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## Estimation of biomass and carbon in several stand types in Nosar Protected Forest, Central Aceh District

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**Abstract.** Forests play a crucial role as one of the main ecosystem components in the global carbon cycle through their functions of carbon absorption and storage. However, this role has been increasingly degraded due to deforestation and land conversion. Forests consist of various vegetation species, each stand type having different capacities to absorb and store carbon. This study aims to estimate the biomass content and carbon stock across several stand types in the Nosar Protected Forest, Central Aceh Regency. Data collection was carried out through direct field surveys using a systematic sampling method with 13 plots consisting of trees, poles, and saplings. Aboveground biomass (AGB) was calculated using the allometric model of Ketterings, which incorporates wood density and diameter at breast height (DBH). The results showed that total AGB reached 1,874.62 ton ha<sup>-1</sup>, with an estimated carbon stock of 881.07 tC ha<sup>-1</sup>. Among all species, *Pinus merkusii* contributed the highest carbon stock (226.04 tC ha<sup>-1</sup>), followed by *Ficus benjamina* (168.19 tC ha<sup>-1</sup>) and *Ulmus lancefolius* (135.01 tC ha<sup>-1</sup>). Meanwhile, species such as *Ficus racemosa* and *Lithocarpus amygdalifolia* contributed the least, only 1.33 tC ha<sup>-1</sup>. The variation in carbon storage potential was more influenced by structural factors such as stem diameter (DBH) and wood density rather than the number of individuals.

### 1. Introduction

The conversion of forests into various forms of land use, such as agriculture, plantations, settlements, and infrastructure, has become increasingly common in line with growing human demands for space and resources [1]. Population growth, urbanization, and economic pressures drive land-use change, which threatens the sustainability of forest functions. This process not only leads to a decline in biodiversity but also disrupts the ecosystem services provided by forests. One of the most affected services is the reduction of biomass reserves stored in vegetation, thereby diminishing the ecosystem's



capacity to sequester carbon [2]. The resulting impact of the declining capacity of forests as carbon sinks is the increasing vulnerability to climate change [3].

Carbon storage is a crucial component in maintaining the balance of atmospheric carbon. Forests play a significant role in this process, particularly through carbon dioxide absorption, which contributes to mitigating the impacts of global warming [4]. The effort that can be undertaken at present is to conserve forest vegetation so that the ecosystem service function as a carbon sink remains sustained. Carbon absorbed by plants is stored in the form of biomass, especially in woody components, making forest biomass a key element in the biogeochemical cycle, particularly the carbon cycle. Of the total carbon contained in forests, about 50% is stored in forest vegetation biomass [5].

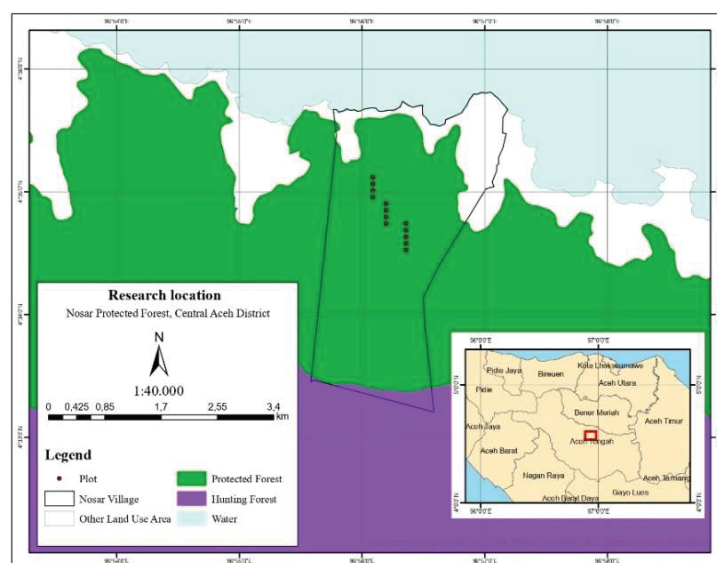
The Nosar Protected Forest in Central Aceh Regency is one of the conservation areas that still maintains natural stands with relatively high vegetation diversity. Its existence is highly important, not only ecologically as a provider of ecosystem services but also for its role in biomass and carbon storage. The diversity of forest stands in the Nosar Protected Forest indicates variations in the capacity of vegetation to absorb and store carbon. Therefore, estimating biomass and carbon across different stand types in this area is crucial as a scientific basis for data provision.

Furthermore, information on biomass and carbon stocks in the Nosar Protected Forest will be highly valuable in the context of sustainable forest management. Such data can support conservation policies, climate change mitigation planning, as well as national and international programs such as Reducing Emissions from Deforestation and Forest Degradation (REDD+). Forest biomass can be indirectly estimated through allometric models that relate stand parameters (e.g., diameter) to stored biomass [6]. Further research focusing on tree growth, biomass accumulation, and carbon stocks across species is needed to generate more accurate and reliable estimates, particularly applicable to the diverse species found in the forest area [7].

## 2. Materials and methods

### 2.1 Site description

This study was conducted in August 2025 in the Nosar Protected Forest, located in Bintang Subdistrict, Central Aceh Regency (Figure 1). Geographically, the research site is situated at coordinates 4°34.873' N and 96°56.205' E, at an elevation ranging from 1,390 to 1,470 metres above sea level.



**Figure 1.** The research location is in Nosar Protected Forest, Central Aceh District

## 2.2 Data collection

Primary data collected included plot coordinates, tree species, and tree diameter. A direct field survey method was employed to determine the plot locations and record their coordinates. Within each plot, every tree was measured for diameter and identified to species level to support biomass and carbon stock analysis. Measurements were carried out across three growth stages using different plot sizes: 20 × 20 m for trees (DBH >20 cm), 10 × 10 m for poles (DBH 10–20 cm), and 5 × 5 m for saplings (DBH <10 cm and height >1.5 m).

The study employed a sampling intensity of 1.6%. Given the total area of the Nosar Protected Forest (809.81 ha), the number of plots was calculated using the formula  $IS \times \text{total forest area}/\text{plot area}$  [8], resulting in 13 plots. Plot establishment followed a systematic sampling method with a random starting point. Data collection was conducted using a non-destructive approach, allowing measurements without damaging the sampled trees to ensure natural conditions were maintained.

## 2.3 Carbon Stock Estimation

Aboveground biomass (AGB) was estimated using the allometric equation developed by Ketterings [9]. This equation was selected because it incorporates wood density ( $\rho$ ), a key variable in determining biomass. The wood density values used in this study were sourced from the Global Wood Density (GWD) Database [10]. Two trees with the same diameter can differ in biomass depending on wood density; therefore, including  $\rho$  enables more accurate species-level estimations:

$$AGB = 0,11 \times \rho \times DBH^{2,62} \quad (1)$$

where biomass is expressed in kilograms, AGB is aboveground biomass, DBH is tree diameter (cm), and  $\rho$  is wood density ( $\text{g cm}^{-3}$ ).

$$C = AGB \times 47\% \quad (2)$$

where C is the carbon content, AGB is aboveground biomass, and 0.47 is the carbon fraction [11].

# 3 Results and discussion

## 3.1. Species Composition and Stand Structure

Species composition and stand structure at the study site were determined based on the number of individuals of each tree species across three growth phases: tree, pole, and sapling. In general, the stand data are presented in Table 1.

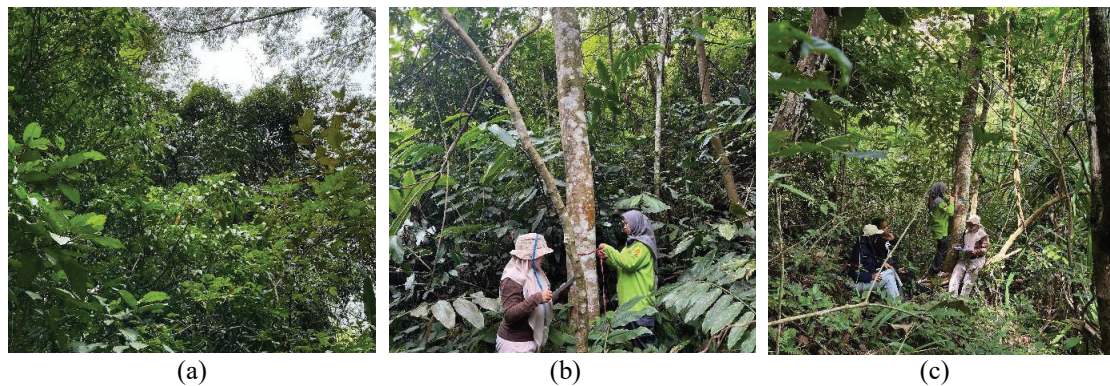
**Table 1.** The composition in the Nosar Protected Forest, Central Aceh District

| No.          | Local Name     | Latin Name                       | Phases    |           |           |            |
|--------------|----------------|----------------------------------|-----------|-----------|-----------|------------|
|              |                |                                  | Trees     | Poles     | Saplings  | Amount     |
| 1            | Pungkeh        | <i>Ulmus lancefolius</i>         | 7         | 1         | 0         | 8          |
| 2            | Kruing         | <i>Dipterocarpus retusus</i>     | 2         | 1         | 0         | 3          |
| 3            | Damar          | <i>Hopea dryobalanoides</i>      | 9         | 9         | 5         | 23         |
| 4            | Gala-Gala Rube | <i>Ficus racemosa</i>            | 1         | 0         | 0         | 1          |
| 5            | Tarap          | <i>Artocarpus Odoratissimus</i>  | 0         | 1         | 4         | 5          |
| 6            | Seumantok      | <i>Shorea macroptera</i>         | 2         | 0         | 0         | 2          |
| 7            | Beringin       | <i>Ficus benjamina</i>           | 2         | 2         | 0         | 4          |
| 8            | Jati Putih     | <i>Tectona grandis</i>           | 6         | 3         | 3         | 12         |
| 9            | Balik Angin    | <i>Ficus sp.</i>                 | 6         | 7         | 2         | 15         |
| 10           | Pagar Anak     | <i>Quercus argentata</i>         | 1         | 0         | 1         | 2          |
| 11           | Rambutan       | <i>Nephelium lappaceum</i>       | 1         | 0         | 0         | 1          |
| 12           | Macang         | <i>Mangifera foetida</i>         | 3         | 0         | 1         | 4          |
| 13           | Durian         | <i>Durio zibethinus</i>          | 6         | 3         | 3         | 12         |
| 14           | Karsen         | <i>Muntingia calabura</i>        | 0         | 2         | 1         | 3          |
| 15           | Sukun          | <i>Artocarpus altilis</i>        | 0         | 0         | 2         | 2          |
| 16           | Pinus          | <i>Pinus merkusii</i>            | 38        | 5         | 3         | 46         |
| 17           | Gesing         | <i>Lithocarpus amygdalifolia</i> | 1         | 0         | 0         | 1          |
| 18           | Kemiri         | <i>Aleurites moluccana</i>       | 2         | 2         | 2         | 6          |
| <b>Total</b> |                |                                  | <b>87</b> | <b>36</b> | <b>27</b> | <b>150</b> |

Based on Table 1, a total of 18 plant species comprising 150 individuals from various families were recorded. Overall, the stand structure consisted of 87 individuals in the tree phase, 36 individuals in the pole phase, and 27 individuals in the sapling phase. This indicates that the stands in the Nosar Protected Forest are dominated by individuals in the tree phase compared to other growth stages.

The highest number of individuals across all growth phases, sapling, pole, and tree, was recorded for *Pinus merkusii*. This species was most dominant in the tree phase, with 46 individuals. *P. merkusii* is a light-demanding species capable of growing under rainfall ranges of 1,000–2,800 mm per year and can thrive up to elevations of 2,000 m asl. Findings by Melinda et al. [12] in Lut Tawar and Linge, Central Aceh, also reported that pine grows well in two elevation zones, namely 1,325–1,358 metres above sea level, supporting its presence in the study area.

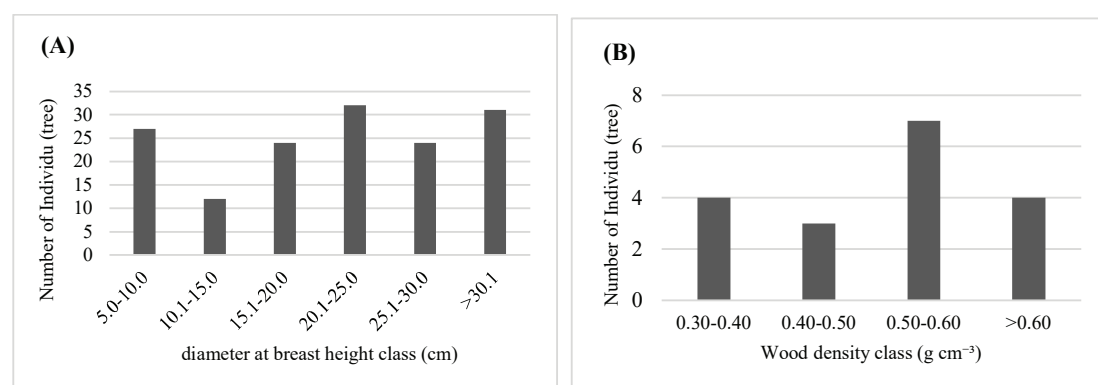
The Moraceae family was the most frequently represented, with three species, *Ficus racemosa* (Gala-gala Rube), *Ficus benjamina* (Banyan), and *Ficus sp.* (Balik Angin), totaling 20 individuals. The dominance of *Ficus* species highlights the ecological role of the Moraceae family in the vegetation structure of the study area. *Ficus* species are ecologically important as their fruits serve as food sources for various fauna, thus contributing significantly to supporting wildlife sustainability in the forest [13]. In contrast, the low abundance of Dipterocarpaceae species, such as *Hopea dryobalanoides* (Damar) and *Shorea macroptera* (Seumantok), is likely associated with anthropogenic pressures, particularly illegal logging [14]. This condition reflects the influence of human activity on stand structure and composition in the Nosar Protected Forest.



**Figure 2.** (a) The condition of Nosar Protected Forest; (b) Measurement of DBH; (c) The condition of Protected Forest tree stands.

Forest stand structure and composition play a crucial role in determining carbon storage, as variations in species composition, number of individuals, and diameter classes directly influence the amount of carbon stored [15]. The highest number of trees was recorded in the 20.1–25.0 cm diameter class with 32 individuals, followed by the >30.1 cm class with 31 individuals. Conversely, the lowest number of individuals was found in the 10.1–15.0 cm class, with only 12 individuals. This distribution indicates that most tree stands in the study area are dominated by medium to large diameter classes ( $\geq 20$  cm), while smaller diameter classes are relatively underrepresented.

These findings are consistent with the results of Mulyadi et al. [16], who reported that medium diameter classes generally contain relatively high numbers of individuals, although in some locations, smaller diameter classes tend to dominate. Variations in species composition and diameter class distribution contribute to a complementary forest community, where the presence of individuals across different size classes reflects balanced growth and forest regeneration [17]. The higher proportion of individuals in medium to large diameter classes suggests that the forest still retains a relatively mature stock of trees. Nevertheless, the potential decline in larger diameter classes must be considered carefully, particularly due to illegal logging activities targeting commercially valuable species such as those within the Dipterocarpaceae family. The distribution of tree diameter classes in the study area is presented in Figure 3.



**Figure 3.** The distributions of (A) DBH classes, (B) total wood density classes.

### 3.2. Biomass Estimation

Biomass was calculated using the equation developed by Ketterings, focusing on aboveground biomass (AGB). Tree biomass values were determined by several factors, including diameter at breast height (DBH), wood density, and the number of individual trees of each species. The results of the aboveground biomass estimation for each stand are presented in Table 2.

**Table 2.** Recapitulation of biomass by species

| Local Name     | Latin Name                       | Mean DBH (cm) | Wood density (g/cm <sup>3</sup> ) | no. of ind trees | AGB (kg)         |
|----------------|----------------------------------|---------------|-----------------------------------|------------------|------------------|
| Karsen         | <i>Muntingia calabura</i>        | 15.4          | 0.300                             | 3                | 149.03           |
| Kemiri         | <i>Aleurites moluccana</i>       | 21.2          | 0.303                             | 6                | 1,342.55         |
| Sukun          | <i>Artocarpus altilis</i>        | 9.5           | 0.320                             | 2                | 26.00            |
| Gala-Gala Rube | <i>Ficus racemosa</i>            | 22.2          | 0.352                             | 1                | 130.90           |
| Seumantok      | <i>Shorea macroptera</i>         | 32.2          | 0.425                             | 2                | 832.29           |
| Beringin       | <i>Ficus benjamina</i>           | 50.9          | 0.459                             | 4                | 11,276.18        |
| Balik Angin    | <i>Ficus</i> sp.                 | 17.6          | 0.468                             | 15               | 1,657.64         |
| Durian         | <i>Durio zibethinus</i>          | 20.0          | 0.516                             | 12               | 2,462.83         |
| Macang         | <i>Mangifera foetida</i>         | 28.8          | 0.525                             | 4                | 2,345.69         |
| Pinus          | <i>Pinus merkusii</i>            | 26.8          | 0.530                             | 46               | 18,194.44        |
| Pungkeh        | <i>Ulmus lancefolius</i>         | 40.2          | 0.550                             | 8                | 10,801.88        |
| Tarap          | <i>Artocarpus Odoratissimus</i>  | 9.6           | 0.550                             | 5                | 144.89           |
| Jati Putih     | <i>Tectona grandis</i>           | 17.2          | 0.594                             | 12               | 1,701.22         |
| Kruing         | <i>Dipterocarpus retusus</i>     | 27.5          | 0.600                             | 3                | 1,526.68         |
| Damar          | <i>Hopea dryobalanoides</i>      | 17.7          | 0.610                             | 23               | 3,588.14         |
| Gesing         | <i>Lithocarpus amygdalifolia</i> | 22.4          | 0.690                             | 1                | 261.75           |
| Pagar Anak     | <i>Quercus argentata</i>         | 20.0          | 0.740                             | 2                | 659.88           |
| Rambutan       | <i>Nephelium lappaceum</i> L.    | 21.6          | 0.789                             | 1                | 273.19           |
| <b>Total</b>   |                                  |               |                                   | <b>150</b>       | <b>57,375.21</b> |

where AGB (Aboveground Biomass)

The total biomass calculated for all species in the study area was 57,375.21 kg (Table 2). *Pinus merkusii*, with a relatively large DBH of 26.8 cm, wood density of 0.530, and a large population of 46 individuals, produced the highest total AGB at 18,194.44 kg. Similarly, *Ficus benjamina*, with a medium DBH of 50.9 cm and a higher wood density of 0.459, contributed significantly to the total biomass with 11,276.18 kg due to its higher number of individuals. In contrast, species such as breadfruit (*Artocarpus altilis*), with a smaller DBH (9.5 cm), lower wood density (0.320), and a limited number of individuals, contributed very little to the overall biomass, producing only 26.00 kg.

Although represented by only a few individuals, species with high wood density, such as *Ficus racemosa*, which was recorded with a single individual, still contributed considerably to the total biomass, amounting to 130.90 kg. This finding indicates that stand biomass is not solely determined by the number of individuals but is influenced by a combination of DBH, wood density, and the number of individuals of each species. Species with large DBH, high wood density, and abundant populations, such as *Pinus merkusii*, typically account for the largest proportion of total biomass. Conversely, species with smaller DBH and fewer individuals tend to contribute relatively little to overall biomass.

### 3.3. Carbon stocks

The carbon concentration contained in organic material/biomass is assumed to be 47%; therefore, the estimated amount of stored carbon was obtained by multiplying biomass values by 0.47. A summary of carbon stock by species is presented in Table 3.

**Table 3.** Recapitulation of carbon stock by species

| Local name     | Latin name                       | AGB (ton ha <sup>-1</sup> ) | Carbon stock (tC ha <sup>-1</sup> ) |
|----------------|----------------------------------|-----------------------------|-------------------------------------|
| Karsen         | <i>Muntingia calabura</i>        | 35.16                       | 16.53                               |
| Kemiri         | <i>Aleurites moluccana</i>       | 62.99                       | 29.61                               |
| Sukun          | <i>Artocarpus altilis</i>        | 18.52                       | 8.70                                |
| Gala-Gala Rube | <i>Ficus racemosa</i>            | 2.82                        | 1.33                                |
| Seumantok      | <i>Shorea macroptera</i>         | 25.95                       | 12.20                               |
| Beringin       | <i>Ficus benjamina</i>           | 357.84                      | 168.19                              |
| Balik Angin    | <i>Ficus</i> sp.                 | 106.49                      | 50.05                               |
| Durian         | <i>Durio zibethinus</i>          | 99.27                       | 46.66                               |
| Macang         | <i>Mangifera foetida</i>         | 54.85                       | 25.78                               |
| Pinus          | <i>Pinus merkusii</i>            | 480.94                      | 226.04                              |
| Pungkeh        | <i>Ulmus lancefolius</i>         | 287.26                      | 135.01                              |
| Tarap          | <i>Artocarpus Odoratissimus</i>  | 30.35                       | 14.26                               |
| Jati Putih     | <i>Tectona grandis</i>           | 83.94                       | 39.45                               |
| Kruing         | <i>Dipterocarpus retusus</i>     | 38.65                       | 18.16                               |
| Damar          | <i>Hopea dryobalanoides</i>      | 162.91                      | 76.57                               |
| Gesing         | <i>Lithocarpus amygdalifolia</i> | 2.88                        | 1.35                                |
| Pagar Anak     | <i>Quercus argentata</i>         | 18.65                       | 8.77                                |
| Rambutan       | <i>Nephelium lappaceum</i> L.    | 5.14                        | 2.42                                |
| <b>Total</b>   |                                  | <b>1,874.62</b>             | <b>881.07</b>                       |

where AGB (Aboveground Biomass)

Based on the data in Table 3, the total aboveground biomass (AGB) in the study plots reached 1,874.62 ton ha<sup>-1</sup>, with a total carbon stock of 881.07 tC ha<sup>-1</sup>. Among all species, *Pinus merkusii* contributed the largest portion of carbon stock at 226.04 tC ha<sup>-1</sup>, followed by *Ficus benjamina* (168.19 tC ha<sup>-1</sup>) and *Ulmus lancefolius* (135.01 tC ha<sup>-1</sup>). In contrast, the lowest contributions were recorded for *Ficus racemosa* and *Lithocarpus amygdalifolia*, each with only about 1.33 tC ha<sup>-1</sup>. These results indicate substantial variation among species in their carbon storage capacities.

The variation in carbon stock is closely related to differences in wood density, diameter at breast height (DBH), and total tree height across species. Species with larger DBH and higher wood density generally exhibited greater aboveground biomass, resulting in higher carbon stocks. This finding is consistent with the results of Ojeda et al. [18], who reported that species with large diameters contribute more significantly to total carbon stock compared to their number of individuals.

Although *Tectona grandis* showed relatively high levels of biomass and carbon stock (39.45 tC ha<sup>-1</sup>), this value was still lower than that of *Mangifera foetida*, which contributed 25.78 tC ha<sup>-1</sup> despite having fewer individuals. This reinforces the notion that the number of individuals per species is not always the primary factor in estimating carbon stock. Structural factors such as DBH, tree height, and wood density are more relevant in determining a species' contribution to total carbon stock than abundance alone.

#### 4. Conclusions

The results of this study showed that the total aboveground biomass (AGB) in the Nosar Protected Forest reached 1,874.62 ton ha<sup>-1</sup>, with a carbon stock of 881.07 tC ha<sup>-1</sup>. *Pinus merkusii* contributed the largest share of carbon storage, followed by *Ficus benjamina* and *Ulmus lancefolius*, whereas species such as *Ficus racemosa* and *Lithocarpus amygdalifolia* contributed only marginally. Variation in carbon stock was more strongly influenced by structural factors such as diameter at breast height (DBH) and wood density than by the number of individuals per species..

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