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# Assessing Deadwood Carbon Stock within the National Parks of Indonesia

**Nurul Silva Lestari[1*], Eka Susanti[2], Galih Kartikasari[3], Anton Eko Satrio[2], Andrew Mikhov Sion[4], Nori Hariyen[5], Sugianur[6], Anita[7]**

[1]Research Center for Ecology and Ethnobiology, the National Research and Innovation Agency (BRIN). Jl. Raya Jakarta-Bogor KM. 46, Cibinong, Bogor, 16911, West Java, Indonesia
[2]Directorate Ecosystem Services of Conservation Area, Directorate General of Natural Resources and Ecosystem Conservation, Ministry of Environment and Forestry, Bogor, 16121, Indonesia
[3]Center for Standardization of Disaster Resilience and Climate Change Instrument, Ministry of Environment and Forestry, Bogor, 16118, Indonesia
[4]Sebangau National Park, Palangkaraya, Central Kalimantan, 73111 Indonesia
[5]Bukit Tiga Puluh National Park, Indragiri Hulu, Riau, 29355, Indonesia
[6]Kutai National Park, Kutai Timur, East Kalimantan, 75553, Indonesia
[7]Lore Lindu National Park, Palu, Central Sulawesi, 94111, Indonesia

[*]Corresponding author: nurul.silva.lestari@brin.go.id

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**Abstract.** The preservation of national parks has emerged as a significant component of Indonesia's climate mitigation efforts, primarily due to its substantial carbon stocks. However, little is known about the potential carbon stored in deadwoods within these areas. This study aims to estimate fallen deadwood carbon stocks in four national parks in Indonesia. The results show that the density of deadwood in study areas ranges from 0.26 – 0.79 g $cm^{-3}$. Deadwood volume varies between 247.37 – 388.50 $cm^3$. Bukit Tigapuluh National Park has the highest fallen deadwood biomass and carbon stock, accounting for 261.35 and 122.83 tons $ha^{-1}$, respectively, followed by Sebangau National Park (187.41 and 88.08 tons $ha^{-1}$), Kutai National Park (139.91 and 65.76 tons $ha^{-1}$) and Lore Lindu National Park (87.90 and 41.32 tons $ha^{-1}$). This study also found that large deadwood with diameters of >7.5 cm contributes to more than 80% of the total deadwood carbon stock. Understanding the carbon stock stored in deadwood within national park areas is crucial for refining estimates of potential avoided greenhouse gas emissions resulting from the conservation of national park forests.

**Keywords:** Carbon stock; deadwood; national parks

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## INTRODUCTION

Indonesia's national parks cover 16.24 Mha of the country's terrestrial areas, accounting for 60% of the total conservation areas. It consists of 54 management units, spreading across Sumatra to Papua (MoEF, 2022b). According to Indonesia's law No. 5 of 1990, a national park is defined as nature conservation areas with original ecosystems that are managed based on zonation systems. Not only protecting remaining forests and biodiversity, the functions of this area include education, research, science development, cultivation, and tourism. In terms of social and economic benefits, national parks can improve community livelihoods, such as through the involvement of the local community in tourism activities (Anggraini & Gunawan, 2021; P. Nugroho & Numata, 2020; Purnomo et al., 2020). This area also provides materials that can be used for traditional medicines from various plant species (Gailea et al., 2016; Susanti & Zuhud, 2019). In addition, ecosystem services produced by national parks also have significant economic values, which include supporting services from biodiversity and habitat provision, provisioning services from natural resources that can be utilized by humans, regulating services such as habitat protection, water regulation, and carbon sequestration, as well as cultural services. The valuation of environmental services encourages financial motivation to maintain natural resources and can promote the conservation of national park areas (Agustriani et al., 2023; Nugroho et al., 2022).

Despite their important values, national parks in Indonesia have been facing various threats that have led to a decrease in forest areas. A study by Dwiyahreni et al. (2021) reported that in the period from 2012 to 2017, there was a 1.62% reduction in forest cover within terrestrial national parks in Indonesia. The major pressures include road construction, human settlement, and the development of industrial plantations. In addition, forest conversion into agricultural lands also affects forest cover within national parks. Nevertheless, during the same timeframe, there was a modest increase of 0.07% in primary forest cover within national parks. Moreover, the connectivity of the landscape within and surrounding national parks is also expected to decrease substantially, as a consequence of the road development. As a result, the national parks' forests may experience significant fragmentation (Alamgir et al., 2019).

As a major source of greenhouse gas (GHG) emissions in Indonesia, the role of the forestry and land use sector is essential for achieving the climate mitigation target that has been set by the government (KLHK, 2022; Republik Indonesia, 2022). Avoiding deforestation and forest degradation is an important pathway for reducing GHG emissions from this sector, with a mitigation potential of 165.7 MtCO2e $yr^{-1}$ (Novita et al., 2022). This action was also included as a main strategy for achieving net sink status in forestry and land sectors by 2030 (MoEF, 2022a). This indicates that the protection of remaining forest cover that mainly occurs in conservation areas, including national parks, requires more attention from related stakeholders. Many studies have investigated the carbon stock in national park areas (Arifanti et al., 2014; Darmawan et al., 2022; Erly et al., 2019). Most of the studies only include above-ground carbon stocks in the estimation.

Carbon stock in forestry and land sectors can be stored in living biomass (including above-ground and below-ground biomass), deadwood, litter, and soil. However, little is known about the amount of carbon stock in dead wood in Indonesia's forests, particularly in conservation areas such as national parks, where the disturbance level is relatively low compared to other land areas. Deadwood encompasses part of wooden trees that have naturally died, as well as those that have perished due to pest infection, wind-related damage, or other anthropogenic activities. It is commonly found in natural forest ecosystems but rarely occurs in plantation forests, agricultural lands, grasslands, and savannahs (IPCC, 2006). Although the stock may not be as high as living biomass, accounting for the carbon stock of this pool remains important to estimate the total ecosystem carbon stock. This study aims to estimate the amount of carbon stored in fallen deadwoods within national park areas by conducting field measurements. This information can be used to refine the estimate of total carbon stock in forested areas while calculating the potential GHG emissions from deforestation and forest degradation in national parks.

## METHODS

### Data collection

The measurement of fallen deadwood was conducted in four national parks distributed across Sumatra, Kalimantan, and Sulawesi islands, consisting of Sebangau National Park (NP), Kutai NP, Lore Lindu NP, and Bukit Tigapuluh NP between May and July 2021. These national parks represent conservation areas from different regions of the Indonesian archipelago. Sebangau NP is one of Indonesia's largest peat swamp conservation areas and spans approximately 568,700 square kilometers in Central Kalimantan Province. The peat swamp forest ecosystem, accounting for 79.4% of the park's area, is in good condition and provides a habitat for the Kalimantan orangutan (*Pongo pygmaeus wrumbii*). This forest plays a vital role in carbon storage and water management regulation.

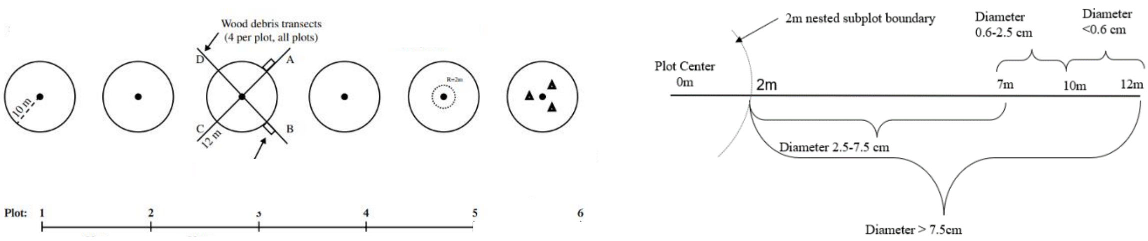
Kutai NP represents the lowland tropical rainforest ecosystem in Bontang Regency, East Kalimantan, spanning 192,709.55 hectares. It is mainly characterized by ironwood, meranti, lime, and mixed dipterocarp vegetation, with occasional but non-dominant mangrove and coastal forests, flooded forests during the wet season, heath forests, and freshwater swamp forests. Lore Lindu NP is situated southeast of Palu City, in Southeast Sulawesi, covering an area of 217,991.18 hectares. This national park primarily comprises mountain and sub-mountain forest ecosystems, accounting for approximately 90% of its area, while lowland forest makes up the remaining 10%. The park's elevation ranges from 200 meters to 2,610 above sea level. Meanwhile, Bukit Tigapuluh NP located across Riau and Jambi Provinces, serves as a representative of the lowland rainforest ecosystem on Sumatra Island. This conservation area covers 144,223 hectares and is a natural habitat for the Sumatran tiger.

Circular plots with a 10 m radius and a distance of 50 m between plots were established. The number of plots in each study area is presented in Table 1.

**Table 1.** Plot number in each study area

| Study area | Ecosystem type | Number of plots |
|---|---|---|
| Sebangau NP | Peat swamp forest | 18 |
| Kutai NP | Dry lowland forest | 18 |
| Lore Lindu NP | Lower montane forest | 18 |
| Bukit Tigapuluh NP | Dry lowland forest | 36 |

This study used planar intersect techniques to collect the data. Four transects with a length of 12 m from the plot center were set up in a direction of 45 degrees from the main transect line (Kauffman et al., 2016) (Figure 2). The measurements were categorized into several diameter classes at different transect lengths. The deadwood with fine size (d: <0.6 cm) was measured within 10 m to 12 m of the transects and small size (d: 0.6 – 2.5 cm) was measured within 7 m to 10 m transects. Meanwhile, medium size dead organic matter (d: > 2.5 – 7.5 cm) was measured in 2 m to 7 m transects and large size (d: >7.5 cm) was measured within 2 m to 10 m transects (Figure 2b). To include the wood piece in the count, it must intersect with the transects. The data collection to measure the carbon stock of fallen deadwood includes wood diameter and wood density.




Kauffman et al. 2016 (a) (b)

**Figure 1.** The layout of sample plots for dead organic matter data collection

### Data analysis

Deadwood biomass was calculated based on wood density and wood volume. Wood density necessitates the oven-dry mass and volume of sample items, which is acquired by assessing the mass of each sample when it is immersed in water. While wood volume was calculated using the following equation (Brown, 1971; Van Wagner, 1968):

$$Volume\ (m^3ha^{-1}) = \pi^2\ x\ (\frac{d_1^2 + d_2^2 + d_3^2 + \cdots d_n^2}{8\ x\ L})$$

Where d is the diameter of the deadwood and L is the transect length of each deadwood diameter class. Deadwood biomass was subsequently determined by multiplying the wood density by the volume. The conversion of deadwood biomass into deadwood carbon stock used a carbon fraction of 0.47 (IPCC, 2006).

## RESULTS AND DISCUSSION

### Deadwood density

This study found that the density of fallen deadwood varies across study sites and diameter classes. Among others, Sebangau NP has the highest deadwood density, ranging from 0.72 – 0.79 g $cm^{-3}$, followed by Bukit Tigapuluh NP with 0.68 – 0.72 g $cm^{-3}$ and Kutai NP with a range of 0.49 – 0.69 g $cm^{-3}$. Lore Lindu NP has the lowest deadwood density value, ranging from 0.26 – 0.35 g $cm^{-3}$. There was no specific trend observed in deadwood density based on diameter classes, even though larger diameter classes tend to have higher wood density in Sebangau NP, Kutai NP, and Lore Lindu NP. Dead fine deadwoods with a diameter of <0.6 cm have a density of 0.26 – 0.72 g $cm^{-3}$. Meanwhile, the wood density for small, medium, and large deadwoods ranges from 0.35 – 0.72 g $cm^{-3}$, 0.35 – 0.73 g $cm^{-3}$ and 0.35 – 0.79 g $cm^{-3}$, respectively (Table 2).

**Table 2.** The density of deadwood in the study area

| | Mean ± se (g cm$^{-3}$) | | | |
|---|---|---|---|---|
| Diameter class (cm) | Sebangau NP | Kutai NP | Lore Lindu NP | Bukit Tigapuluh NP |
| <0.6 | 0.72 ± 0.03 | 0.56 ± 0.03 | 0.26 | 0.72 ± 0.01 |
| 0.6 - 2.5 | 0.72 ± 0.06 | 0.49 ± 0.02 | 0.35 ± 0.04 | 0.71 ± 0.01 |
| >2.5 - 7.5 | 0.73 ± 0.03 | 0.55 ± 0.04 | 0.35 ± 0.02 | 0.68 ± 0.01 |
| >7.5 | 0.79 ± 0.03 | 0.69 ± 0.05 | 0.35 ± 0.02 | 0.70 ± 0.01 |

Deadwoods mainly consist of cellulose, lignin, and hemicelluloses which exhibit exceptional resistance to decomposition. As a result, it will also affect the longevity and turnover of deadwood (Bauhus et al., 2018). The density of deadwood often represents the decay status of the woods. Studies show that there was a decline in the average density of deadwood in various tree species as the state of decay increased. Furthermore, the decomposition of wood is primarily influenced by the quality and size of the substrate, as well as environmental conditions that include temperature, moisture levels, and soil aeration (Didion et al., 2014; Köster et al., 2015).

In addition, species composition differences also lead to substantial variation in deadwood density (Harmon et al., 2013). Other studies also have indicated that as wood decomposition increases, there is a notable reduction in wood density (Di Cosmo et al., 2013). This may explain why this study found that the density of deadwood varies among the study areas, considering the variability of ecosystem characteristics in national park areas. Variations in wood characteristics may be attributed to differences in wood density among species resulting from decomposition phases (Köster et al., 2015). In addition, the decomposition rate in tropical regions is more likely to vary due to the high diversity of decomposing agents and the complexity of environmental factors (Putra et al., 2023).

Top of Form

**Deadwood volume**

Based on our analysis, Bukit Tigapuluh NP has the highest fallen deadwood volume with 388.50 cm$^3$, followed by Lore Lindu NP with 250.95 cm$^3$, Sebangau NP with 248.92 cm$^3$ and Kutai NP with 247.37 cm$^3$ (Table 3). Large deadwood has the highest contribution to the total volume in all study sites. It accounts for 92% of the total deadwood volume in Sebangau NP, 84% in Kutai NP, and 93% in both Lore Lindu NP and Bukit Tigapuluh NP.

**Table 3.** The volume of deadwood in the study area

| | Mean + se (cm$^3$) | | | |
|---|---|---|---|---|
| Diameter class (cm) | Sebangau NP | Kutai NP | Lore Lindu NP | Bukit Tigapuluh NP |
| <0.6 | 1.32 ± 0.19 | 4.17 ± 0.58 | 0.15 | 2.56 ± 0.48 |
| 0.6 - 2.5 | 1.85 ± 0.44 | 15.05 ± 2.67 | 1.79 ± 0.37 | 7.31 ± 1.32 |
| >2.5 - 7.5 | 16.26 ± 3.04 | 20.83 ± 4.31 | 15.43 ± 3.47 | 16.24 ± 2.6 |
| >7.5 | 229.49 ± 50.06 | 207.32 ± 51.65 | 233.58 ± 58.88 | 362.39 ± 47.67 |
| Total | 248.92 | 247.37 | 250.95 | 388.50 |

Deadwood volume can be used as a proxy to estimate carbon stock by applying an appropriate conversion factor. Meanwhile, the quantity of deadwood volume can vary due to various factors, among others, the type of tree species, climatic conditions, and management practices. In cases where there are variations in the volume of deadwood among different species, relying solely upon a particular conversion factor provides only restricted estimates of deadwood carbon. Therefore, it is important to have data and information concerning conversion factors specific to each species as well as their corresponding volumes in order to accurately assess deadwood carbon stock and their associate changes in this carbon pool (Weggler et al., 2012).

There is a probability that the canopy gaps in tropical forests coincide with the variability of deadwood volume. Moreover, areas affected by tree-fall also exhibited an increase in deadwood volume compared to unaffected regions. It is also necessary to conduct further studies to investigate the impact of microclimate on deadwood volume and decay rates. Such examinations are important to find out the factors governing decomposition and carbon equilibrium within rainforest ecosystems (Griffiths et al., 2021).


**Figure 2.** Deadwood in sample plots (a), deadwood measurement (b,c), deadwood sample collection (d)

**Deadwood biomass and carbon stock**

Similar to deadwood volume, Bukit Tigapuluh NP has the highest fallen deadwood biomass with 261.35 ± 29.55 tons ha$^{-1}$. The second highest is Sebangau NP with 187.41 ± 35.02 tons ha$^{-1}$, followed by Kutai NP with 139.91± 22.24 tons ha$^{-1}$. While fallen deadwood volume in Lore Lindu NP is considered high, this national park has the lowest fallen deadwood biomass with 87.90 ± 20.72 tons ha$^{-1}$(Figure 2), which was caused by low wood density in this area.

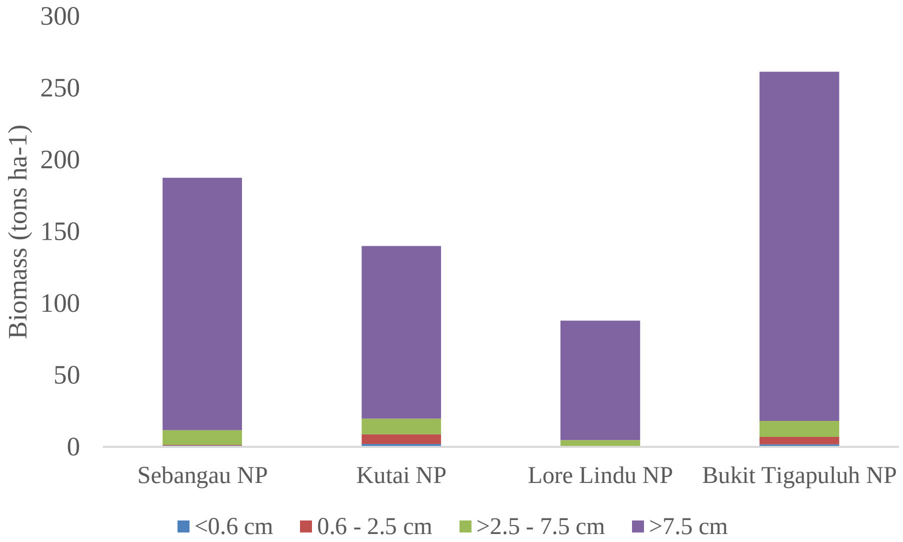



**Figure 3**. Deadwood biomass in Sebangau NP, Kutai NP, Lore Lindu NP, and Bukit Tigapuluh NP

The carbon stock of fallen deadwood in the study areas has a similar pattern to deadwood biomass. Our study found that the carbon stored in fallen deadwood within study areas ranges from 41.32 – 122.83 tons C ha$^{-1}$. Bukit Tigapuluh NP has the highest fallen deadwood carbon stock, accounting for 122.83 ± 13.89 tons C ha$^{-1}$. Meanwhile, fallen deadwood carbon stocks in Sebangau NP, Kutai NP, and Lore Lindu NP are 88.08 ± 6.45 tons C ha$^{-1}$, 65.76 ± 10.45 tons C ha$^{-1}$, and 41.32 ± 9.74 tons C ha$^{-1}$, respectively (Figure 3). Large deadwood contributes to 95% of the total deadwood carbon stock in Lore Lindu NP, 94% in Sebangau NP, 93% in Bukit Tigapuluh NP, and 86% in Kutai NP.

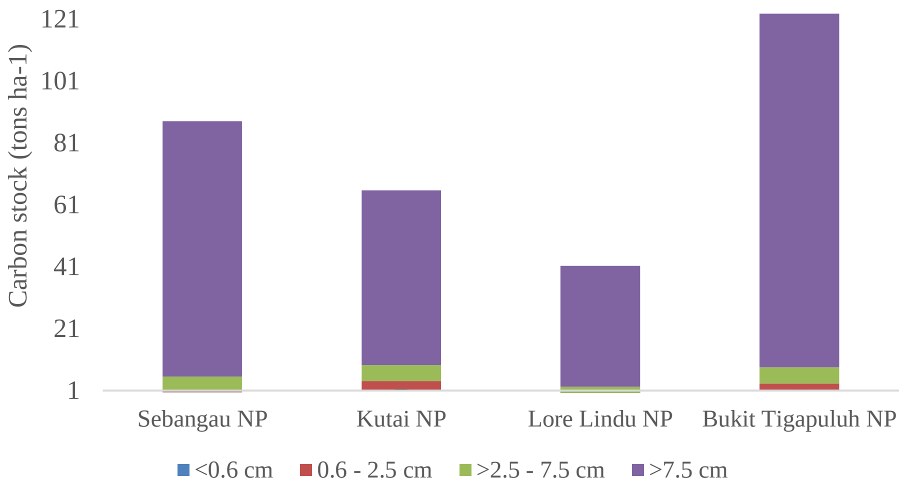



**Figure 4.** The carbon stock of deadwood in Sebangau NP, Kutai NP, Lore Lindu NP, and Bukit Tigapuluh NP

Several factors contribute to the magnitude of deadwood biomass and carbon stock, including ecosystem types, mortality events, chemical properties of woods that are influenced by the composition of tree species, and land management types. In addition, disturbance levels also have impacts on deadwood carbon stock, because of a substantial decrease in the above-ground biomass input from living trees (Holzwarth et al., 2013; Pfeifer et al., 2015). The findings of this study also reveal that national parks have a high potential for deadwood carbon storage. It was found that the change from natural forests to other land uses may result in a decrease in deadwood carbon stock. Natural forests can contain three times the amount of carbon in their deadwood stock when compared to other land uses. The carbon stock of fallen deadwood in this study surpasses that observed in a previous study conducted in secondary forests and shrubs, ranging from 0.1 - 13.3 C ton ha$^{-1}$ (Siahaan et al., 2020). Comparable results were also observed in the carbon stock of woody within peatlands where carbon stock in plantation areas is lower than those in secondary and primary forests (Novita et al., 2021). This variation could be linked to the productivity of living vegetation that contributes to the formation of deadwood (Meriem et al., 2016). National parks mainly consist of natural forests with large tree diameters, while the increased average diameter and height of living trees serve as proof of greater deadwood biomass and carbon (Kotowska et al., 2015).

Despite a substantial amount of carbon stored in protected areas including national parks, there is still a notable deficiency in studies concerning the carbon stored within deadwood throughout the varying states of forests. Numerous studies on carbon stock focused on the biomass of living trees. Whereas substantial amounts of carbon are stored within deadwood in various forest environments (Pfeifer et al., 2015). This carbon pool also has a significant contribution to the total carbon stock in the recovered degraded forests (Adinugroho et al., 2022). However, further studies are required to compare the carbon stock of deadwood in other ecosystems in national park areas, such as mangroves. In this ecosystem type, the carbon stock of deadwood accounts for 1% of the total ecosystem carbon stock, ranging from 1.82 – 27.3 tons C ha$^{-1}$ (Sasmito et al., 2020). Quantifying the carbon stock from deadwood is beneficial for GHG inventory in the forestry sector at the national and site levels, especially given the current scarcity of deadwood data. In addition, it is also important to develop the above-ground and deadwood carbon ratio in various land cover and ecosystem types to simplify the estimates of total carbon stock to support GHG inventory in the forestry and land sectors.

## CONCLUSION

This study provides valuable insights into the density, volume, biomass, and carbon stock of fallen deadwood in several national park areas. The results also highlight variations in deadwood characteristics among study sites and underscore the ecological importance of deadwood in forest ecosystems. The findings reveal that Bukit Tigapuluh National Park has the highest fallen deadwood biomass and carbon stock, accounting for 261.35 tons $ha^{-1}$ and 122.83 tons $ha^{-1}$, respectively. Meanwhile, Lore Lindu National Park exhibits the lowest density with biomass of 87.90 tons $ha^{-1}$ and carbon stock of 41.32 tons $ha^{-1}$. The large deadwood contributes significantly to the total volume and carbon stock in all study sites. Furthermore, this study highlights the potential of national parks as important reservoirs of deadwood carbon storage. Protecting natural forests within these areas is critical for maintaining high levels of deadwood carbon stock. Additionally, the study emphasizes the need for more comprehensive research on deadwood carbon stocks, as this component represents a substantial portion of forest carbon and has a direct impact on greenhouse gas inventories. Recognizing the potential contribution of deadwood is important for forest management and conservation efforts, particularly in the context of climate change mitigation and biodiversity preservation. Additional research on deadwood carbon stock accounting across various ecosystems and land cover types, along with assessing its ratio to other carbon pools, is essential for estimating climate mitigation potential in national park areas.

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