The carbon dioxide (CO₂) sequestration potential of conservation plant *Aquilaria malaccensis*

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**Abstract.** Climate change is the challenge provided with the most attention within all circles in the 21st century. This phenomenon allegedly originates due to the increasing concentrations of CO₂ gas in the atmosphere. Therefore, efforts are continually designed to slow down or halt the process to avoid significantly impacting life on earth. The common mitigation approach is by encouraging the planting of trees to optimize CO₂ sequestration. This study, therefore, aimed to determine the CO₂ sequestration capacity of *Aquilaria malaccensis* in natural forests and plantations. Particularly, *Aquilaria malaccensis* is an endemic plant of Indonesia's tropical forests, with critical or endangered status. The allometric method was adopted, with purposive and non-destructive sampling techniques, then a multilevel plot was used during CO₂ sequestration analysis. This plant species absorbed the gas at the tree category in natural forests (9.57 tons CO₂ eq/year), and similarly with plantation forests (2.35 tons CO₂ eq/year). The tree biomass category in natural forests (5.22 tons CO₂ eq/year), and plantations (1.28 tons CO₂ eq/year), alongside the pole category in natural forests (1.9 x 10⁻³ tons CO₂ eq/year) rank lowest. The carbon content in the tree category ranked highest at the natural (2.61 tons CO₂ eq/year), compared to plantation forests (0.64 tons CO₂ eq/year), while the carbon composition in pole category at the natural and plantation forests were (9.8 x 10⁻⁴ tons CO₂ eq/year) and (2.2 x 10⁻³ tons CO₂ eq/year), respectively.

1. **Introduction**

Climate change is a serious problem faced by all countries worldwide, and the negative impact magnitude poses a threat to the sustainability of human lives and other living things [1]. Therefore, the international forum attributed climate change as one of the seventeen Sustainable Development Goals and is understood expected to be resolved by 2030, precisely on the thirteenth goal [2]. All countries have a similar mandate to conduct mitigation and adaptation efforts [3]. The massive efforts are projected to slow the climate change rate and reduce the risks and impacts on life. Moreover, the global forum relies on the need to take strategic steps in line with mitigation.

This ought to be performed in time because climate change's consequent impact is very disturbing, featuring an increase in the average atmospheric temperature of the sea and terrestrial ecosystems [4]. Also, there is a forecast for the development of erratic seasons, with much longer dry season, therefore posing a risk to food security and a tendency for clean water crises [5]. These challenges also expose potential for the extinction of various organisms in both aquatic and terrestrial ecosystems [6]. Furthermore, this possibly occurs due to stress and death of microorganisms resulting from an increase in water and soil temperatures [7]. Therefore, it is important to identify the instigators of climate change as well as possible solutions.
The increased amount of carbon dioxide (CO₂) in the atmosphere is considered one of the causes of climate change, and the records show an accumulated estimate of 50% [8]. Moreover, the CO₂ concentration is potentially reduced in principle through photosynthetic mechanisms in natural ecosystems. Therefore, forests are determined to play a very important role in this aspect [9], resulting from the ability to function as carbon dioxide sinks. The photosynthesis process involves absorption and storage of CO₂ as an organic material within the plant biomass [10]. Moreover, the earth’s surface is characterized by approximately 90% biomass, stored within forests in the form of wood, branches, leaves, roots and forest waste (litter), animals, and microorganisms [11]. Therefore, massive vegetation covers are needed to mitigate the risks associated with climate change and is achievable by planting trees.

All plants comprising chlorophyll have to capacity to perform photosynthesis and consequently impact positively on CO₂ uptake. Ardiansyah [12] reported on the ability for Bintaro (Cerbera toothpaste) to absorb 4.5 tons of CO₂eq/year, while Mahogany (Swietenia macrophylla) is 0.22 tons, 0.2 and 0.48 and 1.47 tons are recorded for Trembesi (Samanea saman), Sono (Dalbergia latifolia roxb), and Pulai (Alstonia scholaris), respectively. Planting a sufficient quantity of trees is one of the strategic remediation techniques, although each species demonstrates a different absorbance capacity. Therefore, it is necessary to note the exact types of plants with huge sequestration tendency for ecological functions, including emission reduction, and the high economic value obtained by providing power to the community. There is also a need to study the ecological benefits of aloes-producing plants, including Aquilaria malaccensis, especially for the CO₂ uptake capacity, due to the very high economic potential. This species' sequestration data is a very important basic information in formulating priority plant species for environmental conservation. Therefore, this research aimed to determine the CO₂ sequestration capacity of A. malaccensis in forests and plantations.

2. Materials and methods

This research was performed using quantitative approaches and methods, at Trenggalek Regency, East Java and Musi Banyuasin Regency, South Sumatra Province, from September 2018 to July 2019. These areas were selected because of the high amount of Aquilaria malaccensis in natural forests and plantation settings. Both sites are situated at similar height of ± 300-700 meter above sea level (m asl), and the respective topography served as an important consideration. This was due to the significant influence of altitude on plant growth and development, especially for A. malaccensis. Furthermore, CO₂ sequestration was calculated using an allometric formula through a non-destructive sampling approach. This means there was no need to collect samples from nature, as each individual was physically observed without destroying the habitat and natural conditions.

The sampling location was determined based on the study sites' vegetation structure, and the technique adopted was purposive sampling. This study was performed with 10 plots sectioned with an individual area of 0.3 Ha. Each was further divided into a 4-storey sub-plot, including subplot A measuring 30 x 100 m partitioned to observe the tree category, while the pole category was observed in B, with a dimension of 15 x 40 m. Subsequently, sub-plot C (2 x 2 m) and D (1 x 1 m) were mapped to examine the sapling and seedling categories, respectively, as shown in Figure 1.
The plants observed in this study were categorized based on the classification of [9] as follows: 1) The seedlings are saplings with heights and diameter below 150 cm and 10 cm, respectively; 2) Pole is a sapling with heights measuring over 150 cm, with a diameter less than 10 cm; 3) Stakes are trees with diameters between 10-20 cm; 4) Tree is a woody plant measuring a diameter above 20 cm.

The data obtained were analyzed for two purposes, including (1) to calculate the density of *Aquilaria malaccensis* in natural forests and plantations and (2) to measure the CO$_2$ uptake. This was achieved using the following formula.

2.1. Population density
Population density of species or group of plants was expressed as the number of individuals per unit area, using the formula according to Odum [14] as follows:

$$D_i = \frac{n_i}{A}$$

Where: $D_i$ = population density of *Aquilaria malaccensis*; $n_i$ = total number of individual *Aquilaria malaccensis*, and; $A$ = total area of habitat sampled/observed

2.2. Calculation of carbon above ground level for plant biomass.
The acquisition value of Diameter at Breast Height (DBH) in subplot A and B were included in the allometric formula Chave *et al* [9] as follows:

$$Y = 0.059 \times \rho \times DBH^2 \times T$$

Where: $Y$ = Total biomass in kg; DBH = Diameter at breast height of trees in m; $T$ = Plant height, and; $\rho$ = Wood density, for natural forest = 0.68 gr/cm$^3$ and for plantations 0.61gr/ cm$^3$.

2.3. Calculation of carbon content in forest ecosystem
Calculation of carbon content in forest ecosystem [15], used a formula with a conversion factor of 0.5.

$$C = B \times 0.5$$

Where: C = Amount of carbon stock in tons/ha, and; B = Total biomass of calculated stands (tons/ha)

2.4. Calculation of carbon dioxide (CO$_2$)
The results from evaluating the carbon level were then converted as follows.

$$\text{CO}_2 \text{ uptake (ton/ha)} = \left(\frac{\text{bmr CO}_2}{\text{bmr C}}\right) \times C \text{ content}$$

Where: bmr CO$_2$ = relative molecular weight CO$_2$ = 44, and; bmr C = relative molecular weight C = 12
3. Results and discussion

This study was conducted in two locations, characterized natural vegetation, as observed in Musi Banyuasin Regency, South Sumatra Province, while Trenggalek Regency, East Java Province, possessed plantation forests. The density of *A. malaccensis* species were respectively presented in Table 1 and Figure 2.

Figure 2 showed significantly different population densities of *A. malaccensis* in each plant category at the natural forest. This phenomenon was attributed to the highest density of 32 individual seedlings observed in five study plots. The pole category demonstrated the second-highest value at an average of 16, while the stake was third at 7. The tree category was ranked lowest, with a mean of 4 individuals. This condition was possibly influenced by various factors, including (1) the size of *A. malaccensis*, as those with bigger values tend to facilitate an increase in the hunting rate, while (2) diameter greater than 20 cm were cut down by the community to obtain sapwood. Furthermore, the results are congruent with Ng [16], where the aloes demonstrated a very promising market opportunity. These characteristics consequently instigated rampant hunting in the wild and threatened the *Aquilaria* spp population.

![Figure 2](image-url)

**Figure 2.** Comparison of *Aquilaria malaccensis* quantity in each plot in the forest. Sources: Primary research data, 2018-2019

The population density of *A. malaccensis* was observed to occur in small numbers, and further classified in the higher growth category. This condition was very common in natural forest vegetation due to the dynamics of the ecosystem, shape the structure and the triangular profile, where the seedlings predominate, leading to fewer numbers. These findings are congruent with research by Mohamed *et al* [17], where the population density continuously decreased according to size, therefore instigating seedling domination. Also, parent plants (trees) tend to naturally produce seeds in very large quantities, subsequently falling on forest soil/litter surfaces. Under favorable environmental conditions (high humidity and low temperature), the seeds eventually germinate into seedlings. These findings support Borogayary *et al* [18] research, where the investigated *A. malaccensis* seeds successfully germinated in areas with sufficient humid. However, high exploitation was not proportional to the germination rate, which was highly dependent on the microclimate and, therefore, facilitated extinction risk.
Figure 3 shows that across plots, the stake category dominated compared to the other categories. This condition was since *A. malaccensis* plantations was planted by community groups that had an institutional structure. They planted uniform size seedlings simultaneously and carried out regular maintenance as the group leader monitors them. On the other hand, *A. malaccensis* was spread over an area with similar ecosystem characteristics, so the soil type and microclimate conditions were the same. This was what causes all of *A. malaccensis* plots to had the same category, namely the stage, and at the same time dominating this area because if we looked closely, from the planting age which had reached 8 years, it should had a diameter between 10-20 cm.

The total number of *A. malaccensis* individuals fundamentally differ between plantations and under natural forest conditions. This discrepancy was attributed to the stakes category, which was most dominant in natural forests, followed by trees, before seedlings and poles. Besides, the species in this location were also intentionally planted by the community. These findings support previous research by Tan *et al* [19], where the threat of poaching prompts the development of cultivation cultures within the community. Moreover, a similar study had been performed on 8 years old *A. malaccensis* in 2011, at a community in Pule Subdistrict, Trenggalek Regency. The samples showed varied growth rates and were further classified in each category. However, the majority reached the growth phase in the stake category, while some planted simultaneously demonstrated a faster development rate. During the current investigation, a total of 65 individuals were recognized to have reached the tree category in 5 observation plots.

In addition, some of these individuals produced fruit and seeds. These findings support Soehartono and Newton [20], where *Aquilaria* spp entered the reproductive period at 5 years of age or more. Therefore, some samples identified in the plantations reached the reproductive period and produced a significant quantity of seeds, especially in plot 2 and 5. This outcome indicated the suitability of planting *A. malaccensis* in this region because of the ability to breed and produce new individuals. The results also reinforce research by Kinnaird and O’Brien [21], where the environmental conditions serve as a determinant factor for reproductive success or failure. Therefore, it is important to evaluate these conditions before breeding attempts outside the natural habitat. This assessment was performed to obtain the proper options for ex-situ conservation due to the continuously declining number of individuals in the natural habitat.
The amount of biomass was strongly influenced by the number of individuals due to *A. malaccensis* to perform photosynthesis. This process resulted in starch formation, which is consequently stored through the plant physiological mechanism into biomass. The finding is consistent with the research of Yao [22], where some photosynthetic products are in the form of tree biomass at the roots, stems, leaves, flowers, and fruit. This facilitates the development of greater individual contents in an ecosystem. Therefore, an understanding of the process shows the organic carbon (C-organic) composition of 50% of plant biomass. These elements are owned by plants and enter into the carbon cycle when leaves, branches, and fruits fall, and also on the instance of plant death and decomposition.

**Figure 4.** Comparison of potential CO\(_2\) sequestration of *Aquilaria malaccensis* (ton CO\(_2\) eq/ha). Sources: Primary research data, 2018-2019

The carbon dioxide uptake in all plant categories present at both locations was greater than the biomass and carbon content. This condition is assumed to have been caused by the plant physiological mechanism based on the intrinsic ability to absorb carbon dioxide coherently through photosynthesis. Furthermore, the product in the form of starch is stored in all parts, including the roots, stems, leaves, flowers, and fruit biomass, both above and below ground level (bellows ground), and is commonly referred to as carbon sinks [24][1]. Therefore, carbon content is lowest, compared to both biomass and carbon uptake, due to the 50% organic carbon composition stored in all parts, sourced from the photosynthesis process [5]. Therefore, *A. malaccensis* has an ideal contribution as a conservation plant, because of the emission reduction capacity, which is ideal in climate change mitigation. The outcome of this research is considered important, based on the suggestions of Pierrehumbert [25], where climate change mitigation is recommended to avoid worsening global conditions. Conversely, the biomass and carbon content of *A. malaccensis* also play an important role in carbon and biogeochemical cycle mechanism, especially to maintain ecosystem stability.
4. Conclusion

The carbon sequestration capacity of *A. malaccensis* in the natural forests and plantations were 10.35, and 3.06 tonnes/ha/year, respectively. This outcome was influenced by the age, volume, and number of plants. Meanwhile, *A. malaccensis* has the potential to conserve for the future, and carbon dioxide is possibly absorbed in preparation for carbon trading. Planting more *A. malaccensis* will provide for positive impact on environment and economic.

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