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Quantification of deadwood biomass, carbon stock, and carbon dioxide equivalent across decay classes

Aghimien Ehimwenma VICTOR Rain Forest Research Station, Ore, Ondo State, Nigeria
Akintan Cornelius IMOLE Rain Forest Research Station, Ore, Ondo State, Nigeria
Demirel BAWA Institute of Botany and Botanical Garden, Faculty of Biology, University of Belgrade, Serbia
Fousseni FOLEGA Department of Botany, Faculty of Sciences, University of Lomé, Togo

Deadwood constitutes an important yet frequently overlooked carbon pool in tropical forest ecosystems, contributing significantly to carbon storage and climate change mitigation. This study quantified deadwood biomass, carbon stock, and carbon dioxide equivalent (CO_2e) across three decay classes (Sound, Intermediate, and Rotten) along the Sobe road dualization corridor in Edo State, Nigeria. Using a stratified systematic sampling design, 55 coarse woody debris samples were measured for diameter, length, basal area, and volume. Biomass was estimated using decay-adjusted wood density, while carbon stock and CO_2e were calculated following IPCC guidelines. Sound deadwood recorded the highest mean biomass (0.824 ± 0.645 kg ha^{-1}), carbon stock (0.392 kg C ha^{-1}), and CO_2e (1.440 kg CO_2e ha^{-1}), whereas rotten wood exhibited the lowest values due to advanced decomposition. Biomass differences among decay classes were highly significant. Deadwood volume demonstrated an almost perfect positive relationship with carbon stock, indicating that volume is a reliable predictor of carbon storage. The findings emphasize the importance of incorporating decay-class-specific deadwood assessments into forest carbon inventories, Monitoring, Reporting and Verification systems, and climate mitigation initiatives to improve carbon accounting accuracy in disturbed tropical landscapes.

Keywords: Deadwood, Carbon Stock, Coarse Woody Debris, Carbon Accounting, Tropical Forest, Climate Change Mitigation, CO_2 Equivalent

INTRODUCTION

Forests are central to regulating the global climate because they capture and store massive amounts of atmospheric carbon dioxide (FAO, 2020). While forest carbon inventories typically focus on living trees (Brown, 2002), deadwood represents a highly dynamic and significant carbon pool. The Intergovernmental Panel on Climate Change (IPCC) recognizes deadwood as one of the five primary forest carbon pools, alongside aboveground biomass, belowground biomass, litter, and soil organic carbon (IPCC, 2019). Deadwood locks away carbon gathered during a tree's life and releases it slowly back into the ecosystem through the natural decay process (Harmon et al., 1986).

Recent research has emphasized that deadwood carbon stocks can contribute substantially to total ecosystem carbon, with estimates ranging from 0.11 to 1.01 t C ha^{-1} across different vegetation types. Studies in Indonesian lowland rainforests have demonstrated that natural forests contain approximately three times higher deadwood carbon stocks (4.5 t C ha^{-1}) compared to transformed systems such as jungle rubber (1.5 t C ha^{-1}). This underscores the sensitivity of deadwood carbon pools to land-use change and highlights the need for accurate quantification.

Furthermore, the decomposition pathway significantly influences carbon dynamics in deadwood.

Research from Vietnamese montane tropical forests has shown that wood density progressively decreases across decay classes, with mass loss averaging 0%, 20%, 37%, 54%, and 74% across the five decay stages. The mean carbon concentration in woody debris was found to be 46.5%, consistent with the IPCC default values, though this concentration did not change significantly with decay stage. White-rot fungi were identified as the dominant decomposers, accounting for 88% of decomposition cases in tropical systems.

Despite its ecological importance, deadwood is routinely left out of tropical forest carbon inventories due to logistical challenges and the unpredictable nature of wood decay. Skipping this pool can lead to inaccurate baseline data, which weakens climate initiatives like REDD+ and formal carbon crediting markets (Pearson et al., 2005). The uncertainty associated with deadwood carbon estimates can range from 0.0008% to 0.28%, with decay status having a significant effect on carbon stock estimates. These uncertainties are particularly concerning for national climate policies and REDD+ mechanisms where accurate carbon accounting is essential.

Recent studies have also highlighted the role of disturbance events in deadwood dynamics. Severe storms in tropical forests have been shown to increase CWD carbon stocks by approximately 25%, with most new carbon accumulating in less decomposed and smaller diameter classes. This is particularly relevant for infrastructure-impacted landscapes like the Sobe road corridor, where anthropogenic disturbance creates pulse inputs of deadwood.

This study addresses the critical gap in deadwood quantification by assessing the dynamics along the Sobe road dualization corridor in Edo State. By quantifying biomass, carbon stocks, and CO_2 across Sound, Intermediate, and Rotten decay classes, this research provides empirical data needed to build more accurate, transparent carbon accounting models for infrastructure-impacted tropical landscapes.

MATERIALS AND METHODS

Study area

The research focuses on the road dualization corridor within the Sobe Community, located in the Owan West Local Government Area at the northern edge of Edo State. This region sits within the ecologically sensitive transition zone between the Guinea Savannah and Lowland Rainforest (Latitude 7°00’-7°15’ N, Longitude 5°45’-6°05’ E), with elevations between 150 and 300 meters above sea level.

The local climate is humid and tropical, featuring a long rainy season from April to October (1,500--2,000 mm annually), temperatures averaging 25-32°C, and relative humidity fluctuating between 65% and 90%. This climate creates an ideal environment for rapid biomass production and fast natural decomposition. The landscape is a mosaic of secondary tropical rainforests, derived savannah, regenerating fallow lands, and agroforestry systems. Common tree species include Terminalia superba, Nauclea diderrichii, Milicia excelsa, Albizia zygia, and Triplochiton scleroxylon. The ongoing road dualization project directly clears this vegetation, generating substantial amounts of coarse woody debris (CWD) along its right-of-way.

Sampling design and field protocol

To accurately capture the impact of road construction, Stratified Systematic Sampling Design across a 200-meter-wide corridor (100 meters on either side of the road’s centerline). The study area was split into three zones based on construction footprint:

Stratum I (High Disturbance): Areas directly cleared for the carriageway, drainages, or borrow pits.

Stratum II (Moderate Disturbance): Adjacent areas experiencing partial clearing.

Stratum III (Low Disturbance/Control): Unchanged Forest areas serving as a baseline reference.

Permanent sampling transects (100 m × 10 m, or 0.1 ha) were established perpendicular to the road at 500-meter intervals. Any piece of deadwood intersecting a transect was measured if it met the standard minimum thresholds (diameter ≥ 10 cm and length ≥ 1.0 m) in accordance with global carbon accounting guidelines (IPCC, 2019; Verra, n.d.). These thresholds are consistent with those used in other tropical deadwood studies. For every log, the large-end diameter (D_1), small-end diameter (D_2), and total length (L) were recorded. Each piece was then assigned to a decay class (Table 1) using standard field protocols (Aghimien et al., 2023).

This decay classification system is widely applied in tropical deadwood research and has been validated in studies from Indonesia and Vietnam, where wood density measurements confirmed significant differences between decay classes.

Statistical framework

Deadwood volume (V) was calculated using Smalian's formula, which is standard for volume estimation techniques (Aghimien et al., 2020):

eq. 1

Where:

V = volume

L = length

D_1 = large-end diameter

D_2 = small-end diameter

Biomass was determined by multiplying the volume by a baseline tropical wood density factor (0.43 g cm^{-3}), adjusted by decay-class reduction factors (Aghimien et al., 2015). Recent studies have shown that wood density varies significantly across decay classes, with density values ranging from 0.56 g cm^{-3} in sound wood to 0.15 g cm^{-3} in the most advanced decay stage . Following IPCC (2019) guidelines, carbon stock was calculated as 47% of the total dry biomass, and the carbon dioxide equivalent (CO_2e) was determined by multiplying the carbon stock by the molecular ratio of carbon dioxide to carbon (3.667) as presented below:

Biomass Estimation

Deadwood biomass was calculated as:

eq. 2

Where wood density was assumed to be 0.43 g cm^{-3}.

Carbon Stock Estimation

Carbon stock was estimated using the IPCC conversion factor:

eq.3

Carbon Dioxide Equivalent

Carbon stock was converted to CO_2 equivalent using:

eq.4

Data analysis

Because the field data contained typical ecosystem variations and few outliers, non-parametric tests alongside standard descriptive statistics (mean, standard deviation, and coefficient of variation). A Kruskal-Wallis test was applied to assess differences across decay classes, followed by Pearson correlation and linear regression analyses to map the relationship between physical log dimensions and final carbon estimates. This analytical approach is consistent with methodologies used in recent deadwood carbon assessments across tropical Africa.

RESULTS AND DISCUSSION

Deadwood distribution and biomass changes

A total of 55 deadwood pieces were assessed along the corridor. Rotten logs were the most abundant (n = 23), followed by Sound (n = 19) and Intermediate (n = 13) logs (Table 2), indicating active decomposition under the humid tropical conditions of the study area. Similar distributions have been reported in tropical forests where high temperature and moisture accelerate wood decay.

The analysis showed that decomposition substantially reduced biomass storage. Sound deadwood recorded the highest mean biomass (0.824 ± 0.645 kg ha^{-1}), approximately 5.2 times greater than Intermediate wood (0.158 ± 0.190 kg ha^{-1}) and 8.4 times greater than Rotten wood (0.099 ± 0.137 kg ha^{-1}) (Table 3). These differences were statistically significant (Kruskal–Wallis $H = 20.13$, $p < 0.001$) (Table 4), demonstrating that biomass declines progressively with increasing decay.

The observed trend agrees with previous studies by Harmon et al. (1986), Aghimien et al. (2023), and Masanja et al. (2026), who reported that sound woody debris retains greater biomass because structural tissues remain largely intact. As decomposition progresses, fungal activity and microbial degradation reduce wood density and mass, resulting in lower biomass accumulation. This finding confirms that decay class is a major determinant of deadwood biomass and should be incorporated into biomass estimation protocols for tropical forests.

Carbon stocks and climate implications

Carbon stock and CO_2 equivalent closely followed biomass trends (Table 5). Sound deadwood contained the highest mean carbon stock (0.392 kg C ha^{-1}) and CO_2 equivalent (1.440 kg CO_2e ha^{-1}), whereas Rotten wood contained the lowest values (0.047 kg C ha^{-1} and 0.174 kg CO_2e ha^{-1}). Sound logs therefore stored more than eight times the carbon retained in rotten logs.

These findings demonstrate that although deadwood continues to function as a carbon reservoir after tree mortality, its carbon storage capacity decreases substantially as decomposition advances. Similar observations have been reported in tropical forests of Indonesia, Tanzania, and Vietnam, where carbon stocks decline significantly with increasing decay due to continuous carbon release through microbial respiration.

The relatively lower carbon stock values obtained in this study compared with regional forest assessments may be attributed to the disturbance-focused sampling along the road corridor rather than intact forest ecosystems. Nevertheless, the results highlight the importance of incorporating

deadwood into national greenhouse gas inventories, REDD+, and Nature-Based Solutions because excluding this carbon pool can lead to underestimation of ecosystem carbon stocks.

Structural predictors of carbon storage

Pearson correlation analysis revealed strong positive relationships between deadwood dimensions and carbon stock (Table 6). Deadwood volume exhibited an almost perfect correlation with carbon stock ($r = 1.00$), while basal area ($r = 0.93$) and end diameters ($r = 0.90–0.91$) also showed strong associations.

Linear regression further demonstrated that deadwood volume alone explained 99.985% of the variation in carbon stock ($R^2 = 0.99985$) (Table 7). This exceptionally high coefficient of determination indicates that volume is an excellent predictor of carbon storage.

The strong volume–carbon relationship supports the recommendations of the IPCC (2019) and confirms findings by Aghimien and James (2019), Aghimien et al. (2020), and Sousa and Silva (2024), who identified volume as one of the most reliable field variables for estimating deadwood carbon. Since volume measurements are relatively simple and inexpensive to obtain, they provide a practical approach for rapid carbon assessment in tropical forests, especially in infrastructure-impacted landscapes where laboratory analyses may not be feasible.

CONCLUSION

Deadwood is a major carbon reservoir, but its capacity shifts significantly as it decays. In the tropical transition forest of Sobe, sound logs retain the highest levels of biomass and carbon, while rotten logs lose most of their storage capacity to progressive decomposition. These findings align with recent studies from across the tropics that have confirmed the significant role of decay stage in determining deadwood carbon stocks. The nearly perfect predictive relationship between volume and carbon stock provides a practical, field-accessible method for carbon estimation that does not require complex laboratory analysis.

As tropical landscapes face increasing pressure from infrastructure developments, quantifying deadwood is no longer optional for accurate carbon accounting. Incorporating volume-based, decay-specific assessments into environmental impact inventories will strengthen climate mitigation initiatives and ensure that forest carbon projects are built on solid, realistic data. The uncertainty associated with deadwood carbon estimates can be substantially reduced through systematic decay classification and volume measurement. Future studies should look to integrate larger sample sizes and temporal monitoring to further understand deadwood turnover rates in tropical ecosystems. Additionally, research exploring the relationship between soil carbon dynamics and deadwood decomposition would provide valuable insights into the complete carbon cycle in disturbed tropical forests.

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