Jurnal Pembelajaran Dan Biologi Nukleus p-ISSN: 2442-9481
Vol 10 (1): 11-25, March 2024 e-ISSN: 2685-7332

Analysis of Biomass Potential, Carbon Stock, Carbon Sequestration, Oxygen Production, and Value of Environmental Services CO_2 Uptake in Three Types of Forests in Buton District, Southeast Sulawesi Province, Indonesia

La Nare(*), Fatchur Rohman, Vivi Novianti
[1] Department of Biology, Faculty Mathematics and Natural Sciences, State University of Malang, Jl. Semarang 5, Malang, Indonesia

*__Corresponding author__: narebiologi05@gmail.com

Submitted October 13th 2023 and Accepted February 02nd 2024

Abstract

Global warming is a symptom of an increase in the average temperature of the earth's surface. Global warming is caused by the large concentration of greenhouse gases in the atmosphere. One of the biggest greenhouse gases contributing to global warming is carbon dioxide (CO_2). Forest vegetation can absorb about 50% of total emissions through a sequestration process stored in biomass in all parts of the plant. The study aimed to determine the potential of biomass, carbon stocks, carbon sequestration, oxygen production, and the CO_2 absorption value of environmental services in three types of ecosystems in Buton Regency, Southeast Sulawesi Province. Research sampling was conducted using purposive sampling techniques and roaming methods. Calculation of biomass potential, carbon stock, carbon sequestration, oxygen production, and environmental service value of CO_2 uptake using an allometric formula The results of research on the biomass potential of mangrove forests, lambusango forests, and pine forests were respectively, 16,108.27 tons/ha, 84,693.72 tons/ha, and 14,273.98 tons/ha. The potential carbon stock is 8,054.13 tons/ha, 42,346.86 tons/ha, and 7,136.99 tons/ha. The carbon absorption potential is 29,558.67 tons/ha, 155,412.98 tons/ha, and 26,192.75 tons/ha. The potential oxygen production is 21,504.54 tons/ha, 113,066.12 tons/ha, and 19,055.76 tons/ha, while the value of environmental services CO_2 absorption is 2,221,038,614.63 Rp/ha, 11,677,731,637.57 Rp/ha, and 1,968,123,759 Rp/ha.

Keywords: *Buton Regency, Carbon stock, Global warming, Sequestration*

https://doi.org/10.36987/jpbn.v10i1.5076

INTRODUCTION

Indonesia is committed to achieving the sustainable development goals (SDGs) by controlling climate change, with particular emphasis on protecting and restoring forest areas as carbon dioxide (CO_2) absorbers (Sutopo *et al.*, 2014). Using forests as carbon sinks can accelerate climate change mitigation through monitoring and inventorying carbon stored in different types of forest vegetation (Brandon, 2014). Forests play a crucial role in achieving SDGs, including health, clean water availability, disaster risk reduction, and food security (Keenan *et al.*, 2015). Furthermore, forest ecosystems provide additional benefits such as groundwater retention, flood hazard prevention, soil fertility maintenance, runoff reduction, and erosion and sedimentation rate reduction (Fathoni *et al*., 2021). By managing forests properly, more carbon dioxide can be absorbed by forest vegetation, which will help achieve climate change reduction targets by 2030 and zero carbon emissions by 2050.

Global warming refers to the disturbance of ecosystems on the Earth's surface caused by an increase in the average temperature of the atmosphere, sea, and land (Utina, 2009). The greenhouse gases (GHG) that contribute to this phenomenon include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and fluorescent gases. These gases are responsible for 80%, 8%, 6%, and 16% of GHG emissions (Setiawan, 2022). According to BPS (2023), deforestation in Indonesia is a major contributor to this issue, with a yearly loss of 120,705.8 hectares in forest areas and outside forest areas, coupled with a regeneration rate of only 475 hectares per year. This has led to a decrease in the absorption of carbon dioxide (CO_2) emissions in the forestry sector. One way to tackle this problem is to boost the ability of plants to absorb carbon dioxide and maintain carbon stocks, thereby reducing or controlling the release of carbon dioxide into the atmosphere (Rochmayanto *et al*., 2014).

Forests are one of the vegetation types that can absorb carbon dioxide (CO_2) from the atmosphere (Latifah & Sulistiyono, 2013). They also play a crucial role in balancing carbon dioxide concentrations in the atmosphere, facilitating the exchange of carbon (Liang et al., 2019). Factors such as the type and age of forests, the growth environment, human activities, and climate change influence the carbon cycle in the atmosphere (Higgins & Harte, 2012). Forests can store photosynthesis products in the form of carbon (C), which is about 50% of the total carbon stored on the surface of the earth, indicating their importance in reducing emissions on the earth's surface (Tambunan, 2009). Forest ecosystems store carbon stocks in three primary components: living organs (biomass), litter (necromass), and soil (soil organic matter) (Siregar *et al*., 2018). Stems, leaves, twigs, and branches have a biomass of 68,09% - 82.28%, 4.17% - 14.44%, 6.16% - 10.32%, and 7.15% - 7.45% (Tuah et al., 2017).

Measuring the biomass of trees can assist in estimating the impact of forests on the carbon cycles of a region and the world (Zianis, 2008). Understanding the amount of carbon that is absorbed and released in a forest ecosystem is crucial for determining the carbon content of forests (Irawan & Purwanto, 2020). Furthermore, calculating biomass, carbon stocks, carbon sequestration, and the value of carbon absorption from environmental services is an essential step in preventing climate change in the forestry sector. It helps to estimate carbon sequestration and stocks, as well as the value of carbon trading in specific regions (Iksan *et al*., 2019).

METHOD

The research uses a non-destructive sampling approach. Purposive sampling techniques and roaming methods are employed to collect data. Each forest ecosystem is divided into five plots, each with a size of 100 x 100 meters. The study area was sampled from 10% of each forest ecosystem. The diameter of the trunk was measured above the chest (DBH) by 1.3 meters, and only trees with a diameter of $\geq$ 20 cm were categorized.

Location and Research Tools

The research was conducted between March and May of 2023 in three different forests the mangrove forest, lambusango forest, and pine forest located in Buton Regency, Southeast Sulawesi Province. The study utilized various tools such as measuring tapes, ropes, stationery, mobile phone cameras, MS Excel, SPSS 22 software, thermometers, hygrometers, soil testers, and lux meters. The research location of each forest type in Buton Regency, Southeast Sulawesi (Figure 1).

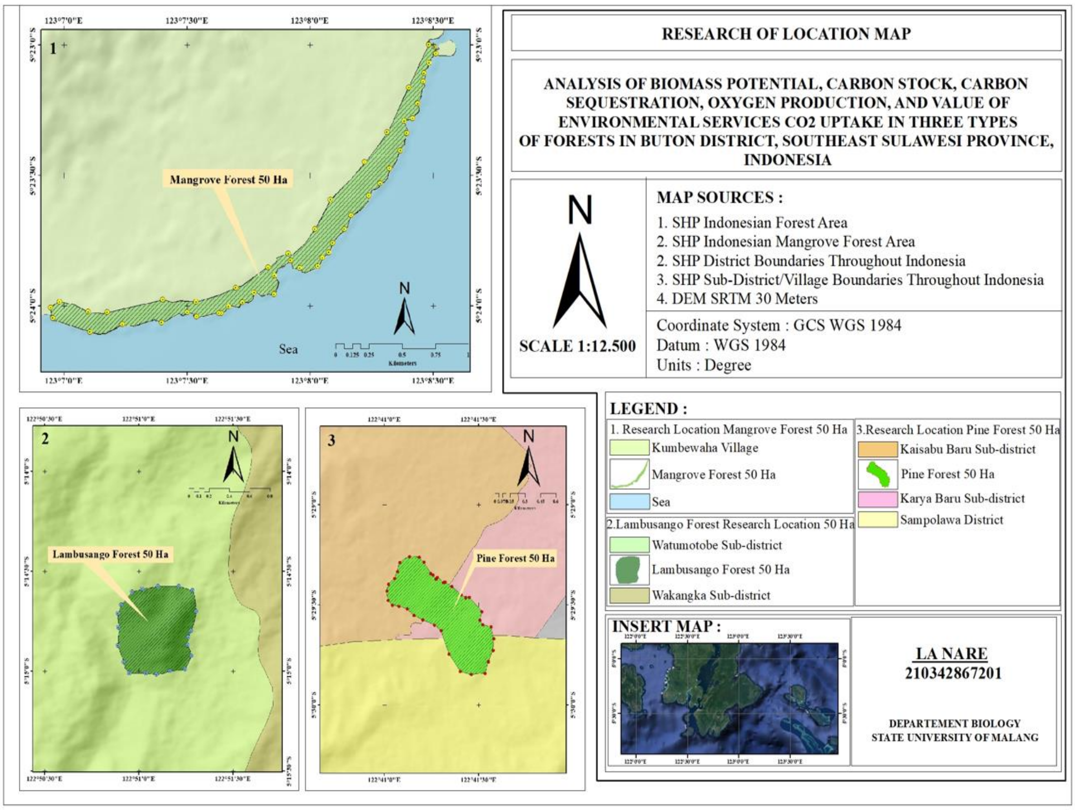

Figure 1. Research the location of three types of forests in Buton Regency

Data Analysis

The data obtained were analyzed in a quantitative, descriptive manner using the following formula:

Biomass Analysis

Biomass on tree trunks uses a general equation (Brown, 1997), namely:

$$B = 42.69 - 12.800 (D) + 1.242 (D)^2 \quad (1)$$

The total biomass of all trees is calculated by adding the biomass of all trees using a formula (Hairiah *et al*., 2011),

$$\textbf{Total biomass of the whole tree} = B1+B2+B3+\ldots+Bn \quad (2)$$

Information: code B1, B2, B3,............., Bn = biomass of each tree

p-ISSN: 2442-9481
e-ISSN: 2685-7332

Carbon Stock Analysis

Carbon stock in biomass is calculated using the formula (Heriyanto & Subiandono, 2012), namely:

Carbon stock = total biomass x 50% **(3)**

Description: 50% = percentage value of carbon stock in biomass

Carbon dioxide uptake Analysis

Carbon dioxide absorption is calculated using the formula Heriyanto & Subiandono (2012), namely:

$$(CO_2) = Mr.\ CO_2 / Ar.\ C \text{ (or } 3.67 \times \text{carbon stock)} \quad (4)$$

Information:
CO_2 = carbon dioxide uptake (ton/ha)
Mr = relative molecular weight of CO_2 (44)
Ar = molecular weight of C atom (12)

Oxygen Production Analysis

Oxygen production is calculated by the formula equation Nowak *et al.* (2019), namely:

$$O_2 = C \times 32/12$$
$$O_2 = C \times 2.67 \quad (5)$$

Information:
O_2 = oxygen production (ton/ha)
C = carbon stock (ton/ha)

The Value of Environmental Services CO_2 Uptake Analysis

The value of environmental services from CO_2 absorption is calculated using a formula (Sribianti *et al.*, 2022)

$$NJL = HJC \times C \quad (6)$$

Information:
NJL = value of environmental services CO_2 absorption (IDR/Ha)
HJC = selling price of carbon (IDR/tonCO_2, US$ 5=IDR 75,140.-) (US$IDR 15,028.00)
C = carbon dioxide uptake (ton/ha)

Statistical analysis

Data analysis was carried out using MS Excel and one-way ANOVA in SPSS 24 to determine differences in biomass, carbon stocks, carbon sequestration, oxygen production in the lambusango forest ecosystem, mangrove forests and pine forests, and environmental factors.

RESULTS AND DISCUSSION

Tree Stands in Mangrove Forests

The research conducted on mangrove forests revealed the presence of six species belonging to three families, with a total of 128 individual trees. These tree stands comprise the Rhizophoraceae, Verbenacea, and Meliaceae families, among which Rhizophora mangle species has the highest number of individuals, as shown in (Table 1).

Table 1. Types and number of trees found in mangrove forests

Species	**Local name**	**Family**	**Amount**
Rhizophora mangle	*Tongke modea*	Rhizophoraceae	57
Avicenia marina	*Api-api*	Verbenacea	10
Bruguiera gymnorrhiza	*Tanjang*	Rhizophoraceae	10
Xylocarpus granatum	*Kontafu*	Meliaceae	9
Rhizophora mucronata	*Tongke*	Rhizophoraceae	15
Rhizophora apiculata	*Bangko*	Rhizophoraceae	27
Total			128

Tree Stands in Lambusango Forest

Based on research conducted in the lambusango forest, a total of 19 species belonging to 14 families and 158 individual trees were identified. These tree stands include families such as Moraceae, Myrtaceae, Fabaceae, Malvaceae, Sapindaceae, Lamiaceae, Urticaceae, Rutaceae, Calophyllaceae, Meliaceae, Ebenaceae, Acharinaceae, Primulaceae, and Dilleniaceae. Out of all the species, *Pterospermum javanicum* was found to have the highest number of individuals. Five species with the highest density are found in the lambusango forest (Table 2).

Table 2. Species and number of trees stand in the lambusango forest

Species Name	**Local name**	**Family**	**Amount**
Pterospermum javanicum	*Bayur*	Malvaceae	14
Pometia pinnata	*Kase*	Sapindaceae	13
Ficus benjamina	*Waringi*	Moraceae	13
Eugenia sp.	*Mbele-mbele*	Myrtaceae	12
Ficus hispida	*Sampola*	Moraceae	10
Total			158

Research conducted in pine forests revealed that *Pinus merkusii* was the only species found, with 120 trees per individual. This is because pine forests are generally homogeneous ecosystems. Pine forests grow naturally in nature and are managed by Perhutani to ensure the sustainability of the ecosystem.

Tree Stand Diameter

Based on the results of the analysis of the average diameter of trees in each forest, both mangrove forests, lambusango forests, and pine forests show differences from each other. The average diameter of the lambusango forest is larger than that of the mangrove forest and pine forest (Table 3).

p-ISSN: 2442-9481
e-ISSN: 2685-7332

Table 3. Comparison of tree stand diameters of each forest type

Types of forests	**Diameter (cm)**	**Total diameter (cm)**
Mangrove forest	27.28 ± 0.26[a]	3,492.19
Lambusango forest	49.93 ± 0.97[b]	7,888.22
Pine forest	26.64 ± 0.27[a]	3,197.13

Information: on a line, the same letter above indicates that the value is not significantly different based on the Kruskal Wallis test with a significant rate of 5% (n = 406; average ± standard error)

Biomass Potential, Carbon Stocks, Carbon Sequestration, and Oxygen Production

These calculations were conducted to estimate the total biomass, carbon stocks, carbon sequestration, and oxygen production for each forest type. The findings revealed that lambusango forests have a higher potential for biomass, carbon stock, carbon sequestration, and oxygen production than mangrove forests and pine forests (see in Table 5).

Table 4. Comparison of biomass, carbon stocks, carbon uptake, and oxygen production

Types of forests	**Biomass (ton/ha)**	**Stock carbon (ton/ha)**	**Carbon sequestration (ton/ha)**	**Oxygen production (ton/ha)**
Mangrove forest	16,108.27[a]	8,054.13[a]	29,558.67[a]	21,504.54[a]
Lambusango forest	84,693.72[b]	42,346.86[b]	155,412.98[b]	113,066.12[b]
Pine forest	14,273.98[a]	7,136.99[a]	26,192.75[a]	19,055.76[a]

Information: on a line, the same letter above the number indicates that the value is not significantly different based on the Games Howel test with a significant level of 5% (n = 406)

The Value of Environmental Services CO_2 Uptake

The economic value of forest carbon, also known as environmental services, can be calculated by determining the amount of tree carbon sequestration in each type of forest. This calculation can then be used to assign a monetary value to each country. Based on international carbon trading data, the current carbon price is set at US$ 5 per ton, assuming a conversion rate of US$1 to IDR 15,028 (see in Table 6).

Table 5. Comparison of the value of environmental services CO_2 absorption

Types of forests	**CO_2 environmental services (IDR/ha)**	**Total CO_2 environmental services (IDR/ha)**
Mangrove forests	22,087,943.57 ± 402,403.36[a]	2,827,256,777.42
Lambusango forest	74,503,836.01 ± 2741610.20[b]	11,846,109,926.07
Pine forest	16,401,031.33 ± 410,754.77[a]	1,968,123,759

Information: on a line, the same letter above the number indicates that the value is not significantly different based on the Games Howel test with a significant rate of 5% (n = 406; average ± standard error).

Environmental Factor Measurement

Environmental factors were measured at the study site, which included air temperature, air humidity, soil pH, and light intensity. The measurement of environmental factors was conducted on every tree within the study site. The results of this measurement showed varying outcomes for different forest types, such as mangrove forests, lambusango forests, and pine forests. The measured environmental factors for mangrove forests, lambusango forests, and pine forests (Table 6).

Table 6. Comparison of measurements of environmental factors in each forest

Types of forests	Air temperature (°C)	Air humidity (%)	Soil pH	Light intensity (Lux)
Mangrove forests	28.99 ± 0.03[a]	87.58 ± 0.20[a]	6.02 ± 0.04[a]	3,046.42 ± 94.98[a]
Lambusango forest	25.74 ± 0.02[b]	94.67 ± 0.15[b]	6.94 ± 0.01[b]	391.3 ± 10.24[b]
Pine forest	28.61 ± 0.01[a]	89.83 ± 0.15[c]	6.93 ± 0.02[a]	3,650.35 ± 85.22[c]

Information: on a line, the same letter above the number indicates that the value is not significantly different based on the Kruskal Wallis test with a significant rate of 5% (n = 406) (average ± standard error)

DISCUSSION

Biomass Potential, Carbon Stocks, Carbon Sequestration, and Oxygen Production

Based on the results of the study, it was found that three types of forests have different amounts of biomass: lambusango forests, mangrove forests, and pine forests. Lambusango forests have the greatest biomass value compared to mangrove forests and pine forests (Table 4). Lambusango forests have a greater biomass value due to many individual trees, heterogeneous species, larger tree diameter sizes, and older age. The value of biomass is highly dependent on the diameter of the tree; the larger the diameter of the tree, the greater the value of biomass. There are two parameters used in calculating plant biomass, namely the diameter of the tree trunk and the density of wood. As a result of tree diameter calculations, lambusango forests have an average tree diameter that is larger than mangrove forests and pine forests (Table 3). Tree trunk diameter affects the increase in biomass by 97,1%, while wood density only contributes 1.9% to the increase in the amount of plant biomass(Effendi, 2012; Suwardi *et al.*, 2013). According to (Stephenson *et al.*, 2014), in their research on 403 species of trees on six continents, they explained that the speed of growth of tree species biomass is directly proportional to the size of the tree diameter.

The diameter of a tree plays a significant role in determining its biomass value, which in turn affects the amount of carbon stored in forests. The relationship between the diameter and biomass of trees has a direct impact on the rate of carbon absorption and photosynthesis. Trees with greater biomass produced during the photosynthesis process have a greater impact on plant growth, including primary and secondary growth (Munir, 2017). Lambusango Forest has a large amount of tree vegetation due to its protected status. The age of the vegetation has a major effect on the diameter of the trees. As the stand gets older, the diameter of the trees increases (Munir, 2017).

Lambusango Forest is a primary or terrestrial forest that has not been damaged or exploited by human activities. The forest is protected by the government and has been declared an animal clan sanctuary under the Decree of the Minister of Agriculture No. 639/Kpts/9/Um/1982 dated September 1, 1982. Research has shown that the lambusango forest has the highest value in terms of biomass potential, carbon stocks, carbon sequestration, and oxygen production compared to other forests such as mangroves and pine forests. The reason for this is that the lambusango forest is free from any threat of destruction. Primary terrestrial forests have a larger carbon stock compared to other forests because of their high species diversity, the density of understory plants, and the amount of litter on the soil surface. The diversity of tree species in forest vegetation can increase aboveground biomass.

The analysis of lambusango forests, mangrove forests, and pine forests shows that there is a direct contrast between the value of biomass and carbon stocks, carbon sequestration, oxygen production, and the value of environmental services and uptake. The greater the plant biomass, the greater the carbon stock, carbon absorption, oxygen production, and the value of environmental services. Meanwhile, mangrove forests have lower biomass, carbon stock, and carbon sequestration values than lambusango forests because they are categorized as secondary forests. It is worth noting that the study only measured biomass above the ground surface, such as the diameter of the tree trunk, and did not measure biomass below the ground surface. As a result, the biomass value of mangrove forests was lower than that of lambusango forests. According to Howard *et al.* (2014), mangrove forests store 50%–90% of total carbon stocks below the land surface. Mangrove sediments have a higher ability to store carbon than carbon stored in mangrove tree fields (Hickmah *et al.*, 2021). Additionally, mangrove forests are located near community settlements, making them vulnerable to disturbance to their stands. According to Hakim *et al.* (2021), secondary forests often disrupt their stands, which can cause low or reduced carbon stocks.

Mangrove forests have a high storage rate of carbon stocks due to their slow rate of organic matter decomposition in the soil. According to Andrianto *et al.* (2015), the rate of decomposition in mangrove forests is slower than in tropical rainforests because mangrove forest are always flooded by seawater. The rate of decomposition is faster in acidic regions than in alkaline regions. The process of decomposition is affected by temperature, and a higher soil temperature can speed up the mineralization process by stimulating microflora metabolism. The litter decomposes faster at higher temperatures (Liu *et al.*, 2005). Mangrove forests are always flooded by seawater, which causes the soil to be wet, leading to a slower decomposition process. The slow rate of decomposition leads to the accumulation of organic matter and nutrient stocks in the soil, allowing carbon to be stored in the environment for a longer period (Andrianto *et al.*, 2015).

The rate at which litter degrades is affected by the type of plant material present. Lignin is one such material that impacts the rate of decomposition. Mangrove leaf litter is rich in lignin, with a content of 19–33%, which makes it difficult for soil microorganisms to break down (Yanti *et al.*, 2021). Conversely, leaf litter from pine forests and lambusango has a low lignin content, typically between 3,6% and 3,65%, and is therefore quickly decomposed by soil microorganisms. The amount of lignin in leaf litter determines the time it takes for soil microorganisms to decompose in a forest area with higher lignin contents, resulting in longer degradation times (Devianti & Tjahjanigrum, 2017; Saptiningsih & Haryanti, 2015).

Maintaining oxygen balance on the earth's surface is crucial, and forest vegetation plays a vital role in producing oxygen. Additionally, forest vegetation can help improve the air quality in urban environments and maintain hygienic standards (Vasylyshyn *et al.*, 2023). According to a study, lambusango forests produce more oxygen than both mangrove and pine forests. The amount of oxygen produced by a forest is directly proportional to the plant biomass, and the faster the process of photosynthesis, the greater the amount of oxygen produced. Tropical forests are responsible for approximately 34% of global oxygen production (Keerthika & Chavan, 2022).

Economic Valuation of Forest Carbon in Buton District

The ability of forests to absorb carbon dioxide from the atmosphere has led to the development of a carbon market where the value of environmental services can be converted into carbon selling value. To determine the compensation for forests, the price of carbon is calculated based on the valuation value of forest areas (Fauzi & Anwar Siregar, 2019). According to the analysis of sequestration, the economic valuation of lambusango forests is the highest compared to mangrove forests and pine forests (Table 5). This value is directly proportional to the biomass and carbon stocks stored in the forest. The economic potential of the forest in absorbing carbon is enormous, and it can play a significant role in reducing carbon emissions. The economic value of lambusango forest carbon can reach around 7 trillion rupiah, mangrove forests around 1 trillion, and pine forests around 900 billion rupiah.

The economic value of carbon is calculated using the Clean Development Mechanism (CDM), which is a policy mechanism for limiting and reducing greenhouse gas emissions in the Kyoto Protocol agreement. Lamusango Forest is a wildlife sanctuary located in the Buton Islands region, and it has the potential to become a carbon storehouse due to its well-maintained vegetation. According to Purnawan *et al.* (2020), protected forests play a crucial role in mitigating climate change through carbon credit mechanisms, which provide the basis for the protection and restoration of damaged forest areas in sustainable forest management. In line with the efforts to reduce carbon emissions, President Joko Widodo signed Presidential Decree No. 98 of 2021, which regulates the economic value of carbon and carbon markets listed in the Nationally Determined Contribution (NDC) document for climate change control (KLHK, 2021). Carbon emitters can compensate for environmental damage caused by carbon dioxide emissions by paying for the economic value of forest carbon (Ikhsan, 2021). Estimating the economic price of carbon is essential to make it easier to pay for carbon prices, which in turn provides an opportunity for protected forest areas, such as the lambusango forest.

The Effect of Environmental Factors on Increasing the Carbon Stock

After observing environmental factors, it was found that the light intensity in the lambusango forest is significantly lower than that of mangrove and pine forests. This is due to the dense canopy cover, which limits the amount of light entering the forest. The

p-ISSN: 2442-9481
e-ISSN: 2685-7332

low light intensity affects the process of photosynthesis in understory plants, resulting in slower growth and development, particularly in plants with dominant canopies. Yusra & Sulistiyowati (2020), found that light intensity plays a crucial role in plant biomass formation through the process of photosynthesis. Low light intensity can negatively impact photosynthesis, leading to lower carbon stocks. Ijazah & Sancayaningsih (2018), also noted that light intensity is closely linked to forest vegetation productivity and dynamics. Higher light intensity leads to increased rates of photosynthesis and respiration, resulting in faster plant biomass formation.

The pH value of the soil indirectly affects the carbon stock in the form of pH concentration, which will affect the availability of nutrients in the soil so that it will have an impact on plant physiological processes (Lubis & Rusdiana, 2012). The results of soil pH measurements in lambusango forests, mangrove forests, and pine forests ranged from 6.5-7, with an average pH of 6.94 ± 0.01, 6.02 ± 0.04, and 6.93 ± 0.02. According to Uthbah *et al.* (2017), Optimum stands to undergo growth and development at a pH ranging from 6.5 to 7.5. From these results, the pH value at the study site tends to be neutral and very good for the growth of forest vegetation. Neutral pH values (moderate) indicate an increase in carbon storage in the soil, while low or high pH causes a reduction in soil stocks and nitrogen (Gebeyehu *et al.*, 2019).

Based on the measurements of environmental factors, air temperature, and humidity, it is evident that the lambusango forest has a low air temperature of 25.74 ± 0.02 °C and a high humidity of 94.67 ± 0.15%. This is caused by the limited light intensity that enters the forest floor because of the tree canopy. The closed canopy of the lambusango forest results in low air temperatures and high humidity. According to Wijayanto & Nurunnajah (2012), the canopy closure of vegetation has a significant impact on the high and low temperatures and humidity of the air. Compared to mangrove and pine forests, lambusango forest has a lower average air temperature. The air temperature at the research location is still favorable for forest vegetation growth since it ranges between 25 and 30 °C. According to Ruchaemi (2013), the optimal temperature for vegetation is between 25 and 30 °C to carry out the photosynthesis process. High and low air temperatures can impede vegetation growth and lead to death (Fajri & Saridan, 2012). Mangrove and pine forests, on the other hand, have high air temperatures and low humidity due to the lack of canopy cover over the forest floor. According to Anggraeni *et al.* (2021), high and low air humidity can adversely affect forest carbon stocks by reducing the absorption of nutrients in plants.

Forest Management as an Effort to Mitigate Climate Change

Forests have the potential to sequester carbon, but this depends on factors such as the extent of disturbance, management practices, and the size of the trees. Estimating ecosystem productivity, carbon and oxygen cycles, and carbon budgets relies heavily on the value of biomass and carbon stocks (Gebeyehu *et al.*, 2019). To combat climate change, the Regional Government of Southeast Sulawesi Province issued Regional Regulation No. 11 of 2019, which focuses on climate change adaptation. This regulation provides a strong foundation for climate change adaptation by promoting the development of forest areas for climate change mitigation. One effective strategy is to replant degraded or damaged forests to increase forest carbon sequestration. Additionally, local communities can contribute to increasing carbon budgets by protecting, conserving, and sustainably managing forests.

Sustainable forest management aims to maintain biodiversity, productivity, and regeneration capabilities. It is important to improve the quality of forests for the benefit of ecological, social, and economic aspects for future generations. While increasing carbon sequestration or avoiding emissions from wrong forest management practices are important, forest management takes precedence over these goals. Forest management can greatly affect carbon sequestration and sources. Approaches that can be implemented to increase carbon sequestration include reducing the burning of tree-cutting waste and avoiding emissions from the natural cycle of forest ecosystems (Riahi *et al*., 2022).

Communities residing around forest areas have been largely overlooked for their potential role in climate change mitigation and adaptation, particularly in combatting degradation, deforestation, carbon stock ownership, and efforts to increase carbon stocks. Climate change mitigation has thus far mainly been discussed at a higher level, among government officials, policymakers, and academics. However, farming communities or those living around forests lack knowledge and understanding of climate change, its environmental impacts, and how to cope with it. To ensure optimal climate change mitigation, policies, and strategies must be implemented at the community level, as they are the owners of forest areas, and the preservation of forest vegetation remains the primary carbon stored on the earth's surface.

CONCLUSION

Biomass potential in mangrove forests, lambusango forests, and pine forests, respectively, is 16,108.27 tons/ha, 84,693.72 tons/ha, and 4,273.98 tons/ha; carbon stocks are 8,054.13 tons/ha, 42,346.86 tons/ha, and 7,136.99 tons/ha; carbon sequestration is 29,558.67 tons/ha, 155,412.98 tons/ha, and 26,192.75 tons/ha; oxygen production was 21,504.54 tons/ha, 113,066.12 tons/ha, and 19,055.76 tons/ha; and the value of CO_2 absorption environmental services, namely 2,221,038,614.63 IDR/ha, 11,677,731,637.57 IDR/ha, and 1,968,123,759 IDR/ha.

REFERENCES

Andrianto, F., Bintoro, A., & Yowono, S. B. (2015). Produksi dan Laju Dekomposisi Serasah Mangrove (Rhizophora sp.) di Desa Durian dan Desa Batu Menyan Kecamatan Padang Cermin Kabupaten Pesawaran. *Jurnal Sylva Lestari*, *3*(1), 9–20. https://jurnal.fp.unila.ac.id/index.php/JHT/article/view/620/566

Anggraeni, P. D., Mahmudati, N., & Hudha, A. M. (2021). Analisis Serapan Karbon Dioksida pada Hutan Lindung Gunung Banyak Kota Batu. *Prosiding Seminar Nasional VI*, 275–282. http://research-report.umm.ac.id/index.php/psnpb/article/view/4762

BPS. (2023). *Angka Deforestasi Netto Indonesia di Dalam dan di Luar Kawasan Hutan Tahun*

p-ISSN: 2442-9481
e-ISSN: 2685-7332

2013-2021 (Ha/Th).

Brandon, K. (2014). Ecosystem Services from Tropical Forests: Review of Current Science Ecosystem Services. In *CGD Climate and Forest Paper*. http://ssrn.com/abstract=2622749copyavailableat:https://ssrn.com/abstract=2622749Electroniccopyavailableat:http://ssrn.com/abstract=2622749http://www.cgdev.org/

. Brown, S. (1997). *Estimating Biomass and Biomass Change of Tropical Forest: A Primer*. Rome, Italy: FAO Forestry Paper.

Devianti, O. K. A., & Tjahjanigrum, I. T. D. (2017). Studi Laju Dekomposisi Serasah pada Hutan Pinus di Kawasan Wisata Taman Safari Indonesia II Jawa Timur. *Jurnal Sains Dan Seni ITS*, *6*(2), 87–91.

Effendi, K. (2012). Potensi Karbon Tersimpan dan Penyerapan Karbon Dioksida Hutan Tanaman Eucalyptus sp. In *Jurnal Pembangunan Wilayah & Kota* (Vol. 1, Issue 3). Universitas Sumatera Utara.

Fajri, M., & Saridan, A. (2012). Ecology study on Parashorea malaanonan (Blco) Merr. in Labanan Forest Research Berau Regency, East Kalimantan. *Jurnal Penelitian Dipterokarpa*, *6*(2), 141–154.

Fathoni, A., Rohman, F., & Sulisetijono, S. (2021). Karakter Pohon Area Sekitar Sumber Mata Air di Malang Raya, Jawa Timur. *Biotropika: Journal of Tropical Biology*, *9*(1), 69–79. https://doi.org/10.21776/ub.biotropika.2021.009.01.08

Fauzi, R., & Anwar Siregar, C. (2019). Estimasi Harga Konservasi Karbon pada Kegiatan A/R CDM di Hutan Lindung Sekaroh, Lombok Timur. *Jurnal Penelitian Sosial Dan Ekonomi Kehutanan*, *16*(1), 1–12. https://doi.org/10.20886/jpsek.2019.16.1.1-12

Gebeyehu, G., Soromessa, T., Bekele, T., & Teketay, D. (2019). Carbon Stocks and Factors Affecting their Storage in Dry Afromontane Forests of Awi Zone, Northwestern Ethiopia. *Journal of Ecology and Environment*, *43*(1), 1–18. https://doi.org/10.1186/s41610-019-0105-8

Hairiah, K., Ekadinata, A., Sari, R. R., & Rahayu, S. (2011). *Pengukuran Cadangan Karbon dari Tingkat Lahan Kebentang Alam Edisi ke 2.* World Agroforestry Centre.

Hakim, R., Suyanto, & Asyari, M. (2021). Estimasi Cadangan Karbon Atas Permukaan Tanah Di Kawasan Hutan Lindung Liang Anggang Kota Banjarbaru Kalimantan Selatan. *Jurnal Sylva Scienteae*, *4*(5), 793–802. https://doi.org/10.20527/jss.v4i5.4201

Heriyanto, N. M., & Subiandono, E. (2012). Komposisi dan Struktur Tegakan, Biomassa dan Potensi Karbon Hutan Mangrove di Taman Nasional Alas Purwo. *Jurnal Penelitian Hutan Dan Konservasi Alam*, *9*(1), 23–32. https://doi.org/10.20886/jphka.2008.5.3.239-249

Hickmah, N., Maslukah, L., Wulandari, S. Y., Sugianto, D. N., & Wirasatriya, A. (2021). Kajian Stok Karbon Organik dalam Sedimen di Area Vegetasi Mangrove

Karimunjawa. *Indonesian Journal of Oceanography*, *3*(4), 419–426. https://doi.org/10.14710/ijoce.v3i4.12494

Higgins, P. A. T., & Harte, J. (2012). Carbon Cycle Uncertainty Increases Climate Change Risks and Mitigation Challenges. *Journal of Climate*, *25*(21), 7660–7668. https://doi.org/10.1175/JCLI-D-12-00089.1

Howard, J., Hoyt, S., Isensee, K., Pidgeon, E., Telszewski, M., Fourqurean, J., Johnson, B., Kauffman, J. boone, Kennedy, H., Lovelock, C., Megonigal, J. P., Rahman, A. (Faiz), Saintilan, N., & Simard, M. (2014). *Coastal Blue Carbon : Methods for Assessing Carbon Stocks and Emmissions Factors in Mangrove, Tidal Salt Marshes and Seagrass Meadows*. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature.

Ijazah, M., & Sancayaningsih, R. P. (2018). Penyimpanan Karbon pada Tegakan Pinus merkusii dan Acacia auriculiformis di Hutan Lindung Mangunan Dlingo, Bantul, Daerah Istimewa Yogyakarta. *Jurnal Biologi, Sains, Lingkungan Dan Pembelajarannya*, 830–837.

Ikhsan, M. Al. (2021). *Nilai Ekonomi Karbon (NEK) dalam Membantu Pendanaan Perubahan Iklim dan Pengurangan Gas Efek Rumah Kaca*. 1–6. https://doi.org/10.13140/RG.2.2.20280.88323

Iksan, M., Al Zarliani, W. O. D., Nare, L., Hafidhawati, S., & Baena, F. (2019). Biomass and Carbon Uptake of Mangrove Forests Pohorua Village, Muna Regency. *International Journal of Applied Biology*, *3*(2), 57–64.

Irawan, U. ., & Purwanto, E. (2020). *Panduan Pengukuran dan Pendugaan Cadangan Karbon pada Ekosistem Hutan Gambut dan Mineral, Studi Kasus di Hutan Rawa Gambut Pematang Gadung dan Hutan Lindung Sungai Lesan, Kalimantan*. Yayasan Tropenbos Indonesia.

Keenan, R. J., Reams, G. A., Achard, F., de Freitas, J. V., Grainger, A., & Lindquist, E. (2015). Dynamics of Global Forest Area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management*, *352*, 9–20. https://doi.org/10.1016/j.foreco.2015.06.014

Keerthika, A., & Chavan, S. B. (2022). Oxygen Production Potential of Trees in India. *Current Science*, *122*(7), 850–853. https://doi.org/10.18520/cs/v122/i7/850-853

Latifah, S., & Sulistiyono, N. (2013). Carbon Sequestration Potential in Aboveground Biomass of Hybrid Eucalyptus Plantation Forest. *Jurnal Manajemen Hutan Tropika*, *19*(1), 54–62. https://doi.org/10.7226/jtfm.19.1.54

Liang, S., Peng, S., & Chen, Y. (2019). Carbon Cycles of Forest Ecosystems in a Typical Climate Transition Zone Under Future Climate Change: A Case Study of Shaanxi Province, China. *Forests*, *10*(12). https://doi.org/10.3390/F10121150

Liu, Q., Peng, S. L., Bi, H., Zang, H. Y., & Li, Z. A. (2005). Decomposition of Leaf Litter in Tropical and Subtropical Forests of Southern China. *Journal of Tropical Forest Science*, *17*(4), 543–556.

p-ISSN: 2442-9481
e-ISSN: 2685-7332

Lubis, S., & Rusdiana, O. (2012). Pendugaan Korelasi antara Karakteristik Tanah terhadap Cadangan Karbon (Carbon Stock) pada Hutan Sekunder. *Jurnal Silvikultur Tropika*, *03*(01), 14–21.

Munir, M. (2017). *Estimasi Biomassa, Stok Karbon, dan Sekuestrasi Karbon dari Berbagai Tipe Habitat Terestrial di Gresik, Jawa Timur Secara Non-Destructive dengan Persamaan Allometrik*. Institut Teknologi Sepuluh Nopember.

Nowak, D. J., Hoehn, R., & Crane, D. E. (2019). *Oxygen Production by Urban Trees in the United States Oxygen Production by Urban Trees in the United States*. *May 2007*. https://doi.org/10.48044/jauf.2007.026

Purnawan, E. I., Jemi, R., Triadi, A., & Perkasa, P. (2020). Potensi Karbon dan Jasa Lingkungan: Studi Hutan Lindung Gunung Bondang Kabupaten Murung Raya, Kalimantan Tengah, Indonesia. *Jurnal Daun*, *7*(2), 100–116. https://doi.org/10.33084/daun.v7i2.2006

Riahi, K., Schaeffer, R., Arango, A., Calvin, K., Guivarch, C., Hasegawa, T., Jiang, K., Kriegler, E., Matthews, R., Peters, G. P., Rao, A., Robertson, S., Sebbit, A. M., Steinberger, J., Tavoni, M., & Vuuren, D. P. van. (2022). Mitigation Pathways Compatible with Long-Term Goals. In *Climate change*. IPCC. https://doi.org/10.1017/9781009157926.005

Rochmayanto, Y., Wibowo, A., Lugina, M., Butarbutar, T., Mulyadin, R., & Wicaksono, D. (2014). *Cadangan Karbon pada Berbagai Tipe Hutan dan Jenis Tanaman Di Indonesia (Seri 2)* (Vol. 53, Issue 9). Kanisius. https://doi.org/10.1017/CBO9781107415324.004

Saptiningsih, E., & Haryanti, S. (2015). Kandungan Selulosa dan Lignin Berbagai Sumber Bahan Organik setelah Dekomposisi pada Tanah Latosol. *Buletin Anatomi Dan Fisologi*, *23*(2), 34–42.

Setiawan, B. (2022). Gas Rumah Kaca. *Buletin Gas Rumah Kaca*, *2*(3), 27–28.

Siregar, Y. F., Wasis, B., & Hilwan, I. (2018). Carbon Stock Potential of Nabundong Forest KPH Region VI North Sumatera. *Jurnal Ilmu Pertanian Indonesia*, *23*(1), 67–73. https://doi.org/10.18343/jipi.23.1.67

Stephenson, N. L., Das, A. J., Condit, R., Russo, S. E., Baker, P. J., Beckman, N. G., Coomes, D. A., Lines, E. R., Morris, W. K., Rüger, N., Álvarez, E., Blundo, C., Bunyavejchewin, S., Chuyong, G., Davies, S. J., Duque, Á., Ewango, C. N., Flores, O., Franklin, J. F., … Zavala, M. A. (2014). Rate of Tree Carbon Accumulation Increases Continuously with Tree Size. *Nature*, *507*(7490), 90–93. https://doi.org/10.1038/nature12914

Sutopo, A., Arthati, D. F., & Rahmi, U. A. (2014). Kajian Indikator Sustainable Development Goals (SDGs). In *Badan Pusat Statistik*.

Suwardi, A. B., Mukhtar, E., & Syamsuardi. (2013). Komposisi Jenis dan Cadangan Karbon di Hutan Tropis Dataran Rendah, Ulu Gandut, Sumatera Barat. *Berita Biologi*, *12*(2), 169–176.

p-ISSN: 2442-9481
e-ISSN: 2685-7332

Tambunan, P. (2009). Penyimpanan Karbon dalam Ekosistim Hutan sebagai Dasar Perhitungan Karbon Bumi. *Jurnal Analisis Kebijakan Hutan*, *6*(3), 207–219.

Tuah, N., Sulaeman, R., & Yoza, D. (2017). Penghitungan Biomassa dan Karbon di Atas Permukaan Tanah di Hutan Larangan Adat Rumbio Kabupaten Kampar. *Jurnal Online Mahasiswa Fakultas Pertanian Universitas Riau*, *4*(1), 1–10.

Uthbah, Z., Sudiana, E., & Yani, E. (2017). Analisis Biomassa dan Cadangan Karbon pada Berbagai Umur Tegakan Damar (Agathis dammara (Lamb.) Rich.) DI KPH Banyumas Timur. *Scripta Biologica*, *4*(2), 119. https://doi.org/10.20884/1.sb.2017.4.2.404

Utina, R. (2009). Pemanasan Global : Dampak dan Upaya Meminimalisasinya. *Saintek UNG*, *3*(3), 1–11. https://doi.org/10.1016/B978-008046620-0/50035-9

asylyshyn, R., Lakyda, I., Melnyk, O., Lakyda, M., Soshenskyi, O., & Pinchuk, A. (2023). Oxygen Productivity of Urban Forests of Kyiv City as a Constituent of its Sustainable Development. *IOP Conference Series: Earth and Environmental Science*, *1126*(1). https://doi.org/10.1088/1755-1315/1126/1/012012

Wijayanto, N., & Nurunnajah. (2012). Intensitas Cahaya, Suhu, Kelembaban dan Perakaran Lateral Mahoni (Swietenia Macrophylla King.) di Rph Babakan Madang, BKPH Bogor, KPH Bogor. *Jurnal Silvikultur Tropika*, *3*(1), 8–13.

Yanti, G., Jamarun, N., & Elihasridas, E. (2021). Pengaruh Perebusan Daun Mangrove (Avicennia marina) dengan Air Abu Sekam terhadap Kecernaan Fraksi Serat (NDF, ADF, Selulosa, dan Hemiselulosa) Secara In-Vitro. *Jurnal Peternakan Indonesia*, *23*(2), 168. https://doi.org/10.25077/jpi.23.2.168-173.2021

Yusra, Y. Y., & Sulistiyowati, H. (2020). Estimasi Stok Karbon Ekosistem Mangrove Pasir Putih Pulau Bawean Desa Sukaoneng. *Bioma : Jurnal Biologi Dan Pembelajaran Biologi*, *5*(2), 112–120. https://doi.org/10.32528/bioma.v5i2.4010

Zianis, D. (2008). Predicting mean aboveground forest biomass and its associated variance. *Predicting Mean Aboveground Forest Biomass and Its Associated Variance*, *256*(6), 1400–1407. https://doi.org/10.1016/j.foreco.2008.07.002

How To Cite This Article, with *APA style* :

Nare L., Rohman, F., & Novianti, N. (2024). Analysis of Biomass Potential, Carbon Stock, Carbon Sequestration, Oxygen Production, and Value of Environmental Services CO_2 Uptake in Three Types of Forests in Buton District, Southeast Sulawesi Province, Indonesia. *Jurnal Pembelajaran dan Biologi Nukleus*, 10(1), 11-25. https://doi.org/10.36987/jpbn.v10i1.5076

Conflict of interest : The authors declare that they have no conflicts of interest.

Author contributions : All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was submited by [**La Nare**]. All authors contributed on previous version and revisions process of the manuscript. All authors read and approved the final manuscript.