Journal of Forestry Research and Management. Vol. 20(3).9-21; 2023, ISSN 0189-8418
www.jfrm.org.ng

Estimating Deadwood Biomass by Decay Classes in the Federal College of Forest Resources Management, Ishiagu, Ebonyi State

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ABSTRACT

Deadwood plays a vital role in biomass storage and carbon cycling, contributing to climate change mitigation. However, there is a lack of quantitative data on deadwood biomass within the landscape of the Federal College of Forest Resources Management (FCFRM), Ishiagu, Nigeria. This study employed a systematic sampling technique, involving grid superimposition across the landscape, to select ten (10) cluster points for estimating deadwood biomass. Data including samples from coarse and fine woody debris for density determination, and diameters and height/length for volumetric estimation, were collected from a cluster design consisting of two nested square plots, measuring 35 m x 35 m and 2 m x 2 m, arranged in transects 100 meters apart. The sampled deadwood pieces were categorized into three decay classes based on 'machete' test: Sound, Intermediate, and Rotten. Biomass was calculated from the computed deadwood volume and density and then summarized for the decay classes. A total of fifteen (15) standing, fifteen (15) lying, and five (5) fine deadwoods were found in the sample plots, resulting in an average expanded deadwood biomass of 16.74 (±4.13) Mg ha^{-1}. Specifically, deadwoods in the 'Sound' decay class had a mean biomass capture of 17.03 (±5.73) Mg ha^{-1}, while the 'Intermediate' and 'Rotten' decay classes accumulated mean biomass values of 19.03 (±5.94) Mg ha^{-1} and 1.87(±0.13) Mg ha^{-1}, respectively. A strong linear relationship was observed between deadwood biomass and diameter, highlighting the influence of deadwood piece size, especially the volume of the large diameter class, on deadwood biomass gradients. Overall, the relatively high deadwood biomass estimates in the study area underscore the importance of effective deadwood carbon management and measures to monitor and manage tree degradation, mortality, and decomposition within the landscape. Further studies are encouraged to measure and report changes in deadwood biomass and carbon stocks across forested landscapes in Nigeria.

Keywords: biomass, deadwood, decay class, density, species, volume

Introduction

Forests play a pivotal role in the global carbon cycle, making them essential for carbon sequestration and mitigating the effects of climate change (McKinley *et al.*, 2011; Hararuk *et al.*, 2020). These ecosystems store up to 50% of the world's organic carbon (Pan *et al.*, 2011; Kamara and Said, 2022). In the context of reporting carbon emissions from land use and forestry sectors, the IPCC identifies five major carbon pools (IPCC, 2003). Among these, deadwood carbon is a dynamic pool with varying turnover rates (Woodall *et al.*, 2012; Pfeifer *et al.*, 2015) and is integral to sustainable forest management (Bujoczek, *et al.*, 2021). Deadwood comprises of coarse and fine woody debris that are categorized by size, with coarse woody debris encompassing standing deadwood, downed deadwood, and stumps while fine woody debris are small pieces of deadwood that is greater than 0.5cm and less than 10cm in diameter. Deadwood carbon accounting has predominantly focused on coarse woody debris, particularly standing deadwood, given its greater relevance and importance in carbon inventory compared to smaller fine woody debris (Russell *et al*., 2015). Nevertheless, the attention given to deadwood biomass is substantially overshadowed by the focus directed toward other carbon pools, especially aboveground live standing biomass, particularly in tropical forests (Houghton *et al*., 2009; Pfeifer *et al*., 2015). It has been assumed that living tree biomass accounts for the largest proportion of aboveground biomass, with deadwood biomass only contributing a negligible portion (Nascimento and Laurance, 2002; IPCC, 2003; Pfeifer *et al*., 2015). However, the actual importance and contribution of deadwood biomass in tropical forest ecosystems cannot be overemphasized.

Deadwood serves vital ecological functions by providing resources or habitats for a wide range of plant and animal groups, including arthropods like wood-feeding termites, amphibians, reptiles, birds, mammals, vascular plants, bryophytes, fungi and lichens; and is therefore an important driver of biodiversity (Eggleton *et al*., 1995; Gibb *et al*., 2005). Additionally, it acts as a substantial carbon sink and plays a crucial role in energy flow and nutrient cycling processes. Both coarse and fine deadwood can account for a significant portion of total above-ground biomass in various tropical forest types, potentially storing up to 20-33% of the total above-ground biomass (Clark *et al*., 2002; Bradford *et al*., 2009) and approximately 8% of the global forest carbon stock (Baccini *et al*., 2017). Deadwood may even represent over 50% of above-ground carbon stocks in salvage-logged forest stands (Pfeifer *et al*., 2015). However, these carbon sinks are offset by carbon losses resulting from deforestation and forest degradation, particularly in tropical regions, making them a persistent net carbon source (Baccini *et al*., 2017; Mills *et al*., 2023).

Forest degradation and disturbance factors, like logging, fuelwood extraction for local energy and forest fires are integral components of prevalent human-induced tropical forest land use change processes. These processes impact not only the stocks of aboveground living biomass but also contribute variably to deadwood carbon stocks and emissions. While some studies suggest that forest degradation and disturbance lead to increasing emissions and loss of deadwood carbon, exacerbating woody debris decomposition (Nascimento and Laurance, 2002; D'Amato *et al*., 2017). These indicate a rise in the accumulation of deadwood carbon stocks in human-modified forest ecosystems, especially in the long-term following disturbance events (Pfeifer *et al*., 2015; Woodall *et al*., 2015; 2021).The fate of deadwood carbon stocks is influenced by various factors, including land use history, site topography and steepness, soil nutrients, debris/species composition, and debris decay stage, leading to variable decomposition rates and estimates of deadwood carbon stocks (Pfeifer *et al*., 2015; Hararuk *et al*., 2020; Bujoczek *et al*., 2021; Ma *et al*., 2023). As a result, site-specific estimation and monitoring of deadwood biomass and carbon stocks and fluxes are necessary, considering the variability in decay levels of woody debris.

Decay class is an essential attribute that helps quantify woody debris by elucidating its decomposition stage (Russell *et al*., 2015). Different systems have been developed for this purpose, with no universally accepted standard. Common systems include the five-class system, categorizing deadwood into various decay stages (sound, moderately decayed, advanced decay, highly decayed, and completely decayed) (Harmon *et al*., 1995; Di Cosmo *et al*., 2013; Pfeifer *et al*., 2015), and the simpler three-class system (sound, partly soft/intermediate, and soft/rotten) (Chojnacky and Heath, 2002). Typically, woody debris is assigned to decay classes based on tactile criteria, such as tool penetration distance, or visual criteria, such as colour or plant colonization (Russell *et al*., 2015). Understanding deadwood biomass estimates across different decay classes is crucial for effective deadwood carbon management and inventory.

Despite its significance, there is a paucity of quantitative data on deadwood biomass pools globally, with even less information available on downed deadwood components (Chojnacky and Heath, 2002; Russell *et al*., 2015). Furthermore, most carbon studies in Nigerian forest ecosystems have primarily focused on living aboveground biomass, with limited inclusion of deadwood biomass stocks in comprehensive carbon assessments (e.g., Olorunfemi *et al*., 2019). Consequently, the drivers of deadwood accumulation in the Federal College of Forest Resources Management (FCFRM), Ishiagu, Nigeria, remain poorly documented. This study aimed to quantify deadwood biomass in the area using a three-decay-class system.

Materials and Methods

Description of the study area

This study was conducted within the Federal College of Forest Resources Management (FCFRM) Ishiagu, covering 46 ha in size. It is located between latitudes 5°51’58.68’’ and 5°52’30’’ North and longitudes 7°34’13.8’’ and 7°33’54.72’’ East in Ebonyi State, Nigeria (Fig. 1). The area receives an annual rainfall ranging from 1200 to 1600 mm and experiences mean temperature variations between 27°C and 33°C.

The landscape contains a diverse range of vegetation, characterized by various woody species, including timber and fruit trees, as well as other woody shrubs. Some of the notable tree and plant species observed in the landscape include *Adansonia digitata, Albizia adianthifolia, Terminalia ivorensis, Ceiba pentandra, Elaeis guineensis, Eucalyptus camaldulensis, Ficus* spp., *Gliricida sepium, Gmelina aborea,* and *Irvingia gabonensis,* respectively. The landscape comprises of 11 communities with autonomous status (Anyata, 2001). It is located within a semi-urban town primarily engaged in agriculture, with extractive industries and education as the main sources of livelihood (Areola *et al*., 2001). Compound farming is a common practice within each community, although other farming sites with hamlet settlements are also present. Quarrying activities for solid minerals like granite, lead, and salt are prevalent in various parts of these communities, leading to ecological degradation and health hazards for both the landscape and its inhabitants. However, these activities have generated some job opportunities and socio-economic benefits. The communities share a homogenous ancestral descent and farming practices (Ebii, 2003).

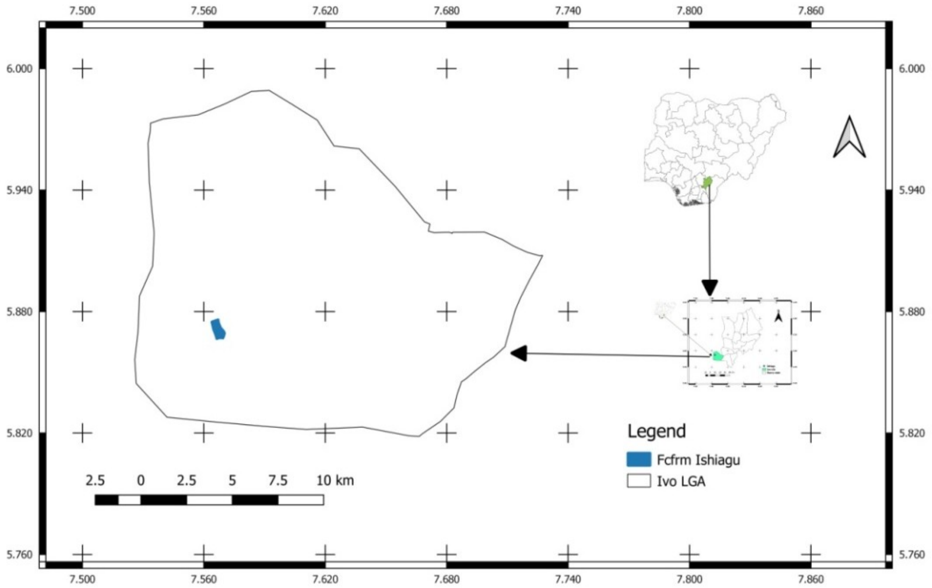

Figure 1: Map showing the location of the study area

Sampling design and sample plot layout

Systematic (grid) sampling is one of the most commonly employed techniques generally in forest biomass/carbon inventory, given its demonstrated accuracy for large-scale assessment yet with minimal sampling effort (Marvin and Asner, 2016; FAO, 2020). In this study, systematic sampling was applied to inventory deadwood biomass using a 1 km by 1 km grid superimposed over the landscape (Aghimien *et al.*, 2020a; FAO, 2020). Systematic grids were selected to establish 10 sample points. The sampling unit was a cluster design, consisting of a set of square nested plots, within every sample point, measuring 35m x 35m. Two of these plots were positioned at right angles to the top of a central plot in an L-shaped transect arrangement, with a distance of 100m between them. These plots are referred to as Elbow, East, and North plots. The cluster-nested plot design was adapted from the '*Field manual for forest carbon inventory in Nigeria*' (FAO, 2020), but it was not an exact replication of the methodology described therein.

Typically, according to FAO, a 35m x 35m nested plot is subdivided into three smaller plots or 'nests,' each with dimensions of 25m x 25m, 7m x 7m, and 2m x 2m for the measurement of biomass with varying diameters. However, in this study, only two nests were considered: 35m x 35m and 2m x 2m. These were used for enumerating coarse deadwood and fine woody debris, respectively. The study focused on components of coarse deadwood, which included standing deadwood and lying/downed deadwood, excluding stumps. Figure 2 illustrates the cluster arrangement depicting the nested plots.

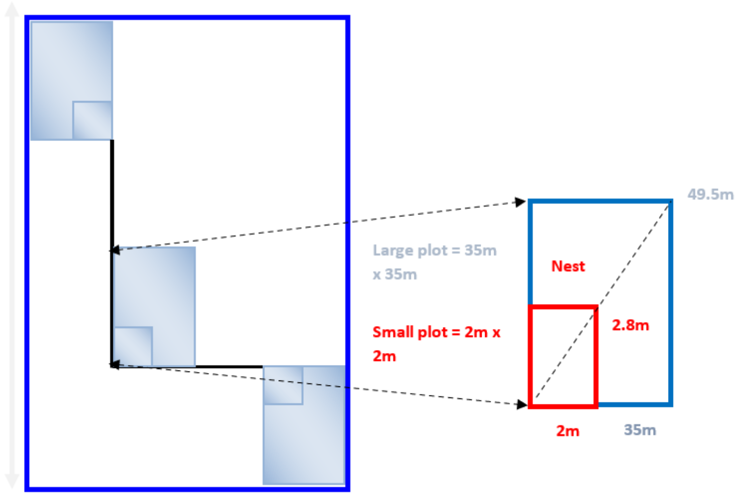

Figure 2: Sketch diagram of the cluster arrangement and nested plots used in the study (Adapted from FAO, 2020).

Measurement for deadwood

The deadwood pool sampled in this study included both standing and lying (downed) deadwood, constituting coarse woody debris, as well as fine woody debris. Coarse woody debris consisted of deadwood pieces with a diameter of at least 5cm and a length or height of 1m, depending on their position (lying or standing). Fine woody debris encompassed deadwood pieces with diameters between 2cm and 5cm, but with heights less than 1m. Coarse deadwood, which included fallen and standing dead logs, dead trees (snags), and large dead branches, was identified and sampled within the larger 1,225 m^2 plots. On the other hand, a complete enumeration of fine woody debris, consisting of dead twigs and small branches, was conducted within the smaller 2 m x 2 m nests. Deadwood exhibits variation in states of mortality and decomposition.

To avoid confusion, especially between standing deadwood and live trees with no foliage, this study adopted the classification for distinguishing and accounting for different classes of standing dead trees highlighted by FAO (2020). It was necessary to consider both standing deadwood classes based on the state of decomposition: Class 1 - trees with branches and twigs that resemble live trees (except for the absence of leaves; ensuring the dead tree is not deciduous); and Class 2 - tree with signs of decomposition (in addition to the loss of foliage), without twigs and branches (Fig. 3).

In this study, a three-class system was used to identify and classify all the deadwood pieces into decay classes for further statistical analysis. The decay class to which a deadwood belonged was determined using a "machete" test, which assigned deadwood into one of three density categories: sound (S), intermediate (I) or rotten (R), by striking the wood with a machete and assessing its penetrating behaviour (Chojnacky and Heath, 2002; Russell *et al.*, 2015; FAO, 2020). If the machete: (1) bounced back, the deadwood piece was classified as sound (S); (2) partly sank into the wood, it was classified as intermediate (I); and (3) sank into the soft wood, and the wood crumbled, then the piecewas categorized as rotten (R).

Before extracting samples from the deadwood for wood density measurement, some dendrometric parameters were assessed for all the identified deadwood pieces within each plot for volume estimation (Fig. 3). For standing deadwood, the diameter (cm) was measured at both ends – the base (D_{base}) and the top (D_{top}), as well as the DBH, where possible. A few snags did not reach breast height, so DBH was omitted in such deadwood measurements and taken as D_{base}, as the variable was not necessary for volume estimation. DBH data only assisted in informing our sample collection for laboratory mensuration, ensuring that the samples included varying diameter classes while appropriately determining the category (coarse/fine) of the deadwood, especially when it was challenging to visually assess it. The height (H, m) of the standing deadwood was also measured. For downed deadwood, measurements included diameter at the deadwood base (D_{base}), diameter at the top (D_{top}) and the length of the woody debris (L) using a tape measure. All sections of the deadwood falling outside the plot boundaries were excluded.

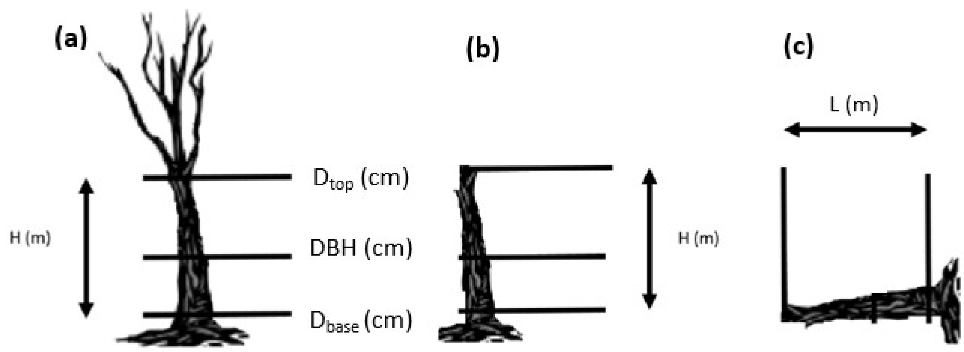

Figure 3: Typical parameters measured for (a) Class 1 standing deadwood, (b) Class 2 standing deadwood, and (c) lying deadwood (Adapted from FAO, 2020)

Estimation of deadwood biomass and statistical analysis

Representative samples were collected from each of the deadwood biomass components. Following FAO (2020), wood samples were obtained from at least 5-10 deadwood for each density class, covering various diameter sizes, which were taken to the laboratory for wood density determination. The samples were initially extracted and weighed within the landscape using a balance. The volume of each sample was determined using the water displacement method. To obtain the dry weight, samples underwent oven-drying until a constant weight was achieved at a temperature of 105°C for density determination. The density estimates, calculated from the ratio of dry weight to fresh volume, were used to convert the volume of each deadwood piece to deadwood biomass. The volume of each deadwood piece was computed from the measured dendrometric variables, assuming the deadwood to be a frustum of a truncated cone (Baker *et al.*, 2007; Aghimien *et al.*, 2020a,b). The following formula, adopted from Baker *et al.*, (2007) was used to estimate deadwood volume, as presented in equation 1. Here, “h” represents both the height (H) for standing deadwood and the length (L) for downed deadwood.

$$\text{Volume} = \left(\frac{\pi . h}{12}\right)\left(D_{base}^2 + \left(D_{base} . D_{top}\right) + D_{top}^2\right) \ldots \ldots \ldots$$

Deadwood volumes were then converted to dry biomass using deadwood density values obtained during the biomass inventory, following Kueppers *et al.*, (2004).

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$$\text{Deadwood Biomass} = \sum_{i}\sum_{k=1}^{n} V_{k,i} \times \rho_i \ldots\ldots\ldots\ldots 2$$

where V (cm^3) represents the volume of any deadwood piece (k), i labels the deadwood class, ρ is the deadwood density (gcm^{-3}), and the sum is across all pieces and deadwood classes within each plot. Since the deadwoods were measured in subplots/nests of two (2) different sizes, an expansion factor was required for each nest to standardize all measurements to a per-hectare basis. 8.16 and 2500 were used for the larger 1,225 m^2 and smaller 4 m^2 nests, respectively.

Further statistical analysis of the deadwood biomass was conducted based on decomposition grade. Descriptive statistics were initially used to summarize the deadwood biomass across the three (3) decay classes. Non-parametricKruskal-Wallis Testwas conducted to test for significant differences among the classes at a significance level of 0.05. Finally, Pearson correlations analysis was used to evaluate the relationship between deadwood biomass and its dendrometric variables.

Results and Discussion

Structuralcharacteristics of deadwood

A total of fifteen (15) downed/lying deadwood pieces, fifteen (15) standing deadwood, and five (5) fine woody debris pieces were identifiedwithin the ten (10) temporary sample plots across the landscape. Table 1 summarises the descriptive statistics for these deadwood pieces. The diameter at the top and base of the coarse and fine woody debris pieces ranged from 1.2 cm to 12cm and from 1.55 cm to 16cm, respectively. The mean diameters of the deadwood were 4.73 (±0.51) cm and 5.93 (±0.61) cm at the respective ends. The individual deadwood pieces had attained volumes and heights (if standing) or length (if lying) of up to 0.025 m^3 and 16 m, respectively. Tree mortality in the landscape could be attributed to major episodic anthropogenic disturbance agents, including tree harvesting, selective logging for small-scale extractive wood uses, and agricultural expansion, as reported in other degraded tropical landscapes (Pfeifer*et al.*, 2015). Historical quarrying activities in the area could have also led to soil disturbance, facilitating individual tree deaths, the effects of which vary with tree species, age, underlying damages, pest infestations, and diseases. Deadwood accumulation in the area could also be attributed to other factors termed as “background mortality” agents, including self-thinning and senescence, which are not necessarily linked to specific expected disturbance pulses (Russell *et al.*, 2015).

In the landscape, deadwood has sequestered a mean biomass stock of 16.74 (±4.13) Mg ha^{-1}, with a very high upper extreme value of 87.27Mg ha^{-1}. This deadwood biomass estimate is somewhat consistent with the ranges recorded in different tropical forests, despite the relatively lesser tree density and diameter size in the landscape compared to those forests. Saner *et al.* (2012) and Pfeifer *et al.* (2015) reported biomass values of approximately 26 Mg ha^{-1} and 21 Mg ha^{-1} for coarse woody debris in specific lowland forests in North Borneo and Malaysia, respectively.

Table 1: Descriptive statistics of the deadwood variables in the landscape

Variable	Minimum	Maximum	Mean (±SE)	Median	Variance	SD
D_{top} (cm)	1.20	12.00	4.73 (±0.51)	4.00	9.21	3.03
D_{base} (cm)	1.55	16.00	5.93 (±0.61)	4.70	13.21	3.63

H/L (m)	0.14	16.00	1.63 (±0.46)	0.95	7.50	2.74
V (cm^3)	71.18	24857.85	4765.89 (±1176.71)	864.57	4.8 x10^7	6961.49
DB (Mg/ha)	0.25	87.27	16.74 (±4.13)	3.04	597.07	24.44

Deadwood biomass estimates by decay classes

Table 2 presents biomass estimates for deadwood pieces in the landscape categorized into three decay classes. It was observed that over 66% of the deadwood falls into the 'Sound' decay class, while 29% belongs to the 'Intermediate' decay class, and the remaining 6% falls into the 'Rotten' class. The presence of a high proportion of sound individual deadwoods within the landscape, in comparison to the components that have already begun to decay moderately or severely, suggests either low rate of decomposition or high inputs from the living aboveground biomass into the deadwood stocks within the area. This observation aligns with the findings by Pfeifer *et al.*, (2015).

Typically, according to Russell *et al.*, (2015), the mean residence time of deadwood carbon before transitioning into the soil organic matter pool is expected to be about 6-9 years, although it may vary (Russell *et al.*, 2015). Therefore, low decomposition rates and, consequently, a higher proportion of sound deadwood and slightly decayed pieces in the landscape potentially have a positive impact on deadwood carbon retention and balance in the area. This is evident in the substantial amount of biomass captured by deadwood pieces in the 'Sound' decay class, with a mean value of 17.03 (±5.73) Mg ha^{-1}, and only two pieces accounting for a mean biomass value of 1.87 (±0.13) Mg ha^{-1} in the 'Rotten' class. However, despite having the largest number of deadwoods (23) and recording the highest individual biomass estimate (see Fig. 4), the cumulative biomass estimate of the 'Sound' decay class was lower than that of the 'Intermediate' decay class, which had a mean biomass value of 19.03 (±5.94) Mg ha^{-1}. It was observed that most of the deadwood pieces in the largest diameter class belonged to this 'Intermediate' category, which could have contributed to its high biomass stock.

This assertion is consistent with several other studies on deadwood biomass that emphasize the contribution of forest structures, piece size, particularly the volume of the large diameter class, in deadwood biomass gradients. These structural factors, along with wood density and site-specific conditions, have been highlighted in previous studies (Kueppers *et al.*, 2004; Russell *et al.*, 2015; Woodall *et al.*, 2021; Ma *et al.*, 2023).

In general, deadwood biomass and carbon accumulation, distribution, and decomposition in a forest ecosystem or wooded landscape can be sensitive to or influenced by various biological and environmental factors. These include the species and age of the deadwood, climate, disturbances, land use, and terrain topography (Pfeifer *et al.*, 2015; Hararuk *et al.*, 2020; Bujoczek *et al.*, 2021; Ma *et al.*, 2023).

Table 2: Descriptive statistics of dead wood biomass among decay classes

Statistics	Rotten ($Mgha^{-1}$)	Intermediate ($Mgha^{-1}$)	Sound ($Mgha^{-1}$)
Mean	1.87150	19.03269	17.03106
Standard Error	0.128292	5.936808	5.733153
Standard Deviation	0.18143	18.77383	27.49524

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Sum	3.7430	190.3269	391.7144
Uncertainty	0.096945	0.986399	1.614417

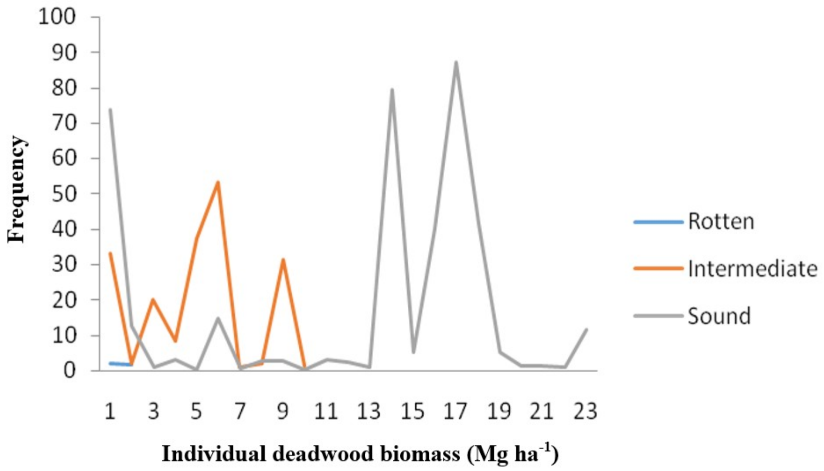

Figure 4: Distribution of deadwood biomass across decay classes

Decay class is a primary driver of deadwood density, whereas the size of deadwood and the site play important roles in determining deadwood biomass (Russell *et al*., 2015; Woodall *et al*., 2021). Standing deadwood generally exhibits contrasting properties when compared to lying deadwood, particularly in terms of density and decay class, and tends to dominate the 'Sound-Intermediate' categories. Standing deadwood is typically less decayed than its downed counterparts, as the latter are more susceptible to changes in biomass density (D'Amato *et al*., 2017; Woodall *et al*., 2021).

However, further statistical analyses suggest that categorizing the deadwood pieces into decay classes did not reveal any apparent differences in deadwood biomass density by decay class (Fig. 5). Instead, the relatively low number of observations for large-sized deadwoodis highlighted (Fig. 4), which is in line with Aghimien *et al.*, (2020a). There was no statistically significant difference between the biomass estimates of the decay classes ($p > 0.05$; see Fig. 5). However, it is worth noting that this lack of significance may have been influenced by the unequal sample sizes among the groups (Sullivan and Feinn, 2012). Nevertheless, it is evident that the landscape stores a substantial overall biomass and carbon stocks in the deadwood pool, despite its low tree density. This underscores the need for adequate forest (carbon) management efforts in the area, since an unabated increase in deadwood biomass is attributed to significant loss in the aboveground biomass and carbon of living trees (Pfeifer *et al*., 2015).

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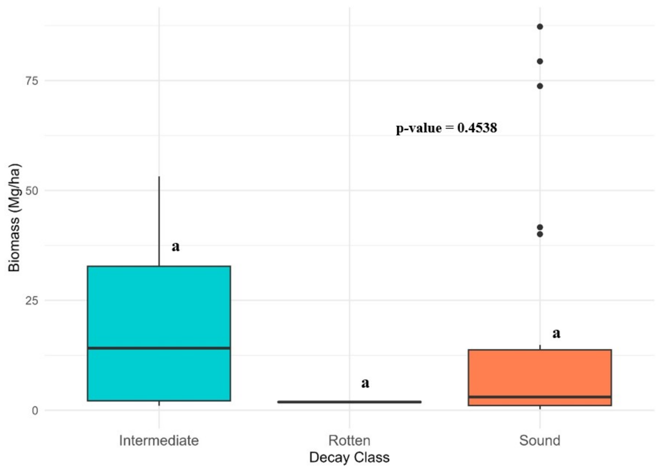

Figure 5: Illustration of non-statistical significance among the decay classes in terms of their deadwood biomass estimates

Correlation analysis of deadwood biomass and dendrometric variables

It was shown that Table 3 presents the correlation matrix, illustrating the strength of the linear relationship between deadwood biomass and its dendrometric variables within the landscape, to understand the potential influence of forest structure and tree growth, while alive, on biomass stock in deadwood. The results indicate a strong positive correlation between biomass and D_b (64%) or D_t (62%) at the 0.05 significance level, but a perfect significant linear relationship between deadwood biomass and volume.

Conversely, only a moderate correlation (48%) was observed between biomass and the length or height of the deadwood, again depending on whether it was lying or standing. This underscores the superior influence of deadwood diameter, which is more directly related to basal area and volume, in determining deadwood biomass compared to height/length. These findings suggest that diameter is a more suitable predictor for estimating deadwood biomass, consistent with observations in most other biomass studies (Aghimien *et al.*, 2020b; Hossain *et al.*, 2023; Alade *et al.*, 2023). This variable, when coupled with wood density and decay class, provides a robust and accurate model and approach for deadwood biomass estimation (Chojnacky and Heath, 2002; Woodall *et al.*, 2021).

Table 3: Pearson correlation matrix of the variables in the landscape

	Diameter @ base (cm)	Diameter @ top (cm)	Length or Height (m)	Volume (cm^3)	Biomass ($Mgha^{-1}$)
Diameter @ base(cm)	1.0000				
Diameter @ top(cm)	0.9662*	1.0000			
Lengthor Height (m)	0.0151	-0.0233	1.0000		
Volume (cm^3)	0.6433*	0.6153*	0.4769	1.0000	
Biomass ($Mgha^{-1}$)	0.6432*	0.6152*	0.4770	1.0000*	1.0000

* Correlation is significant at the 0.05 level

Conclusion

The decay class plays a crucial role in determining deadwood density and biomass, as it reflects the decomposition rate and the flux of biomass/carbon within the deadwood pool. However, this study sheds light on the additional influence of deadwood size and volume on deadwood biomass stocks. Despite a relatively substantial amount of deadwood biomass within the study landscape, comparable to carbon estimates in denser tropical forest ecosystems, the majority of the deadwood biomass is stored within the 'Intermediate' decay class.

This observation, while not significantly different from other classes, highlights the weighted effect of larger-sized deadwood within this category on total biomass stocks. In general, the landscape exhibits a low decomposition rate and high biomass retention, as evidenced by the small proportion of 'Rotten' deadwood present. Deadwood diameter demonstrates a stronger relationship with deadwood biomass and potentially serves as a more effective predictor in accurate deadwood biomass and estimation. Finally, the high biomass estimates for the limited deadwood pieces found in the study area suggest a potential reduction in aboveground living tree biomass and carbon. This emphasizes the need for proactive deadwood biomass/carbon accounting and management, as well as effective monitoring of tree disturbances, mortality, and decomposition within the landscape.

Funding: This research did not receive any external funding.

Declaration of Competing Interest: The authors declare no competing interests that could have influenced this work.

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