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QUALITY ASSURANCE AND QUALITY CONTROL IN FOREST INVENTORIES IN TERRA FIRME FOREST IN AMAZONAS-BRAZIL

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Abstract: The main challenges of tropical developing countries are: climate change and sustainable development. In Brazil, land use and land use change are the leading approaches for development and sources of greenhouse gases emissions. The rational use of old-growth mature forests is part of the solution, although forests assessments have high uncertainty levels towards stocks estimations. These are related to quality data from forest inventories. Our objective was: identify, quantify e analyze the effect on stock estimation of non-sampling errors. Fixed area plots were installed in mature *terra firme* forest (Manaus). Field work was carried out by two teams, sampling the same plots, not simultaneous. All received training prior to field work. Non-sampling errors (NSEs) were observed in the field. Field data from each team was analyzed individually and them compared between each other through ANOVA test. Overall, NSEs was present in 0.5% to 9.5% of all sampled trees. Most common NSE was incorrect usage of diameter tape. In terms of DBH measures, over 90% of all sampled trees showed a difference in DBH value < 1 cm, representing a deviation up to 2.5% of its true value. Finally, ANOVA test showed that mean stock estimation didn't present significant statistical difference between one team and the other.

Keywords: non-sampling errors, monitoring, stocks estimation.

GARANTIA E CONTROLE DE QUALIDADE EM INVENTÁRIOS FLORESTAIS EM FLORESTAS DE TERRA FIRME NO AMAZONAS-BRASIL

Resumo: Os principais desafios que países tropicais, em desenvolvimento, enfrentam atualmente são os efeitos da mudança climática e o desenvolvimento sustentável. No Brasil, o uso e mudança do uso da terra são as principais atividades de desenvolvimento econômico e a principal fonte de emissão de gases de efeito estufa. O desenvolvimento por meio do uso adequado das florestas faz parte da solução, no entanto ainda há muita incerteza acerca de informações relacionadas à estoques. Estas estão relacionadas à qualidade dos dados de inventários florestais. O objetivo deste trabalho foi avaliar um inventário florestal e identificar os tipos de erros não amostrais (ENA) cometidos, quantifica-los e analisar seus efeitos nas estimativas dos estoques. Foram instaladas parcelas de área fixa em uma área de florestas maduras de terra firme (Manaus-AM). O inventário foi executado por duas equipes independentes que amostraram as mesmas parcelas em momentos distintos. Todos os profissionais passaram por um treinamento prévio. Durante as atividades de campo, foram realizadas observações acerca dos erros cometidos. Em seguida, os dados de cada equipe foram analisados individualmente e comparados entre si, por meio da ANOVA. A relação de ocorrência de ENAs variou de 0,5% a 9,5%. O mais comum foi o uso incorreto da fita diamétrica. A diferença de valores de diâmetro, de mais de 90% das árvores amostradas foi inferior à 1 cm, representando na média um desvio máximo de 2,5% em relação ao valor "real". Por fim, a ANOVA apontou que independentemente de ENAs, as médias estimadas não apresentaram diferença significativas.
Palavras-chave: erros não amostrais, monitoramento, estimativas de estoques.

1. INTRODUCTION

Climate change and sustainable development are the greatest challenges developing countries, such as Brazil, face. Opposite to global trends, greenhouse gas (GHG) emissions in Brazil are mainly due to land use, land use change and forestry (LULUCF), which can be translated as: deforestation and forest degradation in the Amazon basin. Deforestation in the Brazilian Amazon since 1977 has accumulated over 770 thousand km^2, in the last decade (2005 to 2014) it averaged over 9,422 km^2.yr^{-1} (PRODES, 2016). Besides carbon emissions, loss of forest cover is also responsible for reducing biodiversity, evolutionary genetic information, local culture and opportunities for livelihood improvement (loss of forest products, e.g. timber).

But, precise estimations of forest variables (carbon, timber, species diversity, etc.) loss are lacking. Uncertainties associated with measurement at individual plots is one of many sources of uncertainty when it comes to estimating forest statistics, such as biomass stock (SAATCHI et al., 2007). Also, the effectiveness of measures taken based on such statistics depends on their reliability, that is, data quality (GASPARINI et al., 2009). Especially when it comes to non-sampling errors: they are difficult to assess and, given the sample size used, systematic bias could remarkably reduce accuracy (GERTNER and KÖHL, 1992). Therefore, information about quality of data collect in forest inventories is vital for understanding the accuracy of their results.

Quality as defined by the Oxford dictionaries, among other definitions, is "*the degree of excellence of something*"[1]. In environmental surveys and monitoring, especially in the forest sector, quality could be defined as the degree of likelihood of true measurements. "Data quality arises from the interaction between the attributes of the analytical data and the intended use of the data" (GASPARINI et al., 2009). In Europe and East Asia there are specific studies towards quality assurance and quality control (*QA-QC*) of environmental assessments and forest inventory (GERTNER and KÖHL, 1992; WAGNER, 1995; FERRETI et al., 2009; GASPARINI et al., 2009). For Brazil, especially in the Amazon Region, quality information on environmental assessments and monitoring are lacking.

When it comes to quality data in forest inventory, there are two main sources of uncertainties: (i) sampling; and (ii) non-sampling errors. Sampling errors are well understood, appropriate statistical sampling protocols can reduce uncertainty levels, as well as, use of adequate allometric equations and *Tier 3* methods of up-scaling mean estimates. Although, there are very few studies of non-sampling errors and their actual impact on the dependent variables, or their level of quality. Therefore, a few questions were raised: (i) how certain are forest inventory data? (ii) what is the size of the uncertainty level of forest inventory data? and (iii) how data quality influences in the final result (mean stocks estimate)?

Thus, our main goal was to analyze forest inventory data quality; identify, quantify and qualify the most common non-sampling errors committed during field work, in Amazonian forests. To do so, sampling units (fixed area plots) were randomly installed at ZF-2 site. Two measuring teams, non-simultaneously, measured the same plots. All measurements were compared. Team leader registered any mistake on measuring DBH. To analyze if forest inventory has standards, ANOVA test was performed between mean estimates from each team. Lastly, all field procedures should compose the measurability, reportation and verification.

2. MATERIALS AND METHODS

[1] https://en.oxforddictionaries.com/definition/quality

2.1. Site description

Work was carried out on the Experimental Site of the National Institute for Amazon Research (Instituto Nacional de Pesquisas da Amazônia, (INPA)), located at 50 km from Manaus (capital city of Amazonas State – Brazil), with central coordinates: 2º 35' 55"S and 60º 02' 14"W (Figure 1). Site vegetation is old growth closed-canopy, undisturbed, *terra firme* forest. Mean rainfall at Manaus was 2,110 mm and mean annual temperature was 26.7ºC for 1910-1983 (National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, N.C., USA). The predominant soil type on plateau forest in the study area, per Brazilian official classification system, is yellow Latosols, with considerable local topographic variation, comprising Oxisols on plateaus, Ultisols on slopes, and Spodosols in valleys associated with streams. Floristic diversity is high, nearly 1,200 trees species have been identified in bearby forests (RIBEIRO et al., 1999), with some trees living for more than 1,000 years (CHAMBERS et al., 1998).

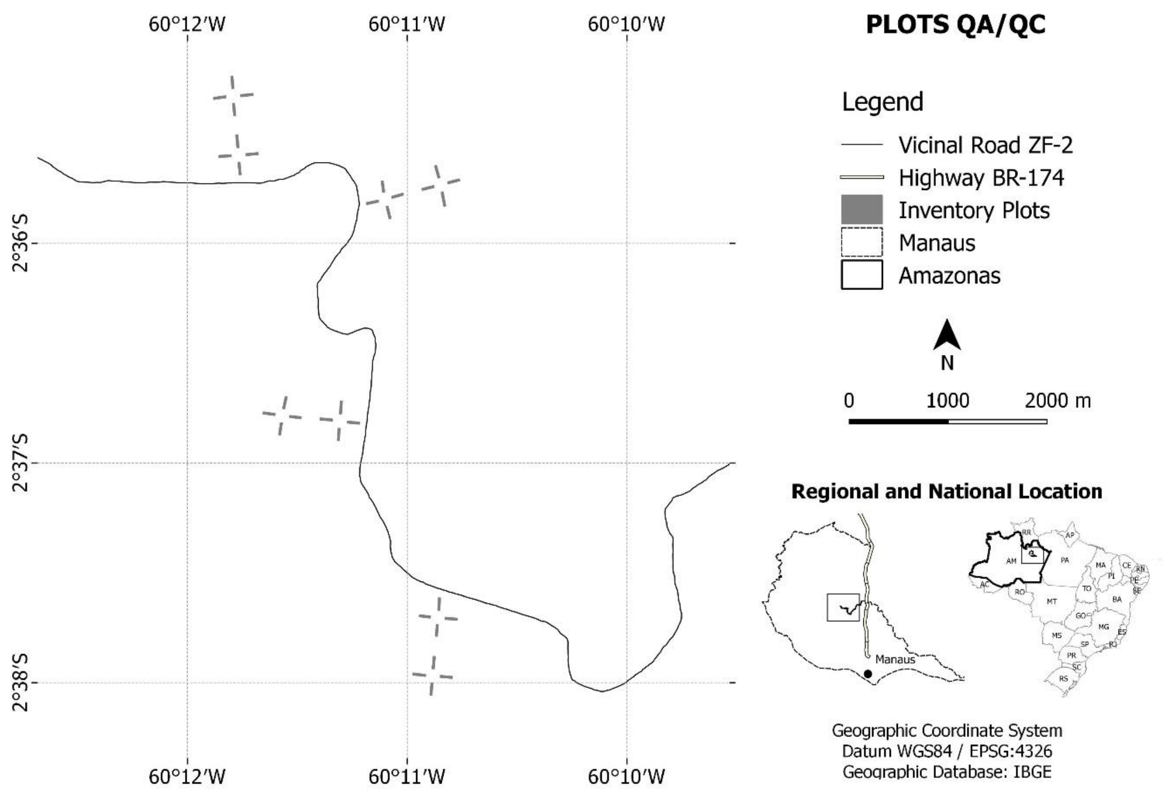

Figure 1. Geographic location of the sampled sites.

2.2. Samples and sampling

In 2015, 32 20 x 125 m (0.25 ha) plots were established in the study site. Sample plots were grouped in conglomerates of two crosses, summing 8 plots per sample point, distributed randomly in the *terra firme* forest. Within each plot, all trees, alive and dead (standing and/or fallen with its base inside the plot), with diameter at breast height (DBH) ≥ 10 cm were identified (per its common name), labeled (numbered aluminum tag, tied up with nylon string) and measured.

2.3. Field teams

Field data was collected by two independent teams. Each team was formed by a forester and two assistants, responsible for identifying, labeling and measuring the sampled trees, locally called as *mateiros*. The forester was the team leader and responsible for verifying the method of tree measuring. The first team counted with two *mateiros* with over 20 years of forest inventory experience, the second with no more than 10 (ten) years. Before field work, all members received training on measurement standard operation procedures, based on literature recommendations (MACHADO and FIGUEIREDO FILHO, 2006). Plot data was collected by both teams, although not simultaneously. This was conducted to assess the level of discrepancy (should there be any) between one measurement and the other.

2.4. Data analysis

From the individual DBH, basal area (BA) was determined and bole volume (Vol.) were estimated from site-specific, single-entry, volumetric equation (LIMA, 2010). An Analysis of Variance (ANOVA) was performed to compare Team's 1 and 2 plot level mean estimates. Should ANOVA results reveal significant statistical difference, it would indicate that field measurement is not standardized and reliable data would depend on the professional executing the forest inventory. Also, from field observation, all tree measurement "transgression" was identified as *non-sampling error*.

2.5. Non-sampling errors identification and quantification

Non-sampling errors are often known as measurement mistakes which cannot be accounted for. These mistakes have direct effect on the quality of the data and are associated with three major concepts of forest inventory: *accuracy*, *precision* and *bias*. Fewer the non-sampling errors are, higher the accuracy of the data will be (HUSCH et al., 1972), on the other hand, standardization of measurement procedures can ensure precision of the collected data, no matter the accuracy. In this study, we observed and registered all errors in forest inventory, to identify the effect on mean estimates of dependent variables (i.e. basal area and stem volume). A few questions were raised: does professional experience have influence in data quality? How often and what kind non-sampling errors occur during field work? Is there any bias associated with any of the non-sampling errors identified?

2.5.1. Estimating DBH

The diversity of mature tropical forests (RIBEIRO et al., 1999; STEEGE et al., 2013) occasionally (averaging from 1.4% to 3.2% of all stem data from forest inventory is estimated, HIGUCHI, 2015) allows sampling of species with specific stem characteristics, such as trees with buttress. Therefore, in some cases, measuring DBH is impaired and it relies on estimation, based on the projection of the stem at 1.3 m from the ground. This alternative is considered the last resort and probably a great source of non-sampling errors.

2.5.2. Incorrect point of measurement (PoM) of the DBH

Forestry literature (MACHADO and FIGUEIREDO FILHO, 2006) states that DBH must be measured at 1.3 m from the ground. Although, there are some expected exceptions (i.e. deformity or bifurcation at or below 1.3 m) that hampers diameter mensuration and occasionally specific characteristics of the tree or its position and/or location that needs attention: in slopes, DBH must be measured at the high point of the topography; DBH of leaning trees is measured at 1.3 m from the base, for example. In these situations, *PoM* must be changed and reported. Should the *mateiros* find the need of changing the *PoM* and do not report it to the team leader, it was considered as a non-sampling error.

2.5.3. Incorrect usage of diameter tape

Stem diameters are always measured by metric and diametric tapes. When observed that the diameter tape was wrongly positioned (i.e. twisted or bent), it was registered as non-sampling error. This type of error is not to be mistaken with the previous. For the *incorrect usage of diameter tape*, the *PoM* must be at 1.3 m from the ground or per its specific condition.

2.5.4. Inclusion of trees outside of the plot and Exclusion of tree inside the plot

Considered as the worst type of non-sampling error, this type of error was evaluated based on an audit data. A third field team assessed the sample plots and for every tree located at the far side of the plot (near the plot's boundary), with a compass and a rangefinder/hypsometer (TruPulse™) it was measured the exact distance of the tree from the plot's center trail. Trees (DBH ≥ 10 cm) measured outside of the plot limits were registered as "*Inclusion*", and trees not measured, were registered as "*Exclusion*".

3. RESULTS AND DISCUSSION

3.1. General description

In total, 4,575 trees were measured in the 32 1/4ha plots. Where 96% (4,379) were classified as "live trees", 3% (121) as palm trees, and 2% (75) as dead trees (standing and/or fallen). Forest structure followed standard tropical old growth forest diameter distribution, characterized as negative exponential (HIGUCHI et al., 2014), with mean DBH = 21.9 (± 0.4) cm, varying from 10 cm to 140.2 cm. In terms of diversity, it was identified 264 species (where 6 are palm trees) grouped in 54 botany families (including Arecaceae – palm trees). As well as in other studies (STEEGE et al., 2013), hyperdominant species were found: 50% of all trees are concentrated in 26, out of 258 tree species.

3.2. Non-sampling errors identification and quantification

Both field teams (1 and 2) registered non-sampling errors (NSE) during plot measurement. Although, during individual comparisons between DBH measures from each field Team, it was identified that trees which had their DBH estimated, presented an elevated level of uncertainty. These estimations of DBH generally occur in trees with obstructions at 1.3 m from the ground and the point of measurement was unreachable. This estimation generated crude discrepancies, up to 20 cm between one measure and the other. At our study, 1.3 % (56 trees) of all live trees (4,379) had its DBH estimated. Therefore, we attributed all DBH estimation as NSE.

Thus, Team 1 averaged 2.5% (± 0.7%), per plot, of NSE, with an overall 2.5% of all trees measured (115 / 4,575) with at least on type of NSE and 97.5% NSE-Free. Team 2 recorded a lower quality performance with an overall 9.3% of registered NSE, averaging 9.3% (± 1.6%). Given the differences between each field team, concentrated basically in time experience, we found that field workers with longer training are less likely to make mistakes.

Analyzing the types of NSE's it was found that: Team 1 most common NSE was mistakes of estimating DBH (42.6% of all registered NSE), followed by: registration error (the information was wrongly registered in the field sheet) (28.7%), incorrect usage of diameter tape (22.6%). As for Team 2, the most common NSE was "incorrect usage of diameter tape" (65.1%), followed by classification error of "biomass category" (where a live tree was mistaken for a dead tree) and registration error, both with 8.3% of all registered NSE (Figure 2).

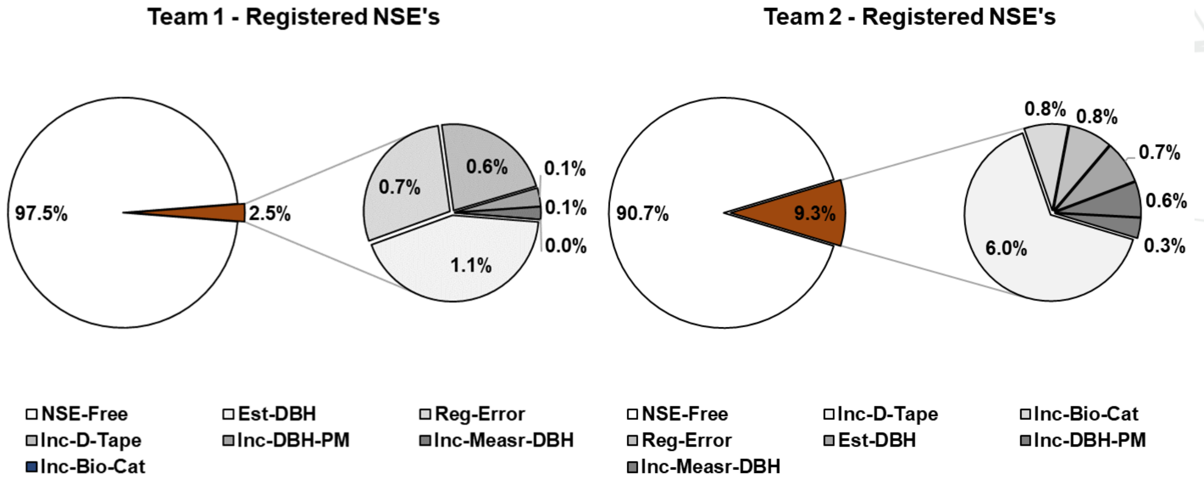

Figure 2. Relationship of all non-sampling errors committed by each field team, during the Quality-Assurance forest inventory. Where: NSE-free = no non-sampling errors registered; Est-DBH = DBH visually estimated; Reg-Error = registration error in the field sheet; Inc.D-tape = incorrect usage of diameter tape; Inc-DBH-PM = incorrect point of DBH measurement; Inc-Measr-DBH = when diameter tape was placed over an obstacle in the tree's stem; Inc-Bio-Cat = incorrect biomass category classification.

Literature about Quality-Assurance and Quality-Control (*QA/QC*) very often discuss quality level criteria. According to the Guidance for Quality Assurance Project Plan (EPA, 2002), from the United States (U.S.) Environmental Protection Agency (EPA), there are Data Quality Indicators (DQIs) that are represented by, among others, bias and precision. Although, DQI must rely on qualitative and quantitative statements to assure quality. Measurement Quality Objectives (MQO) is the individual performance of acceptance goals for the individual DQIs (bias and precision) (EPA, 2002; GASPARINI et al., 2009).

In terms of bias, our findings show that there are no clear relationship between NSEs and the number of trees measured in each plot (R^2 < 0.07 – Team 1; < 0.05 – Team 2), the topography (R^2 < 0.05 for both Teams) or the time of the day at the moment of assessment (R^2 < 0.05 for both Teams). Although, when analyzing the time consumed to fully measured each plot, results from Team 2 showed some evidence of correlation (R^2 > 0.5), whereas Team 1 showed very weak relationship (R^2 < 0.01) (Figure 3).

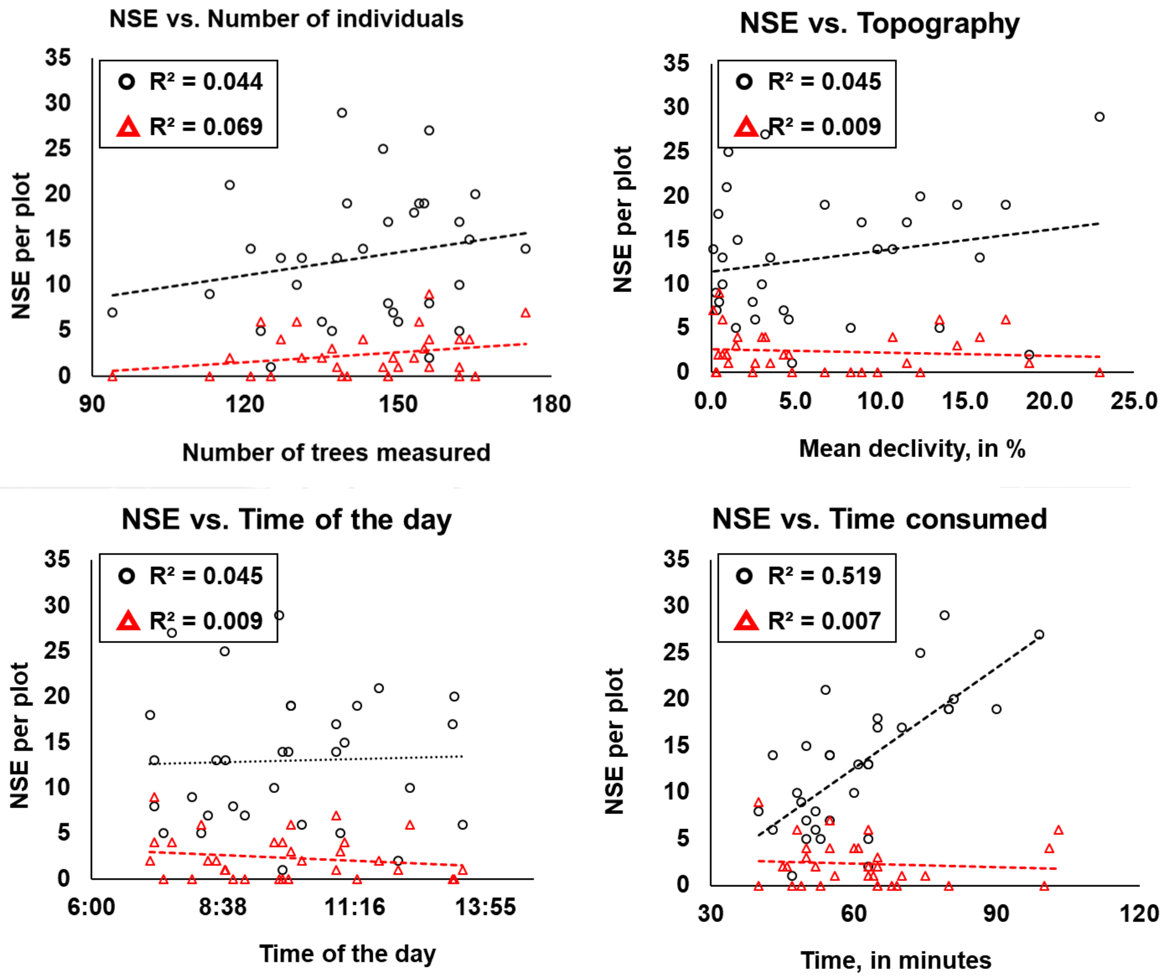

Figure 3. Relationship between non-sampling errors (NSE) committed by each field team, during the Quality-Assurance forest inventory, per each parameter. Open red triangles and red traced line are related to Team’s 1 data, Open black circles and black dotted line are related to Team’s 2 data.

The time taken to sample each plot can be influenced by the number of individuals within each plot, topography and time of the day. Where, the more trees to measure, more time would be consumed. Also, the rougher the terrain (high values of declivity, in %), harder it is to move and measure the trees, which should influence time and NSE. Lastly, as day time passes by, field teams tend to get more tired and more prone to make mistakes. All these, when crossed with "Time", showed little or no correlation (Figure 4). But, situations such as difficulties to measure DBH, caused by embranchment or any deformity at the Point of Measure (PoM) resulting in the necessity for estimation of the diameter, were not accounted for. This should indicate why Team 2 presented a positive and significant correlation (NSE *vs* Time – $R^2 > 0.5$): a more experienced team (Team 1) is more capable to overcome such difficulties, taking less time to commit the same NSE: estimation of the DBH.

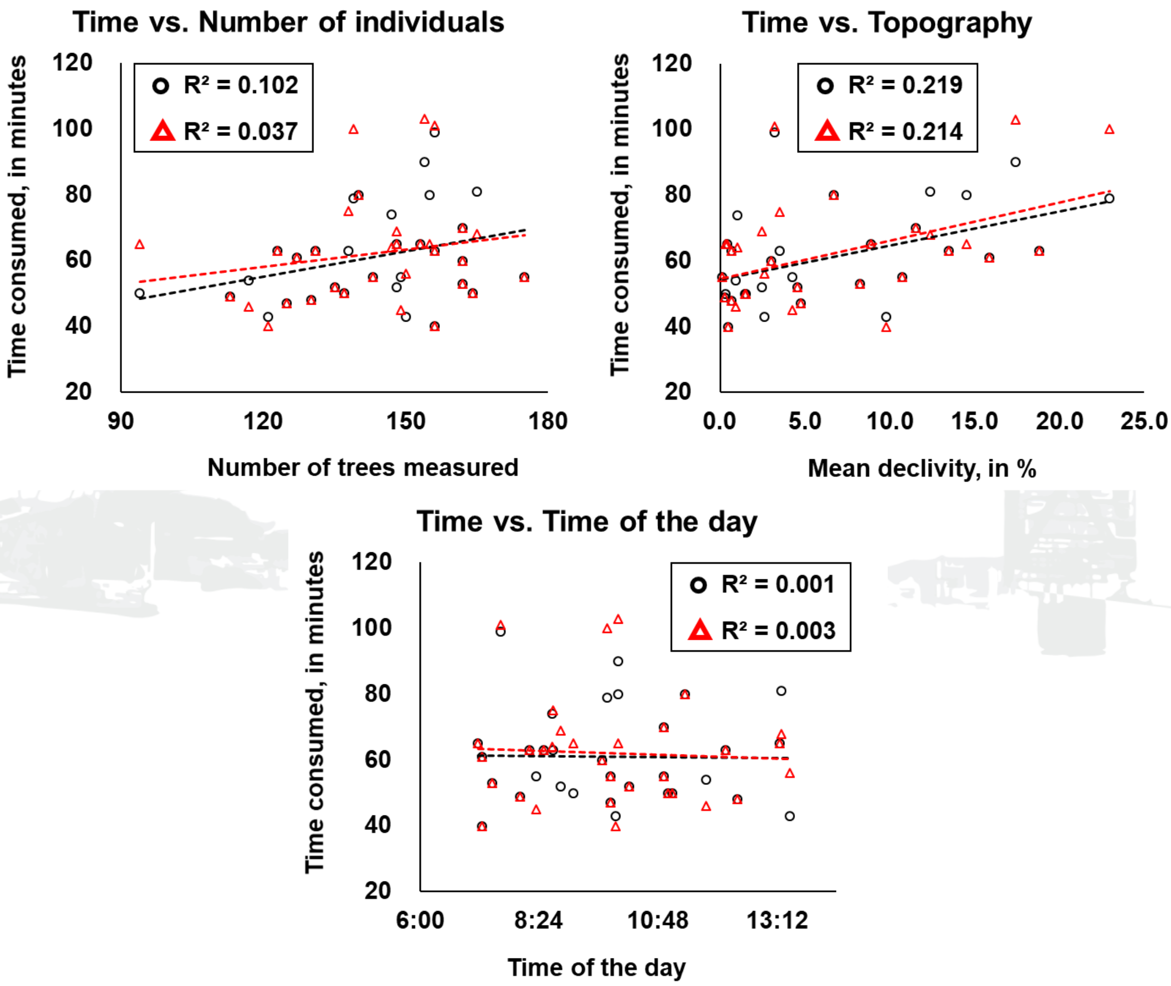

Figure 4. Relationship between the time consumed by each field team to sample each inventory plot. Open red triangles and red traced line are related to Team's 1 data, Open black circles and black dotted line are related to Team's 2 data.

3.3. Measurement errors: quantifying discrepancies and their effects on mean stock estimate

Many Quality Assurance (QA) studies approaches its main components (SHAMPINE, 1993; FERRETTI et al., 2009; GASPARINI et al., 2009), although quantitative values of quality are lacking. As for DBH measurement, Gertner and Köhl (1992) predicted, through an error budget assessment, 2% in standard deviation due to measurement error relative to input variables. Our study used blind check of all sampled plots allowed to compare DBH measurements. Considering the lower presence of NSE in Team's 1 data, we considered it as: Reference data, also as "expected value". Thus, measurement discrepancies were quantified by subtracting Team's 1 data from the "observed measure" (Team's 2 data), estimated in percentage.

Overall, we found that almost ¼ (24.5%) of all DBH measures showed zero difference from "expected" to "observed" value, and 67.3% with a maximum discrepancy of 0.9 cm (Figure 5). In average, these discrepancies correspond to a difference of 2.1% (± 0.4%). All discrepancies higher than 5 cm were observed in trees that had their DBH estimated. The residual distribution, from the analysis between "observed DBH" and "expected DBH", and the estimates based on DBH (Basal area and bole volume) showed a relative uniform distribution – mean (per plot) qui-square (χ^2) estimated, for all variables: DBH (13.5) Basal Area (0.2) and bole Volume (3.4), was considerably lower than the limit (probability = 0.05/mean degrees of freedom = 31; χ^2 = 44.98) (Figure 5).

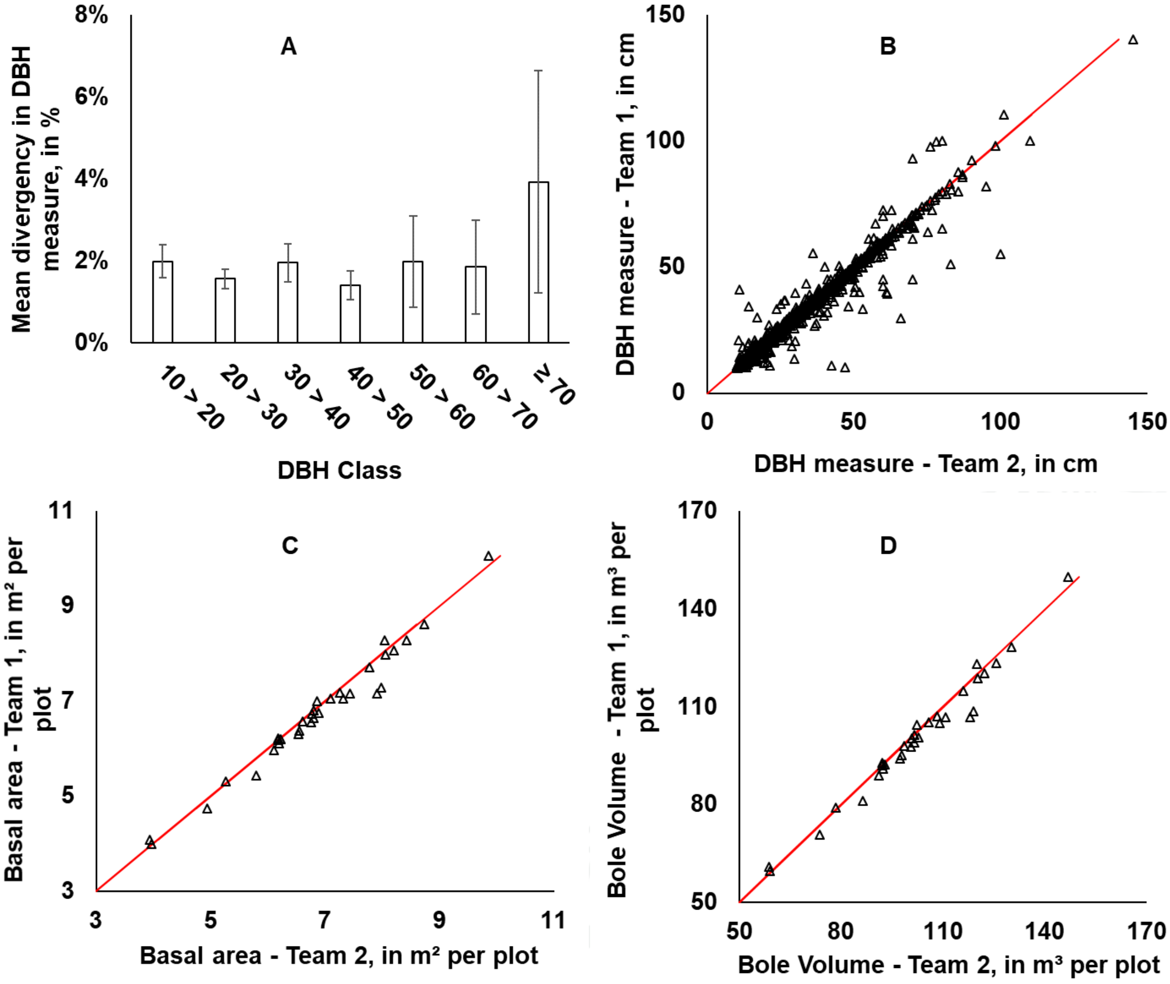

Figure 5. (A) Relationship of the distribution of discrepancy between DBH measurements from Team 1 and Team 2; and (B) Correlation between DBH measures; and (C) Basal Area estimates from Team 1 and 2; and (D) Bole Volume estimates from Team 1 and 2.

Although these discrepancies are present, according to ANOVA results (Figure 6), they seem to not influence mean stock estimation. Comparing both Basal Area and Bole volume estimations, ANOVA showed strong evidence that there is no significant statistical difference ($p > 0.7$ in both cases) between either mean stock estimate. Considering that both dependent variables (Basal area and bole volume) are based solely on DBH, as well as biomass equations (such as SILVA, 2007), our results can be extended for biomass and carbon stock estimation.

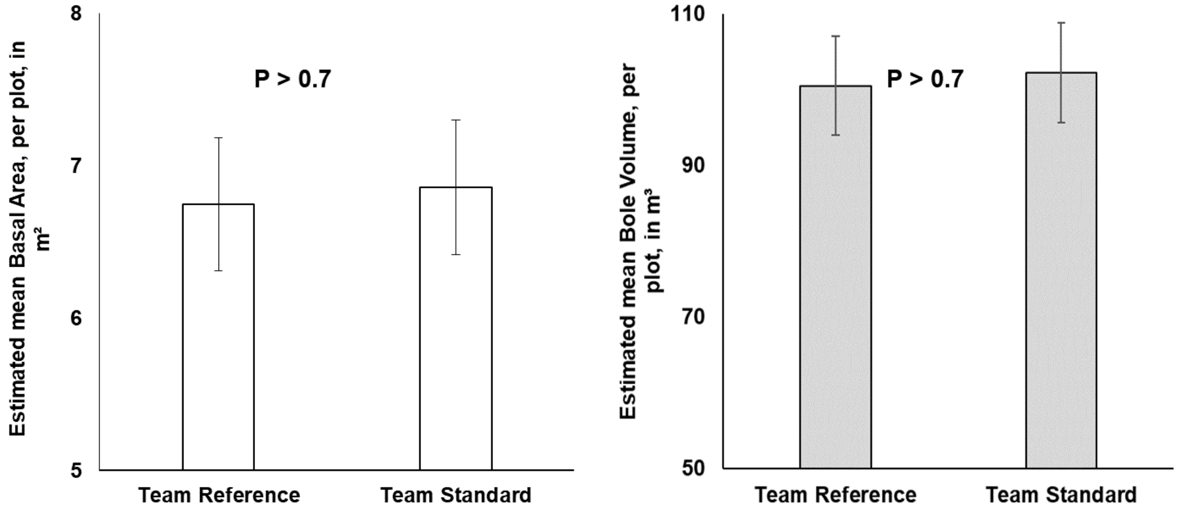

Figure 6. Mean estimate for Basal Area and Bole Volume, per plot, with their respective uncertainty level and the result of ANOVA test between Team 1 and Team 2, Reference and Standard team, respectively.

3.4. Data quality assurance and quality control (QA/QC)

Based on our findings, it is possible to identify some DQI and MQO for forest inventory field data (Table 1). Should forest inventory field data present: less than (<) 10% of NSEs; over than (>) 90% of all DBH value with a discrepancy <1 cm, corresponding to <3% (in average) of its true measure, mean stock estimation of any given DBH dependable variable should have its Quality assured. To guarantee QA, a few Standard Operations Procedures (SOP) must be followed (Table 1).

Table 1. Error type, Standard Operation Procedure (SOP) to avoid error, the effect of each error type, Measure Quality Objective (MQO) and Data Quality Indicator (DQI)

ERROR TYPE		SOP	EFFECT	MQO	DQI
Non Sampling Error	Est-DBH	Must be avoided by measuring diameter above 1.3 m, with a ladder, if possible	Can generate discrepancy in DBH value >5 cm	Must not exceed 10% of all measured trees	Live audit, during field survey
	Reg-Error	Team leader must confirm information at all times	Incorrect registration of any given variable		
	Inc-D-Tape	Field teams must be trainned prior to field survey; Team leader must check DBH	Discrepancy in DBH value 0.1 up to 4.9 cm		
	Inc-DBH-PM				

	Inc-Measr-DBH	measurement at all times			
	Inc-Bio-Cat	Field teams must be trainned prior to field survey; Team leader must check information	Incorrect estimation of net mean available stock		
DBH measure (value)		DBH measurement must attend to standard procedures, at all times	Incorrect estimation of mean stock	< 10% of all measured DBH with a difference ≥ 1 cm	Blind check plots
Mean difference between DBH values				Must not exceed 3% of true value	

Our field team reported that, most NSEs are avoidable if the Team leader warns the *mateiros* during field survey. During this project, it was determined that no warning should be given, to evaluate the “true dynamics of field work”. Considering the NSEs: *incorrect usage of diameter tape*, *incorrect point of DBH measurement*, *Incorrect classification of biomass category* or placement of the diameter tape on any obstacle in the tree’s stem, should the Team Leader notify the respective *mateiro*, the proportion of NSE in forest inventories should decrease by, approximately, 80%.

4. CONCLUSION

Generally, the occurrence of NSEs in forest inventories is inevitable. Although, based on our findings, most of these errors can be minimized or even completely avoided through intensive training, continuous oversight and by following “to the letter” the Standard Operations Procedure (SOP). Nevertheless, should the occurrence of NSEs remain within the MQOs, it shouldn’t affect mean stock estimations. Finally, identify and quantify uncertainty sources in field surveys is fundamental to minimize and avoid them, and increase reliability of forest inventory assessments.

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