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Timber stock inventory in Amazon: simulations of cross-malt conglomerates sampling intensities

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ABSTRACT: A high diversity of tree species and a fact that only a few they have commercial value makes it difficult to establish appropriate sampling to characterize the timber stocks of tropical forests. In contrast, large inventories are needed to subsidize the identification, description, and bidding of public forests for concession. The aim of this study was to evaluate the effectiveness of the cross-malt conglomerate in different sampling intensities to estimate the commercial volume of tree species and their susceptible to exploitation in an Amazon forest under concession. For this, a sampling process in cross-malt conglomerates was simulated with intensities of 20 (0.5%), 40 (1%), 60 (1.5%), 80 (2%), and 100 (2,5%) sampling units from a forest census. The intensity of 100 sampling units was adequate to sampling the timber stock in natural forests, since it generated sampling errors close to or less than 10% established by law. The detection of species susceptible for exploration and the characterization of floristic composition of the tree stratum were other advantages observed. Thus, sampling by cross-malt conglomerates with first random stage is recommended for inventories of production forests in Amazon.

Key words: forest concession; forest production; sampling procedures; timber species

Inventário do estoque madeireiro na Amazônia: simulações de intensidades amostrais por conglomerados em cruz-de-malta

RESUMO: A elevada diversidade de espécies arbóreas e o fato de apenas algumas possuírem valor comercial dificulta o estabelecimento de amostragens adequadas à caracterização dos estoques madeireiros das florestas tropicais. Em contrapartida, os inventários de extensas áreas são necessários para subsidiar a identificação, a descrição e a licitação de florestas públicas para concessão. Este estudo teve como objetivo avaliar a eficácia do conglomerado em cruz-de-malta em diferentes intensidades amostrais para a estimativa do volume comercial das espécies arbóreas e das passíveis de exploração em uma floresta sob concessão na Amazônia. Para isso, o processo de amostragem em conglomerados foi simulado nas intensidades de 20 (0,5%), 40 (1%), 60 (1,5%), 80 (2%) e 100 (2,5%) unidades amostrais a partir de um censo. A intensidade de 100 unidades amostrais foi adequada para amostrar o estoque madeireiro em florestas naturais, uma vez que gerou erros de amostragem próximos ou inferiores à 10% estabelecido pela legislação. A detecção das espécies passíveis de exploração e a caracterização da composição florística do estrato arbóreo foram outras vantagens observadas. Assim, a amostragem por conglomerados em cruz-de-malta com primeiro estágio aleatório é recomendável para inventários de florestas de produção na Amazônia.

Palavras-chave: concessão florestal; floresta de produção; processo de amostragem; espécies madeireiras

Introduction

The Amazon Forest has natural potentialities that provide innumerable possibilities for sustainable development by having one of the largest tropical wood reserves in the world (Silva et al., 2016). Due to the intense deforestation in the Brazilian Amazon, whose degradation reached about 20,000 km² between 2010 and 2011 (Hansen et al., 2013), the global attention has been raised for the protection of this natural resource (Bauch et al., 2009). However, the fragility of its environments indicates the priority need to know the composition and distribution of the species (Oliveira et al., 2008) through forest inventories, besides identification and quantification of the species of economic interest present in the areas under forest management.

In the current scenario of forest concessions in Brazil, phytosociological and floristic inventories of large areas are necessary for the selection and description of eligible forests, in order to subsidize bids as described in Normative Instruction No. 5 of 2006 (Brazil, 2006) and in Execution Standard No. 1 of 2007 (Brazil, 2007) under force in the country. In tropical forests, the high diversity of tree species and the fact that few have commercial value (Akindele & LeMay, 2006) entail high spatial variability that makes it difficult to establish adequate samplings for the characterization of timber stocks.

During the last decades, several sampling processes have been tested in the Amazon forests, aiming at accurate estimates of the timber stock (Cavalcanti et al., 2009; 2011; Ubialli et al., 2011; Queiroz et al., 2011; Oliveira et al., 2014; Péllico Netto et al., 2017). However, the random and systematic processes, combined with different sizes and conformations of fixed area sample units, have been advocated. On the other hand, sampling by Maltese cross conglomerate arises from the proposal of systematically grouping sample subunits to reduce displacement costs in the field (Queiroz et al., 2011), as currently required by the national forest inventory (SFB, 2017).

In this sense, the present study aims to evaluate the effectiveness of the Maltese cross conglomerate in different sample intensities for the sampling of the commercial volume of the tree species and of the possible exploitation in a forest under concession in the Amazon. For this purpose, the hypothesis was that the improvement of the sampling by conglomerates by means of the definition of suitable sample intensities, allows the precise evaluation of the wood potential and the detection of species of commercial and ecological interest in the natural forests.

Material and Methods

The study was carried out in the Jamari National Forest, in the state of Rondônia, between the geographic coordinates 09º00'00" to 09º30'00" S and 62º44'05" at 63º16'64" W. We used the forest census of an area of 1,640 hectares, where all trees with diameter at 1.3 m of soil height (*d*) equal to or greater than 40 cm were measured, identified and georeferenced in a geographic information system. Subsequently, volumes at the commercial height (*h*) were estimated by the equation $\ln(v) = -8.2324 + 0.8631.\ln(d^2.h)$, developed for the study area (Cysneiros et al., 2017).

Sampling units were allocated to Maltese cross conglomerates composed of four subunits of 20 x 100 m, in which the first level was random and the second was systematic, as adopted by the Brazilian Forest Service for the national forest inventory in the Amazon (SFB, 2017). The sample intensities evaluated according to the number of sample units (s.u.) and the percentage of the sampled area were: 20 s.u. (0.5%), 40 s.u. (1%), 60 s.u. (1.5%), 80 s.u. (2%) and 100 s.u. (2.5%). For this purpose, a grid drawn with 100 units was started and, from this, the other samplings were allocated (Figure 1).

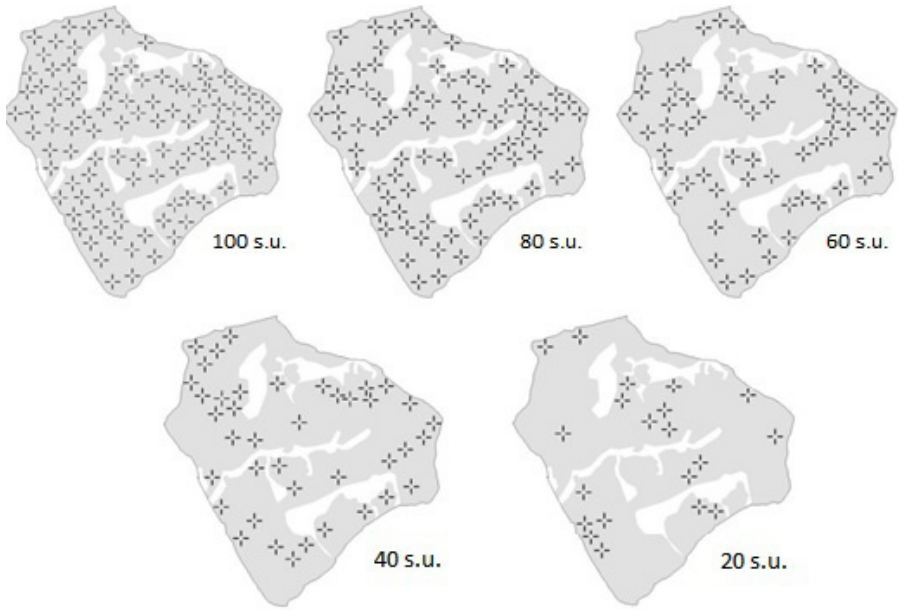

Figure 1. Conglomerate allocation schemes for simulated samplings in a forest management area in the Jamari National Forest.

Subsequently, Bootstrap simulations with one thousand resamples with replacement were performed for each sample intensity, using the boot package (Canty & Ripley, 2017) of the R (R Core Team, 2015) computer program. This allowed evaluating the distribution of the means in each sample intensity to estimate the volumes, as well as to determine the confidence intervals for 95% probability. In addition, the intra- conglomerate correlation coefficient was evaluated, which expresses the degree of dependence between the subunits of the conglomerate (Queiroz et al., 2011), where the limits of $0 \leq r \leq 0.4$ are recommended as acceptable. Otherwise, other sampling procedures may be more appropriate (Péllico Netto & Brena, 1997).

Finally, the efficacy of Maltese cross conglomerates for species detection was evaluated through the species accumulation curve with successive randomization and resampling procedures (Schilling & Batista, 2008) in the computational program EstimateS (Colwell, 2013). The application of this procedure aimed at evaluating the stability of the sample and defining adequate sampling for species composition.

Results

In the forest census, 17,557 individuals were registered in 67 botanical species, of which 32 were considered commercial and could be exploited. Thus, the forest had an average density of 10.7 trees ha^{-1}, mean baseline area of 5.27m^2 ha^{-1} and average total commercial volume of 61.14 m^3 ha^{-1}. Considering only commercial species, these values were, respectively, equal to 6.43 trees ha^{-1}, 3.16 m^2 ha^{-1} and 36.3 m^3 ha^{-1}.

Table 1 presents the descriptive statistics of the estimates generated by the different treatments. It was possible to observe that, with the increase in sample intensity, there was a reduction of the coefficient of variation (CV(%)), reaching 9.97% and 22.2%, respectively, for the total commercial volume and 11.71% and 29.04% for the exploitable commercial volume, as well as reduction of the sampling errors in percentage (E%).

Table 1. Descriptive statistics of total and exploitable commercial volumes estimated by sample intensities of conglomerates in a forest management area in the Jamari National Forest.

Statistics	Sample intensities (s.u.)				
	20	40	60	80	100
	Total commercial volume				
$\bar{y}$ (m^3 ha^{-1})	61.88	56.84	65.18	67.08	64.42
CV (%)	25.24	24.62	23.19	22.64	22.2
$s_{\bar{x}}$ (m^3 ha^{-1})	1.78	1.34	1.02	0.95	0.81
E%	24.15	19.04	12.58	11.25	9.97
r	0.01	0.15	0.07	0.08	0.00
Number of species	45	49	52	55	55
	Exploitable commercial volume				
$\bar{y}$ (m^3 ha^{-1})	39.27	32.77	37.41	38.72	37.67
CV (%)	32.39	30.17	29.52	29.48	29.04
$s_{\bar{x}}$ (m^3 ha^{-1})	1.16	0.92	0.68	0.65	0.55
E%	24.79	22.82	14.52	13.31	11.71
r	0.00	0.07	0.00	0.02	0.00
Number of species	31	31	31	31	31

y = sample average; CV (%) = coefficient of variation; S_x = standard error; E% = sampling error in percentage; and *r* = intra-conglomerate correlation coefficient.

The intra-conglomerate correlation coefficients (Table 1) presented values within acceptable limits ($0 \leq r \leq 0.4$), indicating the effectiveness of the sampling process in conglomerates to estimate wood stocks. Additionally, the distribution of the means obtained by the simulations of the sample intensities (Figure 2) evidenced the stability of the commercial volume estimates. This analysis indicated lower confidence intervals (CI) for intensities of 60 s.u. (Figure 2C), 80 s.u. (Figure 2D) and 100 s.u. (Figure 2E) for the commercial volume of all species, as well as for the intensities of 60 s.u. (Figure 2H), 80 s.u. (Figure 2I), and 100 s.u. (Figure 2J) for the exploitable commercial volume.

The sampling in conglomerates presented adequate performance for the detection of the species (Table 1), noting the presence of 55, corresponding to 82% of all the species contemplated by the inclusion diameter. As for commercial

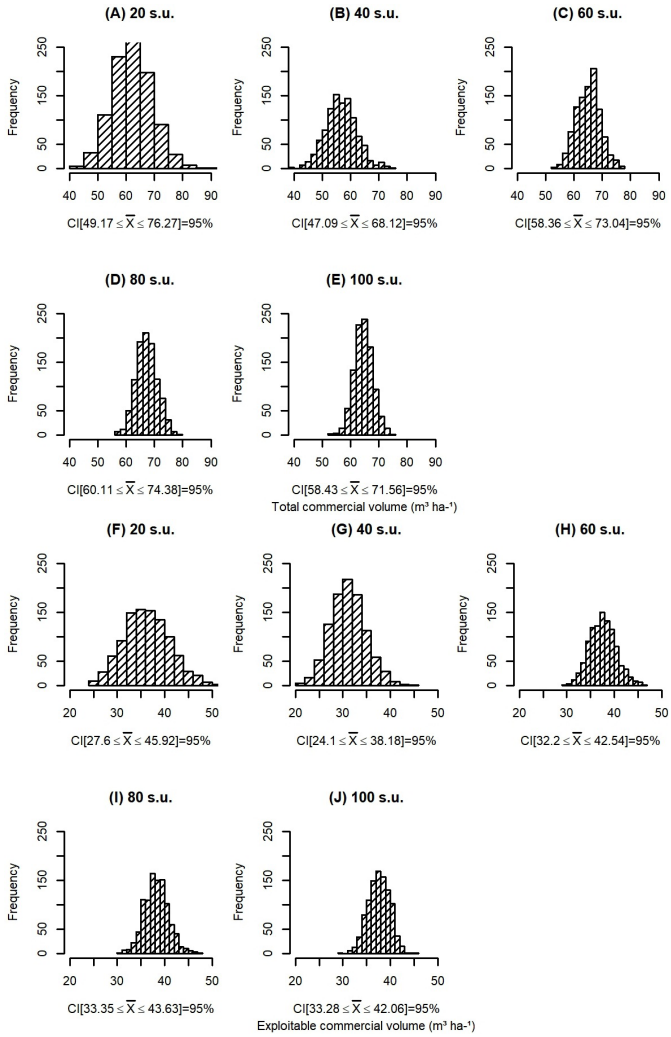

Figure 2. Distribution of the averaged of total commercial volume (A to E) and exploitable commercial volume (F to J) in simulations of sampling intensities in conglomerates in a management area in the Jamari National Forest.

species, this efficiency was also observed, since the lowest sampling intensity (20 s.u.) was sufficient for the detection of 31 of the 32 commercial species, where the only species not detected by the different intensities was *Hymenaea intermedia* Ducke, which corresponds to 0.35% of the individuals present. The species accumulation curve (Figure 3) reinforces the performance of the sampling process, with a tendency to stabilize from approximately 60 s.u. for the total tree species and 40 s.u. for the exploitable ones.

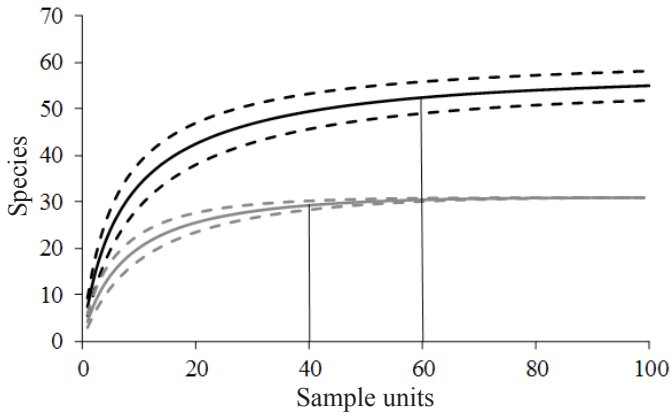

Figure 3. Accumulation curve and deviations for the total of tree species (black) and exploitable species (gray) sampled in a forest management area in the Jamari National Forest.

Discussion

The number of tree species found was a reflection of the sampling criterion, which included only large trees with *d* equal to or greater than 40 cm. However, the results are compatible with other studies that used inclusion criteria for trees with larger diameters, such as Ubialli et al. (2009), with 70 species and 30 cm as the lower limit of inclusion, and Cavalcanti et al. (2009), with 60 species and 40 cm of minimum diameter.

Considering all the tree species of the area under management in the Jamari National Forest, the values of density (trees ha^{-1}) and baseline area (m^2 ha^{-1}) were low when compared to the sampling studies performed in Acre (Cavalcanti et al., 2011) and in Mato Grosso (Ubialli et al., 2009). However, when analyzing only the commercial species, these values are compatible with the results of Cavalcanti et al. (2009).

The decrease observed in the coefficient of variation and the sampling errors (Table 1) are expected with increasing sampling intensity (Cavalcanti et al., 2009), mainly because larger areas of sampling are more effective in contemplating the variability of the population. However, the excessive increase in the area sampled or the sampling intensity may lead to an increase in the costs of implementing forest inventories.

The 10% percentage error (E%) established by Implementing Rule no. 1 of 2007 for inventories in natural forests was reached for commercial volume at the highest sampling intensity (Table 1). For the total commercial volume, the error was only 1.71% higher than the one established for 100 s.u., indicating the effectiveness of the sampling process in conglomerates to evaluate the timber stock of production forests in the Brazilian Amazon.

The stability of the average in most treatments reflected the effectiveness of the cross conglomerate to sample the timber stock of natural forests. However, the reduction in the estimated mean by the treatment of 40 s.u. (Figure 2) was a reflection of the occurrence of sample units with lower volumes. These sample units may be inserted in Open Ombrophilous Forest areas, which has a lower stock of wood compared to the Dense Ombrophilous Forest (IBGE, 2012).

For the exploitable commercial volume, the reduction of its average was affected by the presence of zero plots, which may compromise the quality of the estimators (Péllico Netto et al., 2017). The outliers detected by treatments with 60 or more sample units (Figure 2) are common in this forest, reflecting the presence of large trees, such as *Berthollethia excelsa* Bonpl., *Cariniana micranta* Ducke, *Couratari stellata* A. C. Sm., *Dinizia excelsa* Ducke and *Hymenolobium heterocarpum* Ducke, that can present more than 30 m^3 in only one tree (Cysneiros et al., 2017).

The use of Maltese cross conglomerates for natural forests in the Amazon was recommended by Ubialli et al. (2009), who cited the optimization in the measurement time of the secondary units as an advantage. In the present study, the intra-conglomerate correlation coefficient met the acceptable limit condition (Table 1) in all sample intensities, indicating that the sampling process is adequate for estimating the timber stock in natural forests with high tree diversity.

Stabilization of the species accumulation curve (Figure 3) indicated that sampling intensities reached adequate sampling adequacy (Schilling & Batista, 2008), demonstrating the flexibility of the sampling process to characterize the floristic aspects of mature trees in the forest. The importance of this observation is related to the fact that tropical forests present high species diversity, in which only a few have commercial value (Akindele & LeMay, 2006). Stabilization of the accumulation curve for commercial species at lower sampling intensities (Figure 3) indicated that they are widely distributed in the area and that conglomerates were suitable for sampling them.

The Maltese cross conglomerates inventory in this study for different sampling intensities meets the prerogatives of the Implementing Rule no. 1 of 2007 of the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), which determines the limit of error of maximum 10% around the sample mean and probability level of at least 0.95 for commercial inventories in natural forests (Brazil, 2007). Thus, its application is recommended for reconnaissance inventories, in order to select areas suitable for the forest concession and to subsidize the bids for sustainable forest management.

Conclusions

The process of Maltese cross conglomerates sampling is adequate to quantify the total commercial and exploitable timber stocks in natural forests of the Amazon. This process is also appropriate for the detection of exploitable species and for the characterization of the floristic composition of the arboreal stratum.

In order to evaluate the timber inventory and floristic composition in extensive forest areas, it is recommended to use intensities greater than 1.5% of the potential number of sample units, as well as a wide spatial distribution of the conglomerates, in order to cover all object areas of the forest inventory.

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Literature Cited

Akindele, S.O.; Lemay, V.M. Development of tree volume equations for common timber species in the tropical rain forest area of Nigeria. Forest Ecology and Management, v.226, n. 1-3, p.41-48, 2006. https://doi.org/10.1016/j.foreco.2006.01.022.

Bauch, S.; Sills, E.; Rodriguez, L.C.E.; Mcginley, K.; Cubbage, F. Forest policy reform in Brazil. Journal of Forestry, v.107, n. 3, p.132–138, 2009. https://www.fs.fed.us/global/iitf/pubs/ja_iitf_2009_bauch001.pdf. 06 Set. 2017.

Brasil. Instrução Normativa n. 5, de 11 de dezembro de 2006. Altera as diretrizes para o manejo florestal em escala empresarial na Amazônia. Diário Oficial da União, v.143, n. 238, seção 1, p.155-158, 2006.

Brasil. Norma de Execução n. 1, de 24 de abril de 2007. Altera as normas técnicas para o manejo florestal na Amazônia. Diário Oficial da União, v. 144, n. 82, seção 1, p.405, 2007.

Canty, A.; Ripley, B. Boot: bootstrap R (S-Plus) functions. R package version 1.3-20, 2017.

Cavalcanti, F.J.B.; Machado, S.A.; Hosokawa, R.T. Tamanho de unidade de amostra e intensidade amostral para espécies comerciais da Amazônia. Floresta, v.39, n.1, p.207-214, 2009. https://doi.org/10.5380/rf.v39i1.13740.

Cavalcanti, F.J.B.; Machado, S.A.M.; Hosokawa, R.T.; Cunha, U.S. Comparação dos valores estimados por amostragem na caracterização da estrutura de uma área de floresta na Amazônia com as informações registradas no censo florestal. Revista Árvore, v.35, n.5, p.1061-1068, 2011. https://doi.org/10.1590/S0100-67622011000600012.

Colwell, R.K. EstimateS: statistical estimation of species richness and shared species from samples. Version 9. 2013. http://purl.oclc.org/estimates. 22 Jan. 2017

Cysneiros, V.C.; Pelissari, A.L.; Machado, S.A.; Figueiredo Filho, A.; Souza, L. Modelos genéricos e específicos para estimativa do volume comercial em uma floresta sob concessão na Amazônia. Scientia Forestalis, v.45, n.114, p.295-304, 2017. https://doi.org/10.18671/sciforv45n114.06.

Hansen, M.C.; Potapov, P.V.; Moore, R.; Hancher, M.; Turubanova, S.A.; Tyukavina, A.; Thau, D.; Stehman, S.V.; Goetz, S.J.; Loveland, T.R.; Kommareddy, A.; Egorov, A.; Chini, L.; Justice, C.O.; Townshend, J.R.G. High-resolution global maps of 21st-century forest cover change. Science, v.342, n. 6160, p. 850-853, 2013. https://doi.org/10.1126/science.1244693.

Instituto Brasileiro de Geografia e Estatística - IBGE. Manual técnico da vegetação brasileira. 2 ed. Rio de Janeiro: IBGE, 2012. 271p.

Oliveira, M.M.; Higuchi, N.; Celes, C.H.; Higuchi, F.G. Tamanho e forma de parcelas para inventários florestais de espécies arbóreas na Amazônia Central. Ciência Florestal, v.24, n.3, p.645-643, 2014. https://doi.org/10.5902/1980509815744.

Oliveira, N.A.; Amaral, I.L.; Ramos, M.B.P.; Nobre, A.D.; Couto, L.B.; Sahdo, R.M. Composição e diversidade florístico-estrutural de um hectare de floresta densa de terra firme na Amazônia Central, Amazonas, Brasil. Acta Amazonica, v.38, n.4, p.627-642, 2008. https://doi.org/10.1590/S0044-59672008000400005.

Péllico Netto, S.; Brena, D.A. Inventário florestal. Curitiba: Editado pelos autores, 1997. 316p.

Péllico Netto, S.; Pelissari, A.L.; Cysneiros, V.C.; Bonazza, M.; Sanquetta, C.R. Sampling procedures for inventory of commercial volume tree species in Amazon forest. Anais da Academia Brasileira de Ciências, v.89, n.3, p.1829-1840, 2017. https://doi.org/10.1590/0001-3765201720160760.

Queiroz, W.T.; Péllico Netto, S.; Valente, M.D.R.; Pinheiro, J.G. Análise estrutural da unidade conglomerada em cruz de malta na Floresta Nacional do Tapajós, Estado do Pará, Brasil. Floresta, v.41, n.1, p.9-18, 2011. https://doi.org/10.5380/rf.v41i1.21175.

R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2015. http://www.R-project.org.

Schilling, A.C.E.; Batista, J.L.F. Curva de acumulação de espécies e suficiência amostral em florestas tropicais. Revista Brasileira de Botânica, v.31, n. 1, p.179-187, 2008. https://doi.org/10.1590/S0100-84042008000100016.

Serviço Florestal Brasileiro - SFB. Inventário florestal nacional. 2017. http://www.florestal.gov.br/inventario-florestal-nacional. 20 Jun. 2017.

Silva, K.E.; Martins, S.V.; Ribeiro, C.A.A.S.; Santos, N.T.; Azevedo, C. P. Structure of 15 hectares permanent plots of terra firme dense forest in Central Amazon. Revista Árvore, v.40, n.4, p.603-615, 2016. https://doi.org/10.1590/0100-67622016000400004.

Ubialli, J.A.; Figueiredo Filho, A.; Machado, S.A.; Arce, J.E. Comparação de métodos e processos de amostragem para estimar a área basal para grupos de espécies em uma floresta ecotonal da região norte mato-grossense. Acta Amazonica, v.39, n.2, p.305-314, 2009. https://doi.org/10.1590/S0044-59672009000200009.