Original Article

Evaluation of the Plant Necromass Component: Methodological Approaches and Estimates in Atlantic Forest, Northeast Brazil

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ABSTRACT

Necromass is a crucial component for the forest structure. However, there are few studies of necromass quantification in tropical rainforests and lack of efficient sampling methods. This research aimed at verifying the accuracy and effectiveness of sampling methods (Line-intersect sampling - LIS *versus* fixed area plots - FA) for the estimation of necromass in a tropical rainforest. The accuracy and efficiency of the methods were evaluated through descriptive statistics, paired t-test, ANOVA and relative efficiency. LIS method was more accurate and efficient, but it requires high sampling to meet sample error of 15%. Necromass at the forest fragment studied accounted for about 12.28% of the tree biomass. These findings show the importance of this compartment inclusion when quantifying carbon stocks in humid tropical forests, which acts as a true reservoir of carbon.

Keywords: sampling, fixed area, fallen dead wood, transect.

1. INTRODUCTION

Forests naturally produce woody residues through the fall of dead branches and trunks or whole trees (Cruz & Silva, 2009). This vegetal detritus, known as necromass, constitute a crucial component of the forest structure acting both in quantitative aspect and in the functioning of the ecosystem (Sanchez et al., 2009; Gove et al., 2012; Bassett et al., 2015). Necromass stores a considerable amount of carbon (Russell et al., 2015; Iwashita et al., 2013). It is a sink of other nutrients on the forest floor beside being a habitat for a wide variety of organisms (Sefidi & Marvie Mohadjer, 2010). Necromass is divided into two categories: fine litter or litter (diameter of pieces < 2 cm) and coarse litter (diameter > 2 cm) (Palace et al., 2012). The coarse litter is divided into standing dead wood and fallen or downed necromass (Barbosa et al., 2009; Palace et al., 2012).

The coarse litter stock is responsible for a high percentage of above-ground carbon stock in tropical forests, ranging from 10% to 20% (Houghton et al., 2001) or 20% to 40% (Palace et al., 2012). The high percentage of coarse litter stock and its strong relation to carbon storage, nutrient cycling, global warming and global climate change reinforces the need to include the necromass compartment in forest inventories (Weedon et al., 2009; Zhou et al., 2014). Using these compartments, it is possible to access the amount of C released to the soil and atmosphere adequately (Palace et al., 2012; Zaninovich et al., 2016), becoming an essential attribute for an efficient forest management.

Although necromass contributes considerably to the organic matter and total above-ground carbon, the quantification and dynamics in tropical forests were mostly conducted in areas of extensive natural forest cover, particularly in the Amazon (Rice et al., 2004; Chao et al., 2009; Silva et al., 2016). In reduced and fragmented forests in anthropogenic landscapes, such as the small and numerous remnants of the Atlantic Forest the studies are restrict. Ribeiro et al. (2012) determined the volumes of dead matter in a remnant of Mixed Ombrophylous Forest in Paraná. Cardoso et al. (2012) quantified coarse woody debris in forest remnants in Santa Catarina. The absence of data hinders understanding the potential of forest fragments in provide ecosystem services, especially regarding carbon stocks.

Above-ground necromass quantification in fragmented landscapes faces the high heterogeneity of landscapes in the Atlantic Forest, concerning age, size, shape and patch isolation, type of matrix and existing disturbances. This scenario interferes on the determination of sample units in terms of size and number, and the methodological approach either by area or by transect (Deus et al., 2018). Searching for the most appropriate sampling method for quantifying the necromass and obtaining information related to ecosystem services and forest dynamics becomes increasingly important (Stinson et al., 2011). There is a lack of studies in the Atlantic Forest biome. To fill this gap and allow better planning and valorization of the services by forest remnants, this research aimed at comparing the accuracy and efficiency of two methods for estimating the above-ground plant necromass in a fragment of tropical rainforest.

2. MATERIAL AND METHODS

2.1. Study area

The study was carried out in a remnant of mature Atlantic Forest located in the State Park Dois Irmãos (SPDI), a protected area of the State of Pernambuco, Northeast Brazil (7°57'40" S - 8°00'52" S; 56°23" W - 34°57'31" W). The forest covers 384 ha on a peri-urban matrix under negative anthropogenic impacts. The vegetation consists of Lowland Dense Ombrophylous Forest type (Lima et al., 2018). The climate is warm and humid, type As' according to Köppen classification. The area has an average annual precipitation of 2417 mm, more intense in autumn-winter. Average monthly temperatures are higher than 23 °C (data from National Institute of Meteorology: www.inmet.gov.br). The predominant soil types are Latosol, Argisssol and Quartzarenic Neosol, following the Brazilian Soil Database (Benedetti et al., 2011).

2.2. Data sampling

Two different methods were used to sample the arboreal necromass: the line-intersect method (LIS), developed by Warren & Olsen (1964) and adapted by Van Wagner (1968), and the fixed area plot (FA) method.

Data were sampled in four permanent plots following the RAPELD method (Magnusson et al.,

2005), consisting of plots system (250 m x 40 m each) established systematically and installed by the Program of Biodiversity Research (PPBio), PEDI site. In each plot, five 50 m transects (LIS Method) were placed in the upper part, along which five 10 m x 10 m plots were set up and within these, 5m x 5m subplots in the lower part (AF Method) (Figure 1).

To adjust the volume of the solid obtained for each of the wood pieces for the two evaluated methods, five diameter classes were adopted, divided into small pieces of 2 cm x 3.9 cm; 4 cm x 5.9 cm; 6 cm x 7.9 cm; 8 cm x 9.9 cm and large with a diameter (Ø) greater than 10 cm.

A tactile-visual categorization of the degree of decomposition of each wood pieces was performed following the criteria of Chao & Phillips (2005), modified by Barbosa et al. (2009). Wood pieces were classified into three groups: **DD1**, newly fallen or high resistance parts, without signs of attack from insects or fungi; **DD2**, parts with slight signs of insects and fungi harm, usually parts with small hollows but high resistant to manual touch; **DD3**, parts in an advanced

stage of decomposition with signs of rot in different stages that, in most cases, shattered at the manual touch.

For each degree of decomposition (DD1, DD2 and DD3), 30 samples were collected to calculate the basic density. The samples were collected removing discs (5 cm) from wood pieces with different diameters and degrees of decomposition and equally distributed along all transects and installed plots. Basic densities were determined by the water immersion method, following the NBR 11941 standard of the Brazilian Association of Technical Standards, ABNT (2003).

2.3. Estimates of volumetric stock of dead wood

2.3.1. LIS method

LIS method measures the diameter of each wood piece that intercepts the transect. There were installed 20 transects of 50 m length to sample large pieces (Ø > 10 cm) and small pieces (Ø ≥ 2 cm and ≤ 10 cm). All transects were allocated according to the level curve of the terrain using a clinometer and marked by an alignment made of nylon string and fixed with
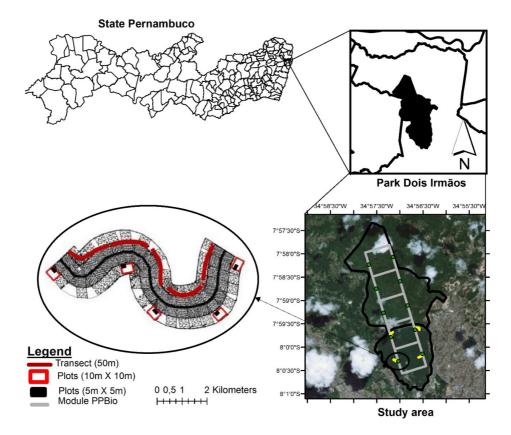

Figure 1. Location of transects and plots set up in the study area, Dois Irmãos State Park, Recife-PE, Brazil.

stacks every 10 m. The wood pieces that intercepted the transect were categorized according to the degree of decomposition and the diameters measured with a tape measure to calculate the estimated volume (V_{Est}), using Van Wagner (1968) equation 1.

$$V_{Est} = \frac{\delta^2 \; x \; d^2}{8 \; x \; L} \tag{1}$$

Where: V_{Est} = estimated volume (m³.ha⁻¹); d = diameter of each piece in the sample line; L= length of a sample line (50 m).

2.3.2. FA method

For FA method, 20 plots (10 m x 10 m) were used to sample large pieces (Ø > 10 cm). In each plot, subplots (5 m x 5 m) were used to sample the small pieces (Ø ≥ 2 cm and ≤ 10 cm), as shown in item 2.2, Figure 1. Volume of large and small pieces was obtained by Smalian's rigorous cubing method, which consists of measuring the diameters at the end of each section of the trunk of all fallen dead trees or branches with using a metal and plastic tape measures. Estimated volume of each section was determined by the equation 2 of Smalian:

$$V_{Est} = L\left[\frac{\pi\left(D_1/2\right)^2 + \pi\left(D_2/2\right)^2}{2}\right] \tag{2}$$

Where: V_{Est} = estimated volume (m³); L (m) = length of measured piece; $D_{1,2}$ = diameter (m), at both ends.

2.4. Calculation of necromass for the different sampling methods

Necromass stock was calculated using the estimated volume (V_{Est}) in the field and the basic density (D_b in g.cm³) by diameter category and decomposition degree. The necromass was obtained by multiplying the volume of each category by their respective basic densities (g/cm³) (Equation 3):

$$\mathbf{Necr} = V_{Est} * D_b \tag{3}$$

Where: Necr = Necromass (Mg.ha⁻¹); V_{Est} = Estimated volume (m³.ha⁻¹); D_b = Basic density (g.cm³).

2.5. Data analysis

To verify the existence of differences between the volume (m³ ha⁻¹) and the necromass (Mg.ha⁻¹) obtained by the different methods by degree of decomposition, we used a paired t-test and ANOVA at 5% of probability in Software R.3.3.1 (R Development Core Team 2016). Sampling accuracy was evaluated, considering a 5% probability level and sample intensity with 15% error limit. Descriptive statistics analyzed the results obtained by each method: Mean, variance, standard deviation, mean variance, standard error of the mean, and the coefficient of variation, absolute error, and relative error.

The efficiency of sampling methods was evaluated by measuring the total time from the plots and transects installation to the measurement of the last piece of fallen wood. With the time measured, the relative efficiency calculation was performed (Miranda et al., 2015), considering the coefficient of variation of the sampling methods, by equation 4:

$$\mathbf{RE} = \frac{1}{T_i * CV^2} \tag{4}$$

Where: RE = relative efficiency; Ti = Time of allocation and measurement of variables in sample units (h); CV = Coefficient of variation.

3. RESULTS AND DISCUSSION

3.1. Basic density of fallen dead wood

The basic density of dead woods is a variable of difficult measurement in pieces in an advanced degree of decomposition. There are no densities estimated at different degrees of decomposition for Atlantic Forest. Thus, the present research presents densities in three degrees of decomposition (DD1, DD2 and DD3) (Table 1).

Early-stage (DD1) pieces exhibit higher density, followed by the intermediate and final degree of decomposition, similar to Silva et al. (2016) findings in the Amazon forest. This is an expected result since the more decomposed material tends to have a smaller mass and a larger volume due to fibers loosening by

Table 1. Mean density (± standard deviation) of dead wood for different decomposition degrees, Dois Irmãos State Park, Recife, Pernambuco, Brazil.

Decomposition degree	Basic density (g.cm⁻³)
DD1	0.6858 (0.02)
DD2	0.5659 (0.02)
DD3	0.4252 (0.03)

decomposition. Thus, forests with a high decomposition rate have a higher volumetric stock and consequently lower plant necromass.

3.2. Estimates of volume and plant necromass

3.2.1 Small pieces

We measured 924 pieces of dead wood using both sampling methods (LIS *versus* FA). LIS method measured 62% of all evaluated pieces, obtaining an average volume of 12.56 m³. ha⁻¹. We recorded 346 (38%) pieces and an average volume of 12.03 m³.ha⁻¹ through FA method. There was no difference (*p*-value = 0.912) of volumetric estimates.

The volume (m³.ha⁻¹) by diameter classes did not differ (*p*-value = 0.811) between the two methods and followed the same pattern, that is, the lowest class accounted for the largest part of the volumetric stock (Figure 2). The high amount of small branches found in the forest explains these results.

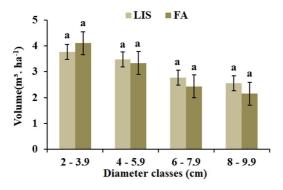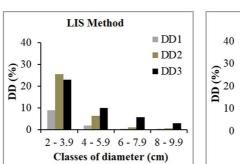The highest percentage of the volume of dead wood in the forest is in the decomposition degree 3 (DD3),

for both methods, indicating that the area had not suffered recent natural or anthropic events involving small branches falling.

The final decomposition class at the LIS method presented a volume of 7.05 m³ ha⁻¹, representing 56.2% of the total volume. The intermediate (DD2) and initial (DD1) classes showed 4.84 m³ ha⁻¹ (38.5%) and 0.67 m³ ha⁻¹ (5.3%), respectively.

We found similar results using the FA method, with DD3 representing 70% (8.60 m³ ha⁻¹), followed by DD2 and DD1, for a total of 3.0 (24%) and 0.73 m³ ha⁻¹ (6.0%). Analyzing the DD by classes of diameter for both methods, we verified that the lowest class (2-3.9 cm) represented 57% and 66% of all pieces of dead wood sampled in the forest, respectively, for LIS and FA methods (Figure 3).

The decomposition degree DD3 was higher in all classes, except for small class (2-3.9 cm) using LIS method, in which DD2 predominated. These results demonstrate that the studied forest is constantly releasing nutrients to the soil and CO_2 to the atmosphere, considering that more than 50% of the pieces of wood are in DD3.

The tree necromass estimation for the small pieces was similar in both methods (Figure 4). LIS method estimated 6.20 Mg.ha⁻¹ and FA method estimated 5.90 Mg.ha⁻¹, without significant differences (p-value = 0.925).

Studies show that the necromass stock obtained for small diameters classes (2 < Ø < 10 cm) ranges from 4 to 9 Mg.ha⁻¹, accounting for 12% to 21% of the total dead wood in a forest (Nascimento & Laurance, 2002). In the Amazon, it is estimated that the dead wood compartment with a diameter < 10 cm is responsible for 12% of the total necromass (Rice et al., 2004). These results show the importance of including small
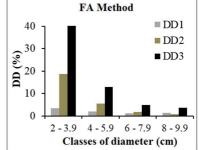

Figure 2. Volume (m³. ha⁻¹) by classes of diameter for the different methods of necromass estimation.

Figure 3. Decomposition degree (DD) by diameter classes for different methods of necromass estimation.

diameter classes in forest inventories, considering that the non-inclusion of this compartment may lead to underestimation of up to 20% of the total carbon stock in a tropical forest.

3.2.2. Coarse pieces

We found 167 pieces of wood with a diameter greater than 10 cm. LIS method measured 56.28% of the total of individuals, obtaining an average volume of 51.58 m³ ha⁻¹, whereas FA method recorded 73 individuals (43.72%) and an average volume of 47.80 m³ ha⁻¹. The volumetric stock (m³.ha⁻¹) did not differ between the evaluated methods (p-value = 0.813).

We found lower volumes than those found by Rice et al. (2004) for the Amazon forest. The authors found 151.7 m³ ha⁻¹ and 164.2 m³ ha⁻¹, respectively, for FA and LIS methods. The differences in biomass on distinct forest typologies can explain the low stock. According
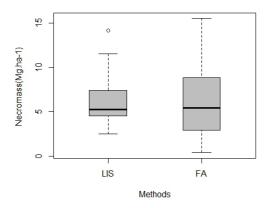
to Chao et al. (2009), forests with a higher amount of aerial biomass show linearly larger accumulations of dead wood. Comparing the total volumetric stock in percentage among all diametric classes, we verified that the class Ø ≥ 10 cm accounted for 81.3% of the total volumetric stock in the LIS method and 80.2% in the FA method (Figure 5).

Woody residues with diameters greater than 10 cm are the main components of the coarse litter in tropical forests, because 80% of the above-ground biomass consists of trees with diameter above 10 cm and the total biomass is represented mostly by few and large trees (Nascimento & Laurance, 2002). In the Atlantic forest, trees with diameters larger than 30 cm account for 6% of all individuals and contribute to 72% of the total biomass, leading to a higher necromass of that diameter class in these forests (Lindner, 2010).

The percentage of the volume of coarse pieces per class of decomposition did not differ from the results found for the small parts, indicating that most of the volume has a high degree of decomposition (DD3), more than 70% of the total. Using LIS method, the final decomposition class had a volume of 41.2 m³ ha⁻¹, 79.8% of the total volume. The intermediate (DD2) and initial (DD1) classes had 4.8 m³ ha⁻¹ (9.6%) and 5.5 m³ ha⁻¹ (10.6%), respectively.

Similar results were found using the FA method. DD3 represented 74% (35.3 m³ ha⁻¹), followed by DD2 and DD1, corresponding to 7.2 (15%) and 5.3 m³ ha⁻¹ (11%), respectively. These results corroborate with Silva et al. (2016), showing that most of volume consists of the final class of decomposition and the smallest part of volume corresponds to woody material at
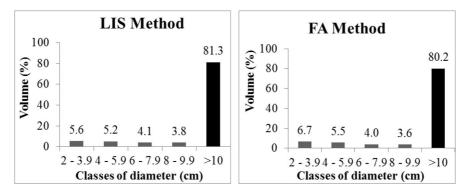

Figure 4. Exploratory analysis of necromass stock (Mg ha⁻¹) of small pieces for different methods of necromass estimation.

Figure 5. Volumetric stock (%) by diameter classes, at Dois Irmãos State Park, Recife, PE, Brazil, for different methods of necromass estimation.

the initial stage of deterioration. The above-ground arboreal necromass for coarse pieces was 25.22 Mg.ha⁻¹ using the LIS method, and 24.65 Mg.ha⁻¹ using the FA method (Figure 6), with no significant differences (p-value = 0.946).

The estimated necromass was relatively below than that recorded in Amazonian forest. Rice et al. (2004) found a stock of 48 Mg.ha⁻¹ and Chao et al. (2009) found 58.5 Mg.ha⁻¹. The smaller number of individuals per hectare (842 ha⁻¹) consisting of 88.6% of the class of diameter 5 to 20 cm can explain the low stock of necromass in the studied fragments in comparison to Amazonian forest. However, the total arboreal necromass (small and coarse parts) corresponds to 12.28% (LIS) and 11.94% (FA) of total biomass above the soil (255.67 Mg.ha⁻¹, unpublished data). Other studies found a tree necromass from 6 to 25% of the
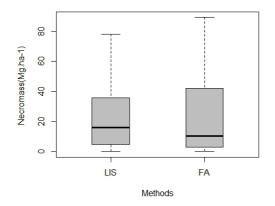
total biomass above the soil (Nascimento & Laurance, 2002; Rice et al., 2004).

3.3. Comparison between sampling methods (LIS versus FA)

We did not find differences in volume estimates (m3 ha⁻¹) and arboreal necromass (Mg ha⁻¹) between the studied sampling methods. However, we observed differences in the precision of the estimates through the descriptive analysis presented in table 2.

We defined error limits of 15%, but the sampling intensity was lower than required, resulting in errors larger than the pre-established limits. Such errors are due to the high variability and irregular spacing of the dead wood pieces in the forest (Miehs et al., 2010), increasing the coefficient of variation and, consequently, the sampling error.

We found the smallest sampling errors in the estimation of small pieces using LIS method (error of 17.77%), while FA method results in higher errors (error of 26.89%). For coarse parts errors increased, but the LIS method also showed smallest errors (38.10%). To obtain the acceptable error for both sampling methods, we calculated the optimal number of sample units required for 15% error (Table 3).

LIS method was more accurate than the fixed area method (Table 3), resulting in a smaller relative error and fewer sample units to reach the admissible error, besides showing lower coefficient of variation in both categories of necromass studied. Woldendorp et al. (2004) verified that the coefficient of variation (CV) is

Figure 6. Exploratory analysis of necromassa stock (Mg ha⁻¹) of coarse piece for different methods of necromass estimation.

Table 2. Comparison statistics for the Line-Intersect (LIS) and Fixed Area (FA) sampling methods, Dois Irmãos State Park, Recife, Pernambuco, Brazil.

Descriptive statistics	Method		Method	
	(LIS)	(FA)	(LIS)	(FA)
	Small pieces		Coarse pieces	
	Transect 50 m	Plot 5 m x 5 m	Transect 50m	Plot 10 m x 10 m
Number of sampling units	20	20	20	20
Average volume (m³. ha⁻¹)	12.56	12.03	51.58	47.80
Standard deviation (m³. ha⁻¹)	5.77	8.58	50.83	48.39
Mean variance	1.66	3.68	129.21	117.08
Standard error	1.29	1.91	11.36	10.82
Coefficient of variation (%)	46	70	99	101
Absolute sample error (m³. ha⁻¹)	2.23	3.31	19.65	18.70
Relative error (%)	17.77	26.89	38.10	39.13

Table 3. Sample intensity needed to reach 15% error limit.

Sample intensity	Small pieces		Coarse pieces	
	Methods		Methods	
	LIS	FA	LIS	FA
Coefficient of variation (%)	46	70	99	101
Relative error (%)	17.77	26.89	38.10	39.13
No. of sample units needed to reach 15% of error	28	65	130	135

Table 4. Relative efficiency of the sampling methods Line-intersect and Fixed Area.

Categories	Methods	Time (h)	CV%	RE
Small pieces (2 cm < Ø < 10 cm)	LIS	15.06	46	3.13
	FA	19.0	70	1.07
Coarce pieces (Ø ≥ 10 cm)	LIS	8.41	99	1.21
	FA	9.85	100	1.01

CV = Coefficient of variation (%); RE = relative efficiency.

highly related to the sampling intensity in both sample methods, LIS and FA. Those results were also proven by Deus et al. (2018), who reported that the increasing in sample intensity decreases the coefficient of variation.

LIS method was more accurate and efficient than FA method. The smaller field time using the LIS method proves its efficiency concerning the FA method. The relative efficiency is presented in table 4, and the method with the highest value is the most efficient.

Palace et al. (2012) reported that LIS method is six times more efficient than the AF method and takes about a third of the time and half of the team in the field, since fixed area method requires higher movement and is difficult in dense forest. However, care should be taken in choosing the best approach, as it depends on the purpose of the forest inventory and forest conditions (Bate et al., 2004). Moreover, efficiency should not be the only parameter to be taken into account when choosing a method. Most precise methods are preferred for inventories that require a high quantitative rigor, while for strategic or rapid inventory surveys, it is possible to opt for the less conventional methods, or highly efficient methods (Miranda et al., 2015).

4. CONCLUSION

Evaluating both methods, the LIS method was more accurate estimating arboreal necromass. It requires lower sample intensity to meet a sample error of 15%

and is more efficient when compared to the FA method. However, the LIS method still requires a high sample intensity. Therefore, the LIS method seems to be more appropriate for the assessment of necromass in the Atlantic Forest. We verified that the stock of fallen dead wood accounts for about 12.28% of the total biomass above the soil in the studied forest fragment, demonstrating the importance of including necromass compartment in researches of carbon stock in tropical forests, which may account for up to 40% of the carbon found above the soil.

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