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Carbon stock estimation of Kelimutu National Park, East Nusa Tenggara, Indonesia

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[1]Department of Forestry, Faculty of Agriculture, Universitas Nusa Cendana. Jl. Adisucipto, Penfui, Kupang 85361, East Nusa Tenggara, Indonesia. Tel.: +62-380-881580, ♥email: lusiamarimpan@staf.undana.ac.id

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Abstract. *Marimpan LS, Khan K, Pramatana F, Purnama MME, Sinaga PS, Sipayung RH. 2026. Carbon stock estimation of Kelimutu National Park, East Nusa Tenggara, Indonesia. Asian J For 10 (1): r100116. https://doi.org/10.13057/asianjfor/r100116.* The increasing rate of global warming each year occurs alongside the decline in environmental quality, deforestation, and land desertification. Forests are major carbon reservoirs and play a critical role in the global carbon cycle, as well as being capable of reducing the impact of global warming. The Kelimutu National Park, East Nusa Tenggara, Indonesia, which contains the tri-colored lakes, must be preserved to maintain stability in CO_2 absorption. The aim of this study was to estimate biomass and carbon stock in forest area of the Kelimutu National Park Forest. This study used a non-destructive vegetation sampling method to estimate biomass including using employing allometric equation to calculate vegetation biomass, while necromass and litter used equations developed by the National Standardization Agency. Furthermore, to determine the potential for CO_2 absorption from the atmosphere, a conversion factor of 3.67 is applied. The study results show that carbon storage in vegetation is 104.33 Mg ha^{-1}, in litter is 7.32 Mg ha^{-1} and in necromass, which includes dead tree and deadwood, amounts to 20.49 and 46.49 Mg ha^{-1}, respectively, resulted total carbon stock of 178.63 Mg ha^{-1}. The CO_2 absorption potential is 601.97 Mg CO_2 ha^{-1}. This research underscores the importance of preserving Kelimutu National Park not only as a geological heritage but also as an asset in global carbon regulation.

Keywords: Carbon storage, CO_2 absorption, Kelimutu National Park, litter, necromass

INTRODUCTION

Forests are a key component of terrestrial ecosystems which deliver various ecosystem services and play a crucial role in human life on Earth (Chu et al. 2019). In the context of climate change, forests are important carbon sinks (Zhang et al. 2012; Indriyani et al. 2024) and have a strategic importance in addressing global warming issues (Nord-Larsen et al. 2019). As a renewable natural resource, forests need to be managed and preserved wisely (Rajashekar et al. 2018).

The degradation of forest ecosystems impacts the capacity of forests to absorb carbon (Chen et al. 2019; Setyasih et al. 2025). Additionally, the increase in carbon emissions caused by human activities has led to severe climate change, marked by global warming (Rawlins et al. 2011; Palacios-Peñaranda et al. 2019). Land cover plays a crucial role in controlling carbon dioxide (CO_2) emissions and its storage within forest stands (Olorunfemi et al. 2019). The rise in global CO_2 emissions is closely linked to anthropogenic activities resulting from fossil fuel combustion and land-use changes (Da Costa et al. 2025). Human involvement, particularly local forest-dependent communities, plays an importan role in carbon management and accounting (Ji et al. 2024).

The increase in atmospheric CO_2 contributes significantly to global environmental issues (Rajashekar et al. 2018). To minimize the impacts of global warming and climate change, efforts to stabilize CO_2 concentrations in the atmosphere are essential (Chen et al. 2019). One approach to stabilizing atmospheric CO_2 levels is through the United Nations Framework Convention on Climate Change (UNFCCC), established via the Kyoto Protocol. The Kyoto Protocol mandates industrialized countries to reduce their emissions by 5% from 1990 levels. Within this protocol, afforestation and reforestation activities are designated as carbon sinks under the Clean Development Mechanism (CDM) framework (Heriansyah 2005; Li et al. 2019). Forest biomass and carbon sinks represent forest services beyond other biophysical potentials, as the substantial biomass in forests helps absorb and store carbon to reduce atmospheric CO_2 (Fairman et al. 2022).

The implementation of forest carbon policies has driven forest management to improve continuously. This policy provides incentives for retaining tree cover and applying longer forest management rotations, including delaying harvesting and thinning (Ribbers et al. 2026). The largest carbon emission reduction comes from avoiding biomass loss from deforestation and forest degradation (REDD+) (Zhang et al. 2025). This policy has been implemented by the Indonesian government as part of climate change mitigation and adaptation efforts, both at the national level and regional level including in East Nusa Tenggara (NTT) Province. As an archipelagic province with a semi-arid climate, East Nusa Tenggara has unique forest biophysical conditions compared to other provinces in Indonesia. Forests in this province are pressured by agricultural expansion by local communities who cultivate coffee and other plantation crops within forest areas. There is also a high rate of illegal logging for traditional purposes, livestock grazing, and firewood collection.

Kelimutu National Park is a national park in East Nusa Tenggara Province covering an area of 5,356.5 hectares. Within the park, there are three crater lakes that have very steep walls with slopes of 70-80°. This park host a great number of biodiversity in which there are at least 140 species of woody plants, 36 species of herbaceous plants, 57 species of birds, 13 species of mammals, and 4 species of reptiles (Wawo et al. 2010). The national park offers a unique three-colored lake which always changes color. There are also diverse plants that occur around the lakes, some are endemic to Kelimutu. The ecosystem in Kelimutu National Park is highly complex and has a distinct composition compared to other forest ecosystems in East Nusa Tenggara.

A major challenge in the management of Kelimutu National Park is the lack of data on carbon storage capacity in the caldera ecosystems like the Kelimutu lakes. Therefore, the aim of this study was to quantify the carbon storage potential of standing trees, dead biomass, and litter around the Kelimutu tricolor lake area. The findings of this study are expected to enrich existing data on forest biomass in the context of Kelimutu National Park which also useful for carbon management and monitoring in the park.

MATERIALS AND METHODS

Study area

Geographically, Kelimutu National Park, East Nusa Tenggara Province, Indonesia, is located at coordinates of 08°43'21" - 08°48'24" S and 121°44'21" - 121°50'15" E (Figure 1). Administratively, Kelimutu National Park located in Ende District which is surrounded by five sub-districts, namely Detusoko, Wolowaru, East Ndona, Ndona, and Kelimutu. There are 24 villages that directly border Kelimutu National Park. The park is located at an altitude of approximately 1,384.5-1,639 meters above sea level (masl). Rainfall ranges from 1,615-3,363 mm per year, with temperatures between 25.5°C and 31.0°C. The soil consists of sand layers and volcanic deposits. Soil types include regosol, mediterranean, and lithosol. The soil around the lake is dominated by rocks, sand, and solidified volcanic lava. Due to the sulfuric vapor in this area, certain types of plants grow well, such as *Vaccinium varingiaefolia*, *Rhododendron renschianum*, *Cassuarina junghuniana*, and *Gleichenia linearis*.

Research procedure

Sampling design

Forest inventory was conducted in the canopy-covered areas of Kelimutu National Park, delineated from Landsat imagery verified through field observations. Based on the delineation results, measurements were carried out to inventory the carbon stock representing varying conditions of vegetation cover with different stand densities (Hoover 2008). The sampling used in this study was a hierarchical cluster method based on stand density levels. Stand density was clustered into three classes, namely sparse, medium and dense stand density based on the NDVI value. The higher the NDVI value (-1 to 1), the denser the vegetation stands in the forest ecosystem.

Once the density levels were identified, sampling plots were determined using stratified random sampling (Sugiyono 2020; Bentsi-enchill et al. 2022). This method was used because sample members from the population were selected randomly, with plot placement done proportionally based on vegetation density levels. It is stated that to meet the normal distribution in a population, a minimum of 30 samples is required (Nurgiyantoro et al. 2009). Within these 30 plots, the number of samples taken was further determined based vegetation density, which was classified into three, namely high, medium, and low-density levels, with the number of samples were determined based on the proportion of area of each density level (Sugiyono 2020). Based on the t-table, the value for 30 samples is relatively the same as for an infinite sample size. In the end, of the park extent of 5,390.37 ha, it was classified into: high-density forest (NDVI value of >0.6-1) covering an area of 3,933.72 ha with 21 sample plots, medium-density forest (NDVI value of 0.41-0.6) covering an area of 1,319.49 ha with 7 sample plots, and low-density forest (NDVI value of 0.2-0.4) covering an area of 137.16 ha with 2 sample plots.

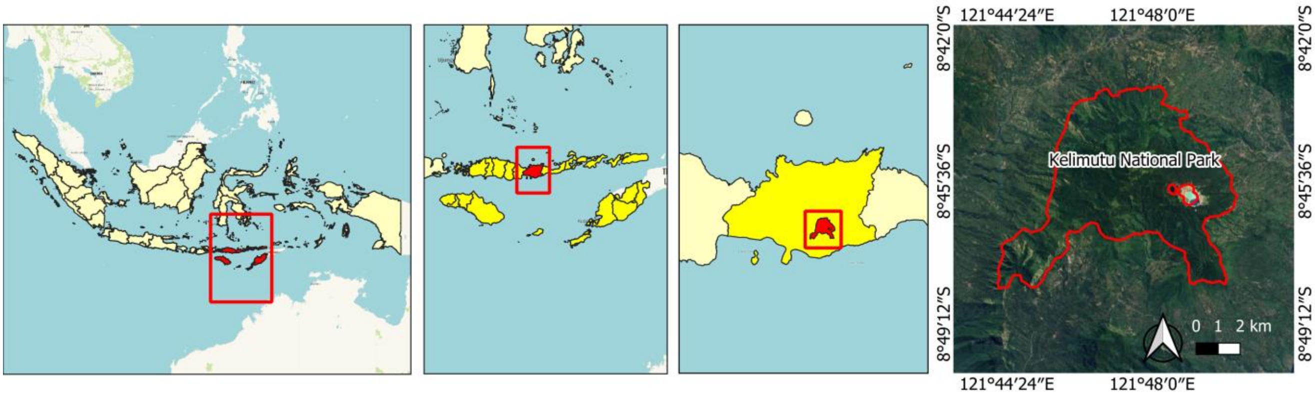

Figure 1. Location of research in the Kelimutu National Park, East Nusa Tenggara Province, Indonesia

Data collection

Data collection was conducted following the method outlined by Pham et al. (2019), with the sample plot size being 25×40 m (0.1 ha). Measurements were taken for vegetation within the 25×40 m plot for trees, 10×10 m plot for saplings, 5×5 m plot for poles, and 2×2 m plot for seedlings. Seedlings are classified as juvenile plants with a height of less than 1.5 meters. Poles are young trees with a height of ≥1.5 m and a diameter of <10 cm. Saplings are young trees with a diameter ranging from 10 to 19.9 cm. Trees are adult trees with a diameter of ≥20 cm (Dendang and Wuri 2015). Plot creation in the field was done by stretching a 25 m rope to the north and 40 m to the east. The plot was made in a rectangular shape, and each corner was tied to stakes (Hairiah et al. 2001). In this study, plot formation was based on the representation of the objects being studied (Makinano-Santillan et al. 2019). The determination and placement of plots in the study area are shown in Figure 2.

Estimation of aboveground biomass and carbon of vegetation

Aboveground biomass was estimated using allometric equation and diameter at breast height (dbh) of the stands (Table 1) and applied to saplings, poles, and trees (Hairiah et al. 2001; Marimpan and Purwanto 2010).

Calculation of necromass

Necromass refers to the biomass of dead trees and deadwood. The calculation of necromass of dead trees used the equation below (National Standardization Agency 2011):

$$Ni = Bi \times f$$

Where, Ni: Necromass (kg), Bi: Biomass (kg), f: Tree integrity level (correction factor)

The calculation of necromass in deadwood used the Brereton formula as prescribed by National Standardisation Agency (2011):

$$N_{km} = V_{km} \text{ x } \rho$$

Where, N_{km}: Dead wood necromass (kg), V_{km}: Dead wood volume (kg), p: Wood density (kg/m^3)

Table 1. Allometric equations used to estimate aboveground biomass

Species	Allometric equations	References
Eucalyptus urophylla	Bt = 0,126 D ^{2,558}	Marimpan and Purwanto (2010)
Other species	Bt = 0,11 ρ D ^{2,62}	Ketterings et al. (2001)

Note: Bt: Total biomass expressed in kilograms (kg), D: Diameter of the stand expressed in centimeters (cm), ρ: Wood density (0.8) expressed in g/cm^3

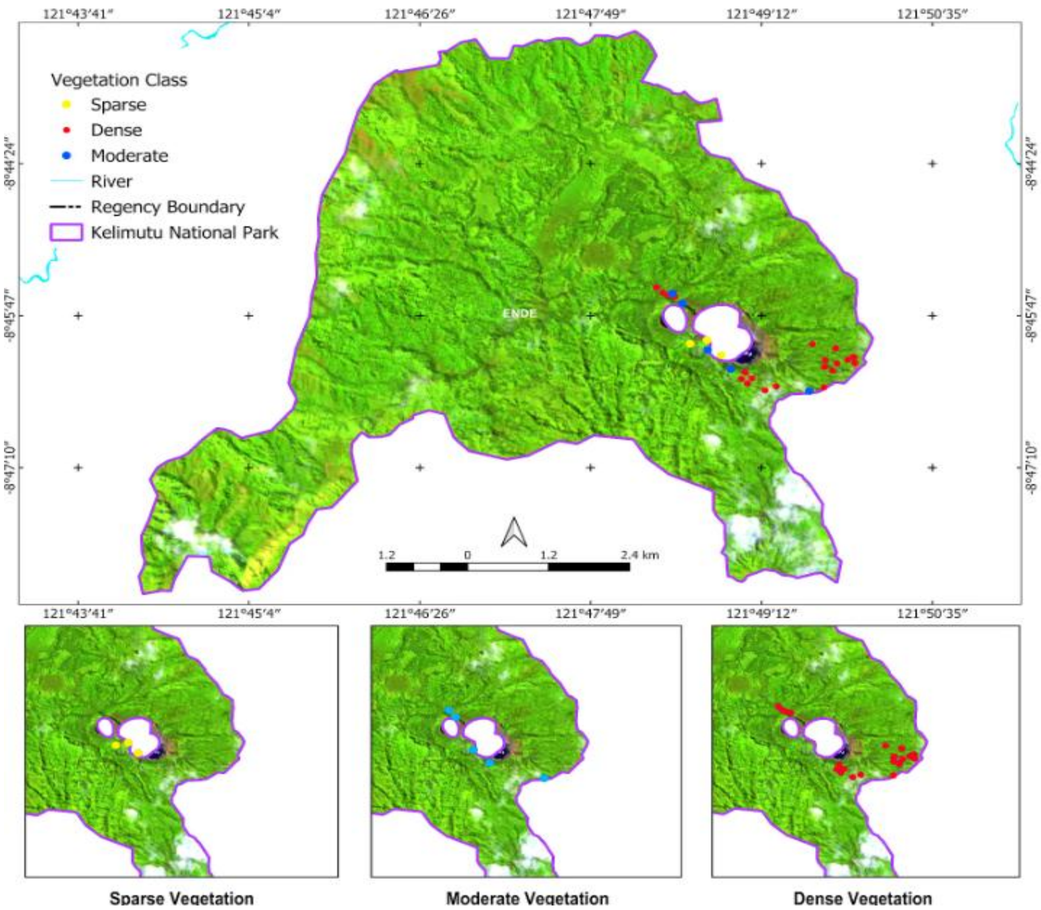

Figure 2. Sampling plot distribution at the research site in Kelimutu National Park, East Nusa Tenggara Province, Indonesia

The volume of deadwood was calculated as follow:

$$V_{km} = 0.25\pi \left(\frac{d_p + d_u}{2 \times 100}\right)^2 \times P$$

Where, Vkm: Dead wood volume expressed in cubic meters (m^3), dp: Diameter at the base of dead wood (cm), du: Diameter at the tip of dead wood (cm), P: Length of dead wood (m), π: 3.14

Calculation of litter biomass

Litter biomass was calculated using the following steps (National Standardization Agency 2011). First, total dry weight was calculated the using the following formula:

$$BKt = \frac{BKc}{BBc} \times BB$$

Where, BKt: Total dry weight expressed in grams (g), BKc: Dry weight of sample expressed in grams (g), BBc: Wet weight of sample expressed in grams (g), BB: Total wet weight expressed in grams (g)

Then, the calculation of the water content percentage was performed using the following equation:

% KA = (BBc -BKc)/BKc x 100% (5)

Where, % KA: Water content percentage, BBc: Wet weight of sample, BKc: Dry weight of sample.

Then, biomass calculation was performed using the following equation:

B = BBt/(1+(% KA)/100) (6)

Where B: Litter biomass, BBt: Total wet weight, % KA: Water content percentage.

Carbon estimation

Carbon calculation at the seedling, sapling, and tree levels was performed with reference to National Standardization Agency (2011):

C = Biomass × 0.47

Where C: Carbon content in biomass (kg), B: Biomass (kg), 0.47: Carbon percentage value

Carbon calculation in necromass, litter, and understory plants is based on the equation found by Chanan (2012):

C = Biomass × 0.46

Carbon storage in the three forest statuses is determined by converting the carbon storage in the sample plots to the forest area. The CO_2 absorption potential from the atmosphere is calculated by converting it to 3.67.

Data analysis

The data obtained were analyzed quantitatively. The calculation of the mean value and standard error was performed to assess the data characteristics and data distribution (Sadono et al. 2021). The results were presented in the form of a histogram to facilitate the visualization of carbon stock in each at each density level. One-way Analysis of Variance (ANOVA) was used to test the relationship between carbon content as the dependent variable and diameter as the independent variable (Zhang et al. 2012; Wirabuana 2021). Tukey's HSD post-hoc test was applied if the ANOVA was significant.

RESULTS AND DISCUSSION

Biomass and carbon measurements in Kelimutu National Park were conducted at 30 sample plots. The distribution of data in this study fell within a normal range, meaning that the selected sample trees represent the forest conditions observed. To determine biomass and carbon content, diameter at breast height (1.3 meters above ground level) was measured. The rationale for using diameter as a variable in this study is that diameter has a strong correlation with other variables such as tree height, crown density, ecosystem fertility, tree basal area, wood density, rainfall, and vegetation composition and structure (Bentsi-enchill et al. 2022). The biomass and carbon storage of vegetation in Kelimutu National Park are presented in Table 2. Based on Table 2, the average biomass in Kelimutu National Park is 221.98 Mg ha^{-1}. Using a 95% confidence level, the confidence interval for standing carbon was 104.33 Mg ha^{-1}. The results of the ANOVA test showed an insignificant value, namely 0.25 (<0.05). The variation in carbon storage within each group is substantial. As a result, even though the averages differ slightly between locations, these differences are "masked" by this large internal variation.

Biomass and carbon stock of vegetation

The average carbon content of vegetation is 104.33 Mg ha^{-1} with the lowest is 0.00 Mg ha^{-1} in the sparse/low density forest, and the highest is 237.17 Mg ha^{-1} in the high density forest (Figure 3). This result suggest that carbon stock of vegetation in Kelimutu National Park is high. This is because the park has high biodiversity, with 140 species of woody plants and 36 species of herbaceous plants (Wawo et al. 2010). In addition, the imagery results show that this forest area has a larger extent of high-density forest compared to areas with medium and low densities. Data obtained from the Landsat 8 OLI Surface Reflectance image (path/row: 110/65) dated January 25, 2024, revealed that the area with high density covers 3,933.72 ha or 72.98% of the total area of Kelimutu National Park, medium density covers 1,319.49 ha or 27.48% of the area, and low density covers 137.16 ha or 2.54% of the area. Furthermore, another factor contributing to the high carbon reserves in this area is its status as a national park, where the harvesting of timber and non-timber forest products is prohibited.

A national park is a conservation area comprised natural ecosystem, managed through a zoning system and utilized for research, science, education, supporting cultivation, tourism, and nature recreation (Republic of Indonesia Government 1999). The communities living in the buffer villages of Kelimutu National Park are strongly committed to maintaining harmony with nature. This is because the indigenous people or local communities who apply sustainability philosophies in their daily lives tend to have higher environmental awareness. The traditions and culture of the Kelimutu people, who always uphold the spirit of forest conservation, support the sustainability of this ecosystem. The ritual "*Pati Ka Du'a Bapu Ata Mata*," which is held every August 14th, aims to offer food to the spirits of the ancestors who have passed away at the summit of Lake Kelimutu as a form of respect to the deceased. This ceremony is also a local wisdom practice of the Lio people in supporting forest conservation in the Kelimutu National Park area.

Carbon content in forests varies greatly due to several factors, including climatic, edaphic, physiographic, and biotic factors. Rochmayanto et al. (2016) stated that the average carbon content for the Bali-Nusa Tenggara Bioregion with primary dryland forest type is 93.07 Mg ha^{-1}. A study conducted on community forests experiencing degradation and deforestation in Bhutan found that the carbon content in vegetation was 130.30 Mg ha^{-1}, and the organic carbon content in the soil was 52.80 Mg ha^{-1} (Delma et al. 2024). Meanwhile a study by Tiki et al. (2024) in Ethiopia found that the total carbon stock in vegetation in community-managed forests was 225.50±26.54 Mg ha^{-1}, which is higher than in state-managed forests, which had 156.24±15.72 Mg ha^{-1}. Research conducted in forests dominated by *Pinus roxburghii* in Uttarakhand, located in northern India, found that biomass and carbon content were 236.31 Mg ha^{-1} and 112.25 Mg ha^{-1}, respectively, while in a protected forest in the area, the biomass and carbon content were 224.85 Mg ha^{-1} and 106.80 Mg ha^{-1}, respectively. In contrast, in the community forest, the biomass and carbon content were 93.58 Mg ha^{-1} and 91.95 Mg ha^{-1}, respectively (Pimoli et al. 2024).

The biomass and carbon stocks in a forest area are strongly influenced by the condition of its ecosystem. Forests with well-maintained ecosystems will support the creation of ecosystem services in a sustainable manner. Proper forest management also contributes to the maximal carbon storage from the forest's net production process. The type and composition of the forest also affect the carbon storage (Chen et al. 2025).

Biomass and carbon stock of litter

The research results show that the biomass and carbon content of litter in Kelimutu National Park are 15.90 Mg ha^{-1} and 7.32 Mg ha^{-1}, respectively. The lowest carbon of litter is 1.38 Mg ha^{-1} in the sparse/low density forest, while the highest is 13.69 Mg ha^{-1} in the high density forest (Figure 4). This indicates that the density of the stand in a forest area significantly affects the biomass and carbon storage in litter. The high litter carbon found in Kelimutu National Park is due to the dense woody vegetation in the area, which significantly correlates positively with the nutrient cycle processes and energy transfer. The denser the vegetation, the more litter is produced, which consequently increases the carbon storage in the litter. The litter carbon stock shows a rising trend as the forest stand density increases.

Table 2. Biomass and carbon stock in Kelimutu National Park, East Nusa Tenggara Province, Indonesia

Components	Units	Content	
		Biomass	Carbon
Vegetation	N	30	30
	Mean	221.98	104.33
	SE	149.05	70.05
	Min	0.00	0.00
	Max	504.62	237.17
Litter	N	30	30
	Mean	15.90	7.32
	SE	6.40	2.95
	Min	3.01	1.38
	Max	29.77	13.69
Necromass			
Dead Trees	N	30	30
	Mean	44.54	20.49
	SE	68.39	31.46
	Min	0.00	0.00
	Max	284.01	130.64
Dead Wood	N	30	30
	Mean	101.07	46.49
	SE	71.04	32.68
	Min	0	0
	Max	293.83	135.16

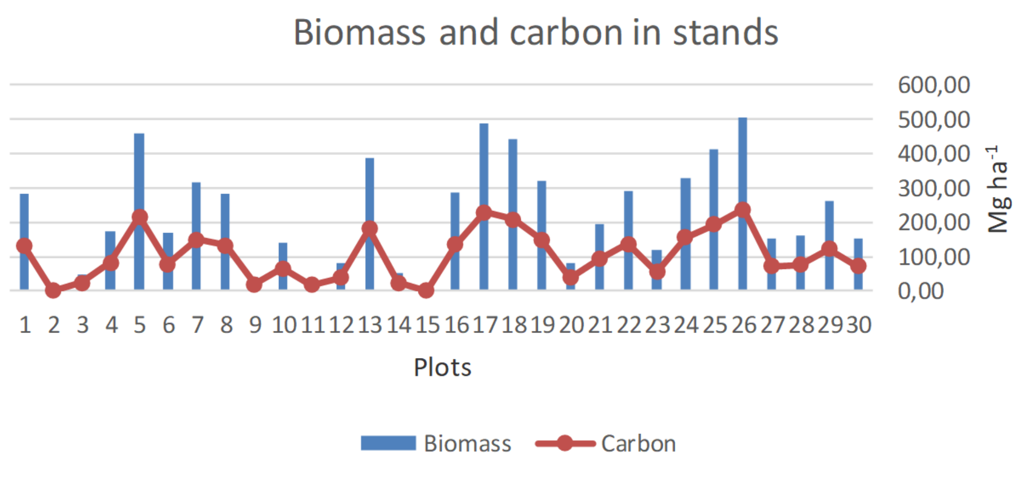

Figure 3. Biomass and carbon stock of vegetation in Kelimutu National Park, East Nusa Tenggara Province, Indonesia

The litter carbon value obtained in our study shows a high value compared to other studies conducted elsewhere. A study conducted in the Bolale Forest, Western Ethiopia found a litter carbon content of 4.91±0.41 Mg ha^{-1} (Chimdessa 2023). This study also found that the highest litter carbon content was in the lowland areas compared to the midland and highland areas. A study conducted in China on slopes of karst found that litter carbon storage amounted to 691.54±332.60 g m^{-2}. A study conducted in Indonesia, specifically in Kupang District and South Central Timor District in three forest statuses, namely production forest, protected forest, and conservation forest, found that the litter carbon content in production forests ranged from 6.10 Mg ha^{-1} to 0.40 Mg ha^{-1} in which in protected forests, the litter carbon content ranged from 5.16 to 0.57 Mg ha^{-1}, while in conservation forests, the litter carbon content ranged from 5.52 to 0.80 Mg ha^{-1} (Marimpan 2023).

Litter distribution significantly affects the nutrient cycle, energy transfer, and various ecosystem services (Hou et al. 2023). This is supported by Kartalaei et al. (2023), who found soil fertility and biological activity are higher in woody vegetation due to higher litter and nutrient input. Litter in the form of leaves, twigs, flowers, fruits, seeds, and even dried bark falls to the forest floor and becomes a source of nutrients for the existing vegetation. Other studies have mentioned that parent material and forest type have a significant effect on the concentration of litter carbon on the forest floor (Feudis et al. 2025).

Biomass and carbon stocks of necromass

The carbon storage potential in necromass in this study is divided into two components: carbon in standing dead trees and carbon in fallen/dead wood. A significant amount of necromass was found in the Kelimutu National Park, both in the form of standing dead trees and fallen dead wood. This is influenced by the forest status, which is categorized as a conservation forest, where activities such as the extraction of fallen or dead wood are prohibited. In this study, we found that the average biomass and carbon stocks in standing dead trees were 44.54 Mg ha^{-1} and 20.49 Mg ha^{-1}, respectively (Table 2). The highest carbon stock in dead trees was 130.64 Mg ha^{-1}, while several plots recorded a value of zero due to the absence of dead trees (Figure 5).

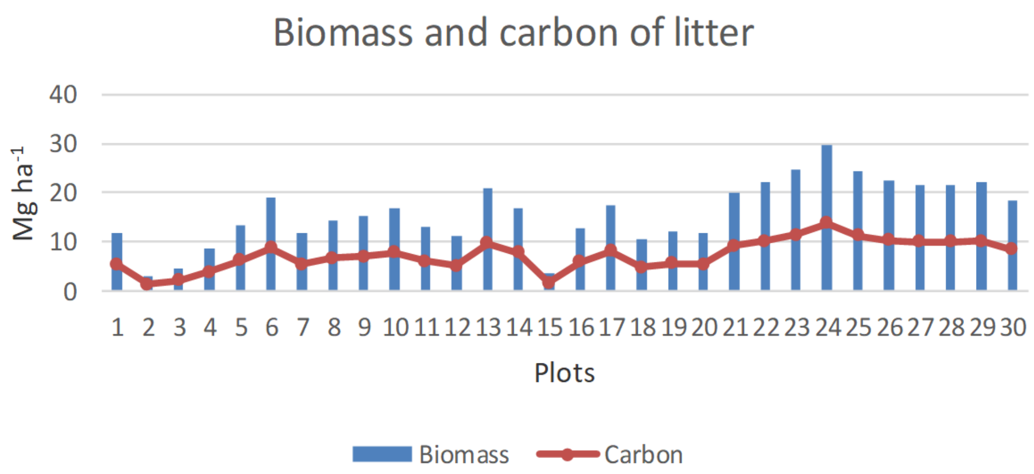

Figure 4. Biomass and carbon stock of litter in Kelimutu National Park, East Nusa Tenggara Province, Indonesia

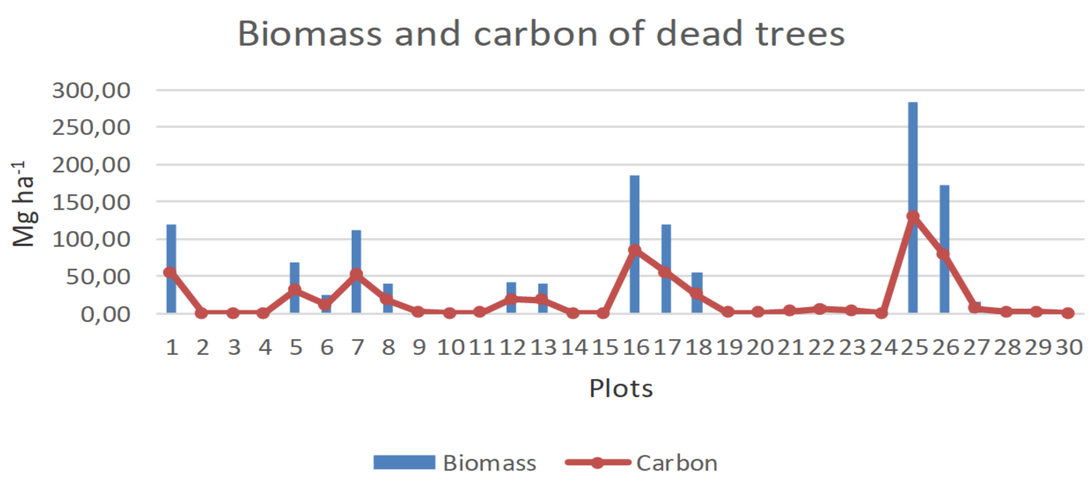

Figure 5. Biomass and carbon stock of dead trees in Kelimutu National Park, East Nusa Tenggara Province, Indonesia

The average biomass and carbon stock in dead wood was 101.07 Mg ha^{-1} and 46.49 Mg ha^{-1}, with the highest carbon stock reaching 135.16 Mg ha^{-1} (Table 2). However, there were several sample plots where no dead wood was found (Figure 6). The plots that lacked tree vegetation and necromass are located in the adjacent area of the lake where only understory plants were found, such as *V. varingiaefolia*, *R. renschianum*, *C. junghuniana*, and *G. linearis*. The carbon stock in dead wood in this study is relatively high compared to studies conducted elsewhere.

A study conducted in a semi-deciduous forest in Cameroon found that the carbon content in dead trees was 2.59 Mg ha^{-1}. This value is smaller compared to the necromass carbon stock found in this study. This is suspected to be due to the differences in the composition of tree species and the forest status, which may allow for the extraction of wood from within the forest. As a result, the necromass carbon stock found in the semi-deciduous forest is smaller.

The results of this study are supported by research conducted in China in the Yellow River Basin, which found that the carbon stock in wood is 33.12 Mg ha^{-1}. The necromass content on the forest floor is influenced by the condition of the forest, whether it is broadleaf, needleleaf, or mixed broadleaf and needleleaf forests (Wang et al. 2024). Meanwhile, research in a semi-deciduous forest in Cameroon found that the carbon stock in dead wood is 12.4 Mg ha^{-1} (Zekeng et al. 2020). It is clear that the overall carbon content in a forest ecosystem is also influenced by the composition of the forest.

In Kelimutu National Park, the contribution of necromass to the carbon stock is significant and highly correlated. This is because there is no practice of wood extraction from the forest area, either in the form of logs or firewood. The communities living in the surrounding villages maintain a strong harmony with the forest and are responsible for the preservation of the ecosystem.

Potential of CO_2 absorption of Kelimutu National Park

Tree vegetation has a significant potential for carbon absorption. Specifically, for forests, if their management is conducted sustainably, it can help reduce the accumulation of CO_2 in the atmosphere. The carbon absorption potential will remain stored in the stand for several decades, as long as the forest remains sustainable and there is no decrease in stand stock throughout the cycle. This means that the number of stands reduced each year is proportional to their growth. To determine how much carbon potential plants can store, measurements need to be taken. The CO_2 absorption potential from the atmosphere of the forest in Kelimutu National Park is presented in Table 3.

By knowing the atomic mass of Carbon (C)=12 and Oxygen (O)=16, the atomic mass of CO_2 is calculated as (1×12) + (2×16) = 44. The mass ratio of CO_2 to Carbon (C) is (44:12)= 3.67. This value is used to determine the potential CO_2 absorption from the atmosphere. The results of this study align with the findings of Brown et al. (1986), who stated that tropical rainforest ecosystems are estimated to store 176 Mg ha^{-1} or around 644.16 Mg CO_2e ha^{-1}. In a study by Iizuka and Tateishi (2015), in forests across eight districts in Japan, total CO_2 sequestration by forest subtypes was found to be 85.0 Mt CO_2e (needleleaf trees), 4.76 Mt CO_2e (evergreen broadleaf), and 21.61 Mt CO_2e (deciduous broadleaf). Adiriono (2009) in research on *Acacia crassicarpa* plantations aged 1 to 8 years showed that the average CO_2 sequestration was 167.49 Mg CO_2e ha^{-1}. A study in Ethiopia found that community-managed forests absorbed 827.6±97.4 Mg CO_2e ha^{-1}, while state-managed forests only absorbed 573.4±57.69 Mg CO_2e ha^{-1} (Tiki et al. 2024).

Table 3. CO_2 absorption potential of Kelimutu National Park, East Nusa Tenggara Province, Indonesia

Number	Component	Carbon stock (Mg ha^{-1})	CO_2 absorption potential (Mg CO_2 equivalent ha^{-1})
1	Vegetation	104.33	351.60
2	Litter	7.32	24.65
3	Necromass		
	Dead Trees	20.49	69.04
	Dead wood	46.49	156.68
Total		178.63	601.97

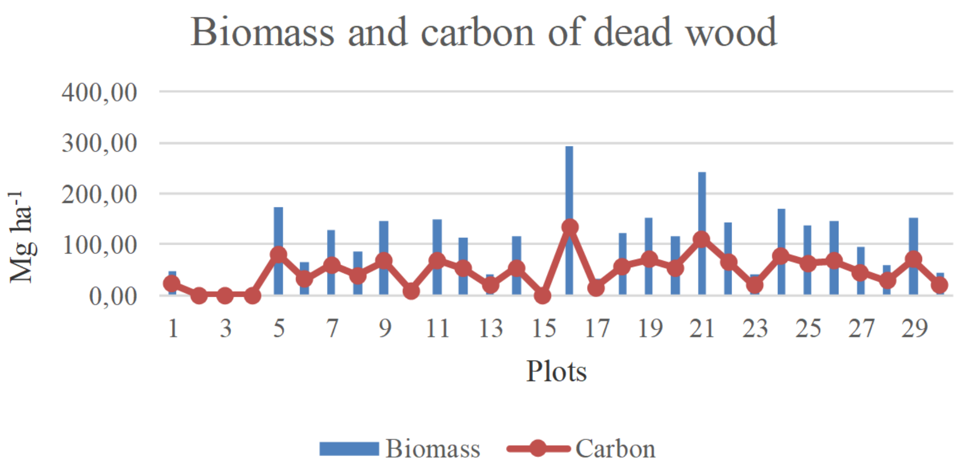

Figure 6. Biomass and carbon stock of dead wood at Kelimutu National Park, East Nusa Tenggara Province, Indonesia

The carbon storage in this forest area is considered comprehensive because it includes the carbon stored in vegetation, litter, and necromass. The ability of the forest ecosystem to absorb CO_2 from the atmosphere is positively correlated with carbon storage. The increase in CO_2 in the atmosphere is significantly influenced by global warming and the ongoing deforestation. However, carbon absorption through reforestation and forest growth is an effective way to mitigate global warming. This prediction allows us to explore forestry practices that maximize carbon absorption by forests, including timber production (Egusa et al. 2024). Young forests are more productive than old forests, making them more effective at absorbing carbon dioxide (Leng et al. 2024).

Forests made up of various tree species enhance CO_2 absorption during photosynthesis. Plants capture CO_2 from the atmosphere, convert it into organic carbon (carbohydrates), and store it in biomass within the plant's roots, stems, branches, leaves, tubers, fruits, and seeds. This entire process is often referred to as primary productivity. However, during respiration, some of the bound CO_2 is released back into the atmosphere. In addition to respiration, part of the primary productivity is lost through processes such as herbivory (consumption by plant-eating animals) and decomposition that occurs naturally in forest ecosystems. Some of the biomass may also leave the ecosystem through water flow or other dispersal agents. A healthy ecosystem optimally absorbs CO_2 from the atmosphere and stores it as forest carbon. Therefore, forest degradation must be addressed to prevent increasing carbon loss. Carbon sequestration in forests is a relevant approach for recovering resources from greenhouse gas emissions and transforming them into useful energy products while reducing the effects of climate change (Eloka-Eboka et al. 2020).

In conclusion, the carbon storage potential in vegetation, litter, and necromass in Kelimutu National Park is considered high for a dry secondary forest type. The CO_2 absorption potential in Kelimutu National Park is 601.97 Mg CO_2e ha^{-1}. Good conservation practices in national plant management significantly contribute to forest preservation, thus positively correlating with carbon storage and CO_2 absorption. This research illustrates that when the forest is well-maintained, it will provide optimal ecosystem services, particularly its contribution to climate change mitigation. It is recommended to conduct research on carbon calculations using direct measurement methods on each type or at least the dominant types in the Kelimutu National Park ecosystem to precisely measure carbon content.

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