	V ub	1361,05	911,07	+ 33,06
	N.of. TREES	285	202	+ 29,12
JUTAÍ-POROROCA	V ub	572,68	0,00	+ 100,00
	N.of. TREES	147	00	+ 100,00
LOURO-AMARELO	V ub	776,92	0,00	+ 100,00
	N.of. TREES	199	00	+ 100,00
LOURO-VERMELHO	V ub	1691,55	1971,31	— 16,54
	N.of. TREES	255	476	— 86,67
MAÇARANDUBA	V ub	24429,84	0,00	+ 100,00
	N.of. TREES	4666	00	+ 100,00
MAPARAJUBA	V ub	831,95	302,77	+ 63,60
	N.of. TREES	214	66	+ 69,16
MARUPÁ	V ub	488,83	6929,82	— 1317,63
	N.of. TREES	126	1998	— 1485,71
MOROTOTÓ	V ub	449,79	186,89	+ 58,45
	N.of. TREES	122	66	+ 45,90
PAU-D'ARCO-AMARELO	V ub	2558,80	598,24	+ 76,62
	N.of. TREES	316	66	+ 79,11
PAU-D'ARCO-ROXO	V ub	2500,95	3044,22	— 21,72
	N.of. TREES	288	681	— 136,45
PIQUIÁ	V ub	3368,33	2772,97	+ 17,67
	N.of. TREES	341	136	+ 60,11
PIQUIARAMA	V ub	385,76	2809,11	— 628,20
	N.of. TREES	46	472	— 926,09
QUARUBA VERDADEIRA	V ub	4053,82	5573,05	— 37,48
	N.of. TREES	451	880	— 95,12
QUARUBARANA	V ub	6209,19	2766,74	+ 55,44
	N.of. TREES	894	957	— 7,06
SUCUPIRA-AMARELA	V ub	427,06	556,59	— 30,33
	N.of. TREES	112	66	+ 41,07
SUCUPIRA-PRETA	V ub	384,94	0,00	+ 100,00
	N.of. TREES	82	00	+ 100,00
TATAJUBA	V ub	2886,53	332,77	+ 88,47
	N.of. TREES	424	136	+ 67,92

TABLE 4: Parameter for the whole area and for all tree species found in the area, by diameter class.

DBH Class	True parameter		Estimated parameter	
	Volume m³	n. of Trees	Volume m³	n. of Trees
60	63199,2	23962	66485,0	23819
70	55047,1	14794	59830,0	14780
80	46346,8	9337	55570,8	10590
90	39551,3	6081	45828,8	6753
100	30399,9	3902	33350,9	4066
110	14640,6	1458	12407,0	1069
120	8813,6	728	9335,1	801
> 125	24453,9	1399	21660,8	1211
TOTAL	292452,5	61661	304568,4	63089