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# Estimating carbon storage of *Eucalyptus urophylla* vegetation in Mutis Timau Nature Reserve, East Nusa Tenggara, Indonesia using remote sensing analysis

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**Abstract.** *Sadono R, Wardhana W, Wirabuana PYAP. 2023. Estimating carbon storage of* Eucalyptus urophylla *vegetation in Mutis Timau Nature Reserve, East Nusa Tenggara, Indonesia using remote sensing analysis. Biodiversitas 24: 1946-1952.* The presence of *Eucalyptus urophylla* S.T. Blake in Mutis Timau Nature Reserve (*Cagar Alam*) in Timor Island, East Nusa Tenggara Province, Indonesia plays an important role in long-term climate change mitigation. Therefore, this study aimed to investigate the carbon storage of *E. urophylla* in Mutis Timau Nature Reserve in varying tree densities using remote sensing analysis. Sentinel 2B satellite image acquired on 10 September 2022 was used to generate the Normalized Difference Vegetation Index (NDVI) using ArcGis 10.8. The NDVI values were then classified to generate the land cover type and density of *E. urophylla*. The NDVI values greater than 0.7 were assigned as the stands of *E. urophylla* and classified into low, moderate, and high density. The total carbon storage of each density area was calculated using the estimated area and secondary data of total carbon storage per ha for corresponding densities. The results of remote sensing analysis showed that *E. urophylla* vegetation was found to cover 73.82% or 9,084.56 ha of the total 12,306.43 ha estimated study area. The estimated area for moderate vegetation density of *E. urophylla* was 5,150.26 ha followed by low and high densities of 3,857.48 ha and 96.81 ha, respectively. The carbon storage of low, moderate, and high density was calculated to be 577,273.38, 996,655.61 and 27,467.90 tons C, respectively, totaling 1,601,396.89 tons C across the nature reserve. The findings of this study recommend that the coverage of *E. urophylla* vegetation needs to be expanded, specifically to become high-density to enhance carbon stock, for example through restoration.

**Keywords:** *Ampupu*, carbon enhancement, climate change, endemic species, Sentinel-2

## INTRODUCTION

The rehabilitation of degraded lands in conservation areas using endemic species plays a crucial role in conserving biodiversity and mitigating the effects of climate change by enhancing the extent and quality of land cover. The presence of trees, at a large extent, not only emits oxygen in the photosynthetic process but also absorbs carbon dioxide, which helps mitigate global warming. Photosynthesis is the process of absorbing carbon dioxide from the atmosphere, converting it into organic carbon, and storing it in the plant biomass such as stems, leaves and fruit (Dinilhuda et al. 2020), and also in root systems. Therefore, tree planting becomes one strategy of the government's strategic plans to reduce atmospheric carbon dioxide which is in accordance with international climate change agreements (Goldstein 2022). The long-term survival of trees in an area is critical for maintaining the carbon stored in their bodies. The two main goals that need to be achieved include maintaining carbon storage through the abundance of trees as well as preserving sustainability and invaluable endemic values for future generations.

*Eucalyptus urophylla* S.T. Blake is an endemic plant to Timor Island and is often called *ampupu* in the local Indonesian name. The conservation strategy to avoid its extinction is manifested by the establishment of a conservation area in the form of a natural reserve, including Mutis Timau Nature Reserve (*Cagar Alam* Mutis Timau). The Mutis Timau Nature Reserve is geologically composed of endemic rocks with marble elements; thus, it is often referred to as Marble Mountain (Kurniawan and Iswandono 2018). The higher elevation of the nature reserve is dominated by homogeneous eucalyptus trees. The existence of this plant represents a highland forest type and the vegetation condition is still natural with pure *E. urophilia* trees. Ecologically, *E. urophylla* is a nesting site for the small mammal *Phalanger orientalis* (Pallas 1766) because of the close proximity among the eucalyptus trees with the canopy covering each other, making it easier for this fauna to move from one tree to another (Nau et al. 2020). This eucalyptus is also a mother tree that produces apis honey, as well as young edible vegetables known as *ampupu* mushrooms (Anna 2015). In addition, Mutis Timau nature reserve plays an important role as a catchment and storage area of Mount Mutis water reserves.

Besides the important role of biodiversity conservation and hydrological regulation, Mutis Timau Nature Reserve also serves as a carbon sink due to the existence of forest cover. It is well known that forest stores a great amount of carbon. For example, aboveground carbon storage in mixed dryland with the open forest is estimated to be 30 tons C ha$^{-1}$, while in the secondary highly dense forest is estimated to be 98.84 tons C ha$^{-1}$ (Tosiani 2015). In the context of eucalyptus forests, forest functions and management types influence potential carbon storage which is typically greater in production forests than in protection and conservation forests. The highest estimate of total carbon storage in the production forest is around 331.15 MgC ha$^{-1}$ (Marimpan et al. 2022). In contrast to the natural forest, Sadono et al. (2020) discovered that the highest estimate of total carbon storage for eucalyptus plantations was 152.28 Mg ha$^{-1}$. It is understandable that the existing stand density and tree dimensions have a strong influence on the plantation. This figure implies that eucalyptus, regardless of forest function or management type, nature forest or plantation plays an important role as a carbon sink.

Despite the lower potential carbon storage per area compared to production forest, the carbon stock in conservation forest is comparable to that in protection forest (Marimpan et al. 2022). Nonetheless, the conservation forest is more protected, timber exploitation is prohibited, and the ecosystem's originality must be preserved to ensure the long-term preservation of *E. urophylla*. The density level of *E. urophylla* trees in conservation forests also varies significantly, from high to moderate and low density, which might affect the variability of carbon storage.

There are several methodologies to estimate carbon stock at a landscape scale as in the case of nature reserves, including fieldwork study, desktop study and a combination of both methods. Field work to obtain carbon storage in large areas is time-consuming and expensive, and sampling inaccessible areas is impossible and dangerous. Therefore, using a combination of readily available secondary and remote sensing data is a viable option for estimating carbon storage over a large area. Remote sensing data can be processed using computer software to generate land cover maps (Nasiri et al. 2022; Kapiri et al. 2023) and carbon storage estimates for each land cover class at different densities (Kusuma et al. 2022).

Based on such rationales, this study aims to investigate the carbon storage of *E. urophylla* vegetation in Mutis Timau Nature Reserve in varying tree densities. In doing so, we employed remote sensing technology in conjunction with computer software to process satellite imagery and provide a land cover base map. We expected the result of this study might be useful in identifying essential required measures to maintain and increase carbon storage in the next future.

## MATERIALS AND METHODS

### Study area description

This study was carried out in the area of Mutis Timau Nature Reserve, East Nusa Tenggara Province, located at 124°10 - 124°20 E and 9°30' - 9°40' S. The nature reserve has an extent of 12,315 ha. The topography is characterized by hilly to mountainous relief, while the slope conditions range from sloping to steep, wavy to mountainous and most of the area has a slope of more than 60%. The highest peak in the nature reserve is Mount Mutis with an altitude of 2,427 m asl, located slightly north of the center of Mutis Timau Nature Reserve (Figure 1). The general geological formations are made up partly of the Sonebait series and a small portion of the Kekneno series, followed by crystal schist, intermediate wet rock, wet rock, Neogene, and Paleogene sedimentary rock, while the soil types include complex and folded mountain shapes, as well as Mediterranean soil.

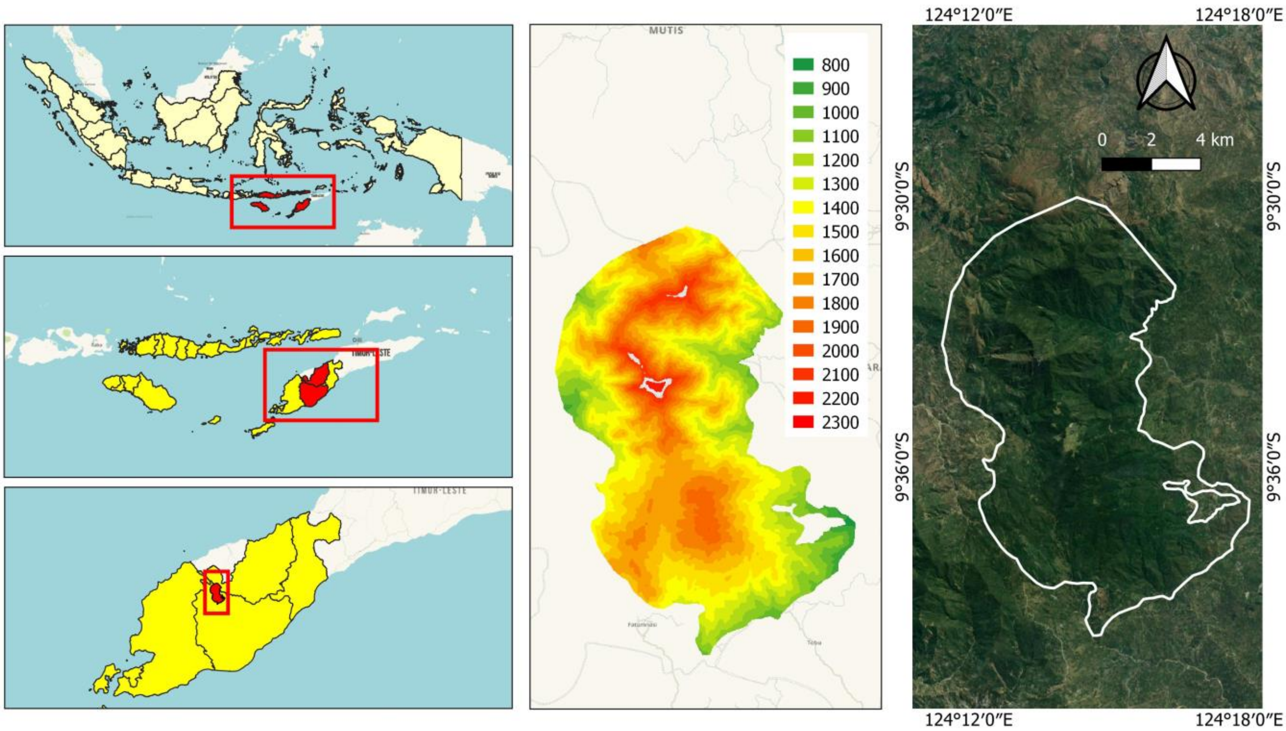


**Figure 1.** Map of study location in Mutis Timau Nature Reserve, East Nusa Tenggara Province, Indonesia

Mount Mutis and its surroundings are the wettest areas in Timor Island with an average annual rainfall of 2000 - 3000 mm, compared to other areas, which only receive 800 - 1000 mm/year. The wet season lasts for seven months, with rain falling on average every month from November to July and temperatures ranging from 14°C to 29°C, and extreme temperatures dropping to 9°C. From November to March, high-speed, strong winds are common in the area. Mutis Timau Nature Reserve has become the primary source of water for three large watersheds on Timor Island, namely Noel Mina and Noel Benain, due to the nearly constant rainfall. The river drainage has a dendritic (Noel Mina and Noel Benain) and a parallel pattern (Noel Fail) due to the relatively uniform slope in the north and surface complexity in the south (BKSDA 2018).

### Research materials

We used remote sensing data to analyze carbon stock in the studied area. Sentinel 2B satellite imagery with a high spatial resolution was used in the study. The image was acquired on 10 September 2022 and obtained from https://scihub.copernicus.eu/dhus/#/home. According to Wang et al. (2022), Sentinel-2 imagery has 13 bands in each imaging region and a maximum resolution of 10 m, as well as red edge bands with different central wavelengths that are sensitive to vegetation (Table 1). The selection of the image was carried out based on the overcast base cover, scene deception, highest satellite picture quality, and accessibility (Emran et al. 2016). The image was pre-processed in advance, geometrically corrected to the World Geodetic System (WGS84) datum (Storey 2014), and projected in GeoTiff format using the Universal Transverse Mercator framework (zone UTM 51S). In addition, geometric and radiometric corrections in a semi-automatic classification algorithm were applied to minimize atmospheric effects that interfere with data processing (Young et al. 2017). After completing this pre-processing step, the image was ready for analysis, as shown in Figure 2.

### Image processing procedure

The image was processed using the Normalized Difference Vegetation Index (NDVI) algorithm in ArcGIS 10.8, a pixel-based analysis that can be used to calculate the greenness index of vegetation with (Band 8 - Band 4)/(Band 8 + Band 4) (Akbar et al. 2020) or (Near Infrared - Red)/(Near Infrared + Red). The underlying theoretical NDVI concept is relatively simple, consisting of observing the best near-infrared light reflected by chlorophyll and red-light radiation absorbed by green leaves (Evangelides et al. 2020). The algorithm produced index values ranging from -1 (minimum) to 1 (maximum), representing non-vegetated and densely vegetated pixels, respectively.

### Data analysis

The obtained NDVI value was used to identify and classify land cover (Abdullah et al. 2019; Arini et al. 2020) using Sentinel 2B satellite imagery into three ascending levels of *E. urophylla* stand density. This includes low, moderate, and high with NDVI range values of >0.7-8.0, >0.8-0.9, and >0.9-1.0, respectively. Land cover of shrubs, grassland, and barren land (Kusuma et al. 2022) was found to have NDVI values ranging in descending levels from 0.7 to 0, while the existing marble stone at the study site was represented by values less than 0. Furthermore, pixel calculation was used to determine the area of each *E. urophylla* stands density level (Karlsen et al. 2021). The estimated area was calculated by multiplying the number of pixels by the size. Sentinel-2 satellite imagery has a spatial resolution of 10 m, meaning that each pixel represents 100 $m^2$ or 0.01 ha of area (Karlsen et al. 2021). Based on a previous study in CA Mutis Timau by Marimpan et al. (2022), this land cover class has potential carbon storage values of 149.65 MgC $ha^{-1}$, 194.27 MgC $ha^{-1}$, and 283.73 MgC $ha^{-1}$ at low, moderate, and high stand density levels, respectively (Table 2).

Finally, the total potential carbon storage of *E. urophylla* was calculated by multiplying the carbon storage of each density level by the calculated area and summing the results.

**Table 1.** Sentinel-2 data band names, central wavelengths, and spatial resolution (Aryal et al. 2022; Wang et al. 2022)

| Name of the Sentinel-2 band | Central wavelength (µm) | Spatial resolution (m) |
|---|---|---|
| B1: Coastal aerosol | 0.443 | 60 |
| B2: Blue | 0.490 | 10 |
| B3: Green | 0.560 | 10 |
| B4: Red | 0.665 | 10 |
| B5: Vegetation red edge | 0.705 | 20 |
| B6: Vegetation red edge | 0.740 | 20 |
| B7: Vegetation red edge | 0.783 | 20 |
| B8: Near infrared (NIR) | 0.742 | 10 |
| B8A: Narrow near infrared (NIR) | 0.865 | 20 |
| B9: Water vapor | 0.945 | 60 |
| B10: Shortwave infrared (SWIR)-Cirrus | 1.375 | 60 |
| B11: Shortwave infrared (SWIR) | 1.610 | 20 |
| B12: Shortwave infrared (SWIR) | 2.190 | 20 |

**Table 2.** Land cover classification of *Eucalyptus urophylla* density based on normalized difference vegetation index with total potential carbon storage in each density class

| Normalized Difference Vegetation Index | *E. urophylla* tree density class | Total carbon storage (MgC $ha^{-1}$) |
|---|---|---|
| $0.7 < NDVI \leq 0.8$ | Low density | 149.65 |
| $0.8 < NDVI \leq 0.9$ | Moderate density | 194.27 |
| $0.9 < NDVI \leq 1.0$ | High density | 283.73 |

Note: the total carbon storage for each land cover class referred to Marimpan et al. (2022)

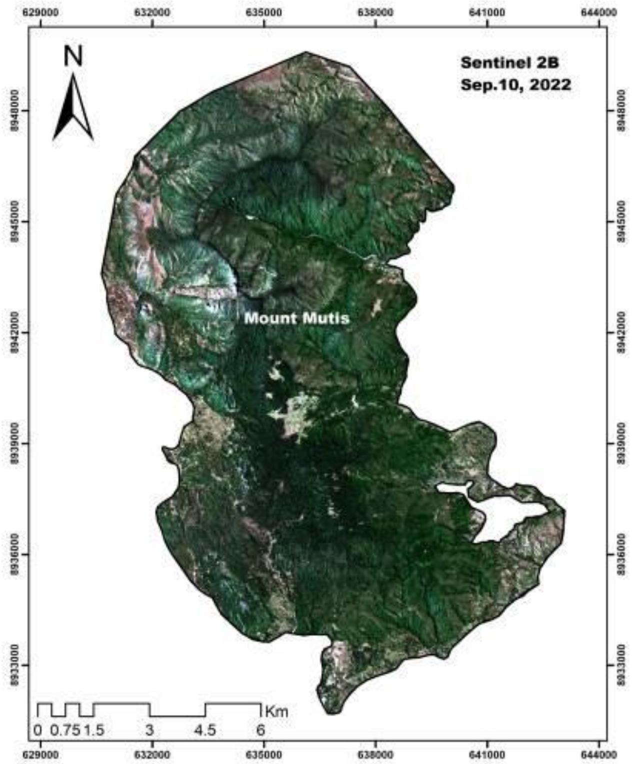


**Figure 2.** True composite image of Mutis Timau nature reserves after pre-processing Sentinel 2B acquired on 10 September 2022

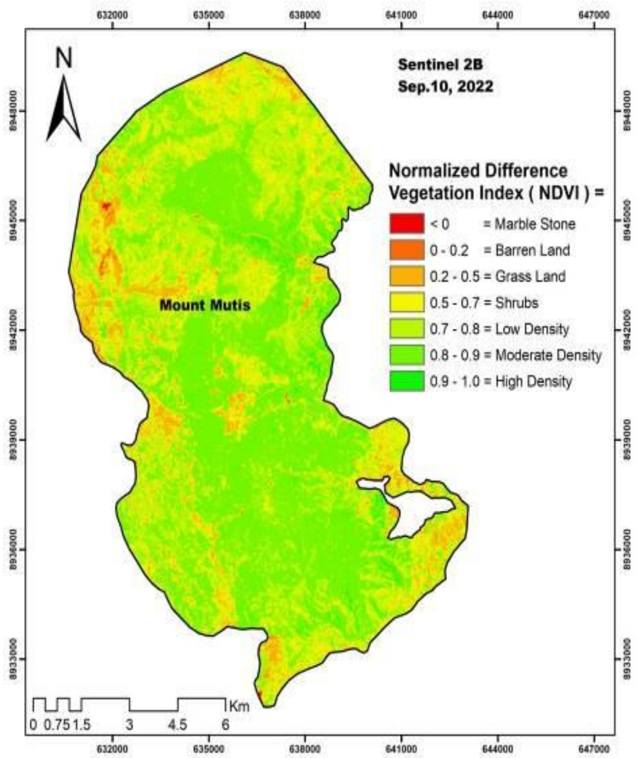


**Figure 3.** Spatial distribution of NDVI within the study area for each land cover class, namely: marble stone, barren land, grassland, shrubs, and low, moderate, and high density of *E. urophylla* trees

## RESULTS AND DISCUSSION

### NDVI threshold and land cover class

NDVI values obtained in Mutis Timau Nature Reserve ranged from -1 to + 1 with values greater than 0.7 being found predominantly in hilly, high-elevation areas. The red color representing marble stone was found specifically in the northwestern corner of the study area, while grasslands and shrublands were found to the north of Mount Mutis. These two land types are also predominant in the study area's heart as demonstrated in Figure 3. The distribution of pixels over NDVI showed that there was an accumulation of values greater than 0.7, with a peak at around 0.83. After the peak, the distribution dropped sharply at NDVI values greater than 0.9 as presented in Figure 4.

NDVI values less than 0 are typically assigned to non-vegetation areas (Zaitunah et al. 2018; Wang et al. 2022) such as rock, sand (Victor 2019), and glaciers (Karlsen et al. 2021). Marble stone, which is easily found in the area (Kurniawan and Iswandono 2018), is represented by values less than 0 in this study. Furthermore, open lands, such as built-up areas and road networks, typically have an NDVI value between 0 and 0.2, while grassland has values ranging from 0.2 and 0.5 (Hashim et al. 2019). Moderate values, such as 0.5 to 0.7, represents shrubs (Victor 2019), while a higher index value, for example, more than 0.7 indicates a higher concentration of woody vegetation on the ground (Aryal et al. 2022), in this case, *E. urophylla*. The higher the NDVI value, the denser the vegetation on the ground, which can be classified from low dense to high dense (Zaitunah et al. 2018).

### Area calculation based on the number of pixels

The estimated area based on remote sensing analysis (i.e. 12,306.43) was slightly lower than the official site's area of 12,315.61 ha (BKSDA 2018). Due to the minimal difference which is less than 0.1%, the area estimation is considered to be within the acceptable range.

The area with the occurrence of *E. urophylla* was estimated to occupy 908,456 pixels out of the total 1,230,643 pixels, accounting for 9,084.56 ha or 73.82% of the study area. Based on the results, the moderate density of *E. urophylla* trees dominated this area with 5,130.25 ha, followed by low density and a small portion of high density with values of 3,857.49 ha and 96.81 ha, respectively. Meanwhile, the number of pixels in the non-*E. urophylla* area was 322,187, which accounted for 3,221.87 ha or 26.18% of the study area. Shrubs were found to dominate this area with 2,414.71 ha, followed by grassland, barren land, and marble stone with values of 770.53 ha, 32.61 ha, and 4.02 ha, respectively, as shown in Table 3.

### Total carbon storage estimation

Based on the analysis, the total estimated carbon for *E. urophylla* covering the area of 9,084.56 ha was 1,601,396.89 tons C with 577,273.38 tons C, 966,655.61 tons C, and 27,467.90 tons C for low, moderate, and high-density classes, respectively. Moderate density contributed to nearly two-thirds (62.24%) while low and high densities contributed 36.05% and 1.72%, respectively, as shown in Table 4.

**Table 3.** Area estimation and proportion of land cover based on the value of NDVI threshold and the number of pixels

| NDVI range | Density level/Land cover | Number of pixels (10 m x 10 m) | Estimated area (ha) | Proportion (%) |
|---|---|---|---|---|
| *E. urophylla* area | | | | |
| 0.7 - 0.8 | Low density | 385,749 | 3,857.49 | 31.35 |
| >0.8 - 0.9 | Moderate density | 513,026 | 5,130.25 | 41.69 |
| >0.9 - 1 | High density | 9,681 | 96.81 | 0.79 |
| | Area for *E. urophylla* | 908,456 | 9,084.56 | 73.82 |
| Non *E. urophylla* area | | | | |
| | Shrubland | 241,471 | 2,414.71 | 19.62 |
| | Grassland | 77,053 | 770.53 | 6.26 |
| | Barren land | 3,261 | 32.61 | 0.23 |
| | Marble stone | 402 | 4.02 | 0.03 |
| | Area for non *E. urophylla* | 322,187 | 3,221.87 | 26.18 |
| Grand total for the study area | | 1,230,643 | 12,306.43 | 100.00 |

**Table 4.** Total carbon storage of *E. urophylla* area classified by density class

| Density class | Estimated area (ha) | Total carbon storage (ton ha$^{-1}$)* | Total carbon storage (ton C) | Proportion (%) |
|---|---|---|---|---|
| Low density | 3,857.49 | 149.65 | 577,273.38 | 36.048 |
| Moderate density | 5,130.25 | 194.27 | 966,655.61 | 62.237 |
| High density | 96.81 | 283.73 | 27,467.90 | 1.715 |
| | 12,306.43 | | 1,601,396.89 | |

Note: *Marimpan et al. (2022)

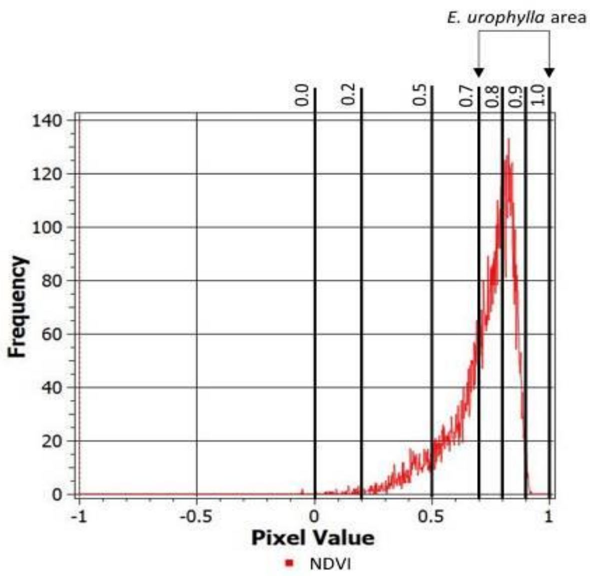


**Figure 4.** NDVI distribution over pixel values demonstrating the accumulation of NDVI in values greater than 0.7

The density of *E. urophylla* and the area of each density class have a significant impact on total carbon storage. According to Bentsi-Enchill et al. (2022), the density is positively correlated with the amount of carbon content, hence, the higher the density of *E. urophylla* canopy cover, the greater the carbon storage, culminating in an equal area (Zhao et al. 2019). This land cover and canopy improvement are consistent with the findings of Zhang et al. (2020) and Sadono et al. (2020) which reported that the larger the area for a higher density, the greater the potential for aboveground carbon storage. Additionally, Kusuma et al. (2022) found that higher density contributes to aboveground carbon storage per ha. The density of trees has also been shown to contribute significantly to increasing carbon storage (Dangwal et al. 2022) (Table 2).

**Management implication for *E. urophylla* in Mutis Timau Nature Reserve**

This study estimated the potential carbon storage in Mutis Timau Nature Reserve in 2022 which plays an important role in the monitoring and evaluation of future changes and spatial distribution. This information serves as the baseline or reference level for detecting changes in carbon storage. The high potential carbon storage in Mutis Timau Nature Reserve was addressed in this study to anticipate the high concentration of atmospheric carbon dioxide, which has attracted significant global attention in the last decades to reduce greenhouse gas emissions through a carbon sink program. Simultaneously, the high potential for total carbon storage in the Mutis Timau Nature Reserve area must be maintained at all times.

This evaluation is necessary to ensure carbon enhancement by expanding the area of *E. urophylla* and increasing its density. Given that the high-density area is imbalanced compared to the low and moderate-density areas, expanding the high-density area should be prioritized to improve carbon storage by for example, enrichment planting in the appropriate areas to fill the gaps among existing *E. urophylla* trees. Besides that, enrichment planting can also be addressed to regenerate the dying *E. urophylla* trees. The expansion of higher-density area will significantly increase carbon storage because total carbon storage per ha differs significantly between low, moderate, and high densities (Marimpan et al. 2022). Furthermore, increasing density from low to moderate and moderate to high density will result in carbon enhancement gains of 44.62 and 89.46 tons C per ha, respectively. Therefore, it is important to note that the carbon gain from moderate to high density is more than twice as higher as the carbon gain from low to moderate density.

Areas of barren land should be given high priority for rehabilitation into vegetated land. The estimated area of barren lands of 32.61 ha poses a great challenge for possible rehabilitation, especially in formerly vegetated lands (Pujiono et al. 2019). If this barren land with a capacity to store very low above ground carbon only 2.5 tons C per ha (Tosiani 2015) is successfully reforested into a low-density *E. urophylla* area with a total carbon storage of 149.65 tons C per ha (Marimpan et al. 2022), it could potentially gain a total carbon enhancement of 147.15 tons C per ha.

The following priority should be to improve the grassland area. The 770.53 ha estimated area, represents a significant challenge for reforestation, particularly from degraded shrublands or even degraded *E. urophylla* vegetation (Pujiono et al. 2019). Improving land cover of these grasslands with a low above ground carbon storage capacity of 4.0 tons C per ha (Tosiani 2015) into a low density of *E. urophylla* area with a total carbon storage capacity of 149.65 tons C per ha (Marimpan et al. 2022) will potentially gain a total carbon enhancement of 145.65 tons C per ha. The carbon enhancement from the revegetation of barren land and the reforestation of grasslands is a significant number, even though it takes a long time and challenging effort to make it a reality.

Carbon enhancement through improved land cover contributes a significant amount of total carbon and eventually contributes to climate change mitigation, depending on the magnitude of the successful area of rehabilitation or reforestation. It should be emphasized, however, that not all of the grassland area must be converted into forested land because grasslands are an important part of the ecosystem in Mutis Timau Nature Reserve (Kurniawan and Iswandono 2018).

In conclusion, *E. urophylla* covers 73.82% or 9,084.56 ha of the total 12,306.43 ha in Mutis Timau Nature Reserve. The vegetation cover of *E. urophylla* in the studied area can be classified into low, moderate, and high densities with NDVI values ranging from 0.7 to 0.8, 0.8 to 0.9, and 0.9 to 1, respectively. The estimated area for moderate density was 5,150.26 ha followed by low and high densities of 3,857.48 ha and 96.81 ha. Furthermore, the potential carbon storage of low, moderate, and high density was 577,273.38 tons C, 996,655.61 tons C, and 27,467.90 tons C, respectively, with a total of 1,601,396.89 tons C. This estimated potential carbon storage indicates that the *E. urophylla* area in Mutis Timau Nature Reserve makes a significant contribution to climate change mitigation. Therefore, to improve carbon enhancement in the study area, *E. urophylla* coverage and density must be expanded.

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