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Climate change control potential of mangrove ecosystems in Rawa Aopa Watumohai National Park, Tinanggea District

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ABSTRACT

The purpose of this study was to determine the estimation of biomass, carbon stocks, oxygen production and the value of environmental services from mangrove tree stands in Rawa Aopa Watumohai National Park, Tinanggea District in helping the potential to control climate change. Biomass measurements were carried out by making 50×50 m plots of 15 plots divided into three different sampling locations. This tree stand calculation uses the allometric equation of mangrove tree species found in the measurement. The calculation of carbon stock was done by multiplying the biomass against the conversion rate of 0.47 (47%) while the estimation of carbon dioxide uptake was multiplied by the biomass value with a conversion rate of 1.4667 obtained from the photosynthesis equation. The results of this study indicate that the biomass content of mangrove tree stands in Rawa Aopa Watumohai National Park, Tinanggea District is 923.81 tons/hectare; carbon stock in mangrove stands is 434.19 tons/hectare; oxygen production is 95.91 tons/hectare; and carbon dioxide uptake in mangrove stands is 204.07 tons/hectare or 26.42 tons/hectare/year. Carbon dioxide environmental services are worth USD 34.37/hectare/year.

Keywords: allometrics, climate change control, carbon uptake, biomass, carbon reserves.

INTRODUCTION

Mangrove forests worldwide sequester 4.19 billion tons of carbon (Hamilton and Friess, 2018). Through the process of photosynthesis and deposition of organic matter in the soil, mangrove forests have the ability to capture and store carbon dioxide from the atmosphere (Alongi, 2016, 2022). In addition, mangrove forests have the capacity to store carbon dioxide for centuries in the form of biomass and soil (Hamilton and Friess, 2018). Restoration and protection of mangrove forests can help reduce carbon dioxide emissions (Griscom et al., 2020; Vanderklift et al., 2019). The gross primary production (GPP) of mangrove forests is up to five times greater than that of other ecosystems, making them the most productive coastal wetlands for supporting and storing "blue carbon". Mangroves are the only blue carbon forests and occupy only 1% of the world's coastal area, responsible for storing up to 15% of organic carbon (C org) in sediments and 1% of forest mass worldwide (Duarte et al., 2013; Kandasamy et al., 2021). Mangrove forests have the capacity to store up to four times more carbon/hectare than tropical rainforests (Yu et al., 2023). Based on MoEF data, Tinanggea District covers 4,239.75 hectares and has decreased to 3,709.53 in 2016–2021, so it has degraded 530.22 hectares. To date, no further research has been conducted in the area. Christy et al. (2019) concluded that sustainable management will emerge from the optimal, environmentally responsible and sustainable use of resources. Therefore, preserving mangrove forests and restoring damaged mangrove forests is important to maintain the balance of carbon in the atmosphere (Choudhary et al., 2024; Jennerjahn, 2020; Rossler et al., 2022).

Carbon reserves stored in mangrove forests, which can have a significant impact on environmental conservation and climate change mitigation (Chatting et al., 2020). From some previous literature, mangroves have the potential to produce many direct and indirect benefits to society, especially their potential to help combat climate change by reducing greenhouse gas emissions Johari and Sukuryadi (2023); Tang et al. (2018); Zhang et al. (2017) with an economic valuation value of ± USD 8,239.39/hectare/year and research Sribianti et al. (2022) resulting in the value of environmental services of total CO_2 absorption of forest stands in Abdul Latief Forest Park is IDR 621,627,835/year. Previous research suggests that there is a lack in the literature on establishing policy strategies that are compatible with the sustainable management of mangroves. Overuse and unsustainable management have the potential to damage mangrove ecosystems (Romañach et al., 2018). The destruction of mangrove ecosystems can threaten the livelihoods of coastal organisms and eliminate the potential to address climate change issues. Our aim is to address the gaps in previous research in estimating the biomass, carbon stocks, O_2 production and environmental service value of mangrove tree stands in Rawa Aopa Watumohai National Park, Tinanggea Sub-district in helping to potentially control climate change.

MATERIALS AND METHODOLOGY

Study area

This study focused on three different locations within the mangrove area of Rawa Aopa Watumohai National Park (Figure 1): downstream of the estuary (station 1), mid-estuary (station 2), and pond (station 3). The environmental characteristics of each station varied greatly. Fishermen and seaweed farmers were located in the lower reaches of the estuary, while fishers were located in the middle reaches of the estuary. In addition, some parts of the estuary were adjacent to community fishponds. Each mangrove species observed at each station was used as research data.

Mangrove sampling

Mangrove stands in the Rawa Aopa Watumohai National Park area in Tinanggea District were the research material. This study used purposive sample method and was based on the criteria of the condition of the study area. Carbon content was measured using a non-destructive sampling method with the variable measured being the biomass of mangrove species. Square transect plots were made for sampling in the field using a roller meter and 50 × 50 of rope to form a square. After that, the stem diameter (dbh) was measured at a height of 1.3 m with a tape measure and then entered in the tally sheet.

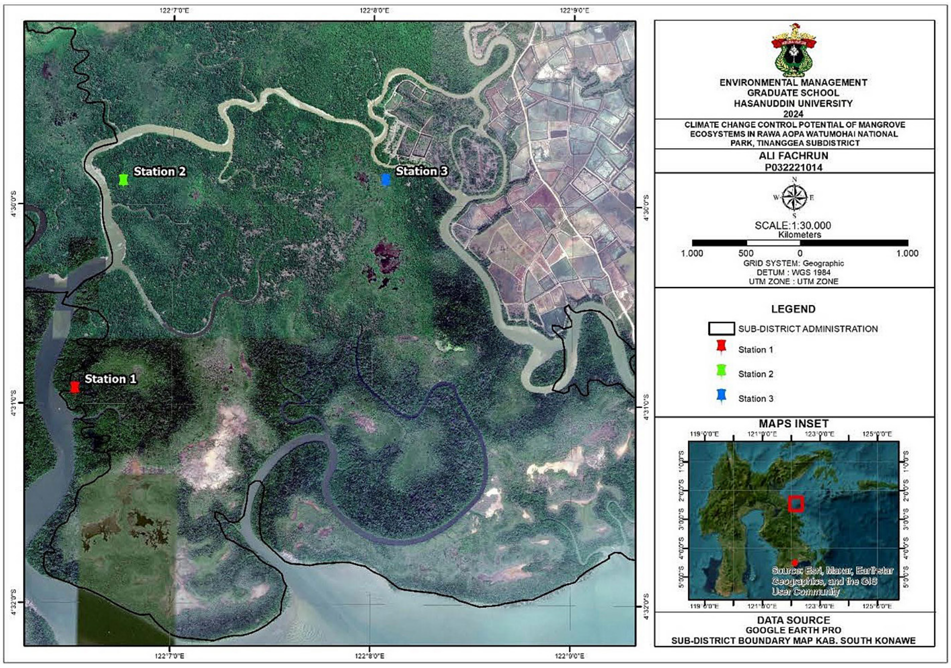

Figure 1. Study area: Red pin = station 1, green pin = station 2, and blue pin = station 3

Data analysis

Mangrove biomass

An allometric equation approach was used in this study to calculate mangrove biomass. A study of the relationship between the size and proliferation of organisms in a particular area is known as allometrics (Sutaryo, 2009). The following biomass allometric equation is shown in Table 1.

Mangrove carbon

The SNI (2011) method was used to calculate carbon stocks and reserves from the estimated standing biomass.

$$C = B \times \%\ C\ organic \tag{2}$$

where: *C* is the carbon content of biomass (kg), B is the total biomass, and C% organic is the percentage value of carbon content, equal to 0.47 (SNI, 2011).

Uptake of carbon dioxide (CO_2)

Vegetation will absorb carbon dioxide in the process of photosynthesis in plants. The amount of carbon dioxide absorption can be calculated using the formula (Baharuddin et al., 2014) as follows:

$$CO_2 = B \times 1.4667 \tag{3}$$

where: CO_2 is carbon dioxide uptake (kg), and B is biomass (kg).

Production of oxygen (O_2)

Plants will take in CO_2 during the photosynthesis process and release O_2. To determine how much oxygen (O_2) is produced, use the following formula (Daud et al., 2018)

$$O_2 = C \times 2.67 \tag{4}$$

where: O_2 is net oxygen production (kg/year), and C is net carbon stock (kg/year).

Environmental service value of carbon dioxide (CO_2) sequestration

The following formula is used to calculate the carbon dioxide sequestration value for environmental services analysis:

$$VES = SPC \times C \tag{5}$$

where: *VES* is the value of environmental services (USD/ha), *SPC* is the selling price of carbon (Forest Digest, 2024, USD 2.9/ton), and C is carbon sequestration (tons/hectare/year).

RESULTS AND DISCUSSION

Based on research conducted on forest stands in Rawa Aopa Watumohai National Park, Tinanggea District, several tree-level mangrove species were found (Table 2).

Total biomass potential

The total amount of aboveground plant life is referred to as biomass, and is quantified in kilograms of dry weight/unit area. Vegetation biomass is the sum of the biomass of living plants, both above and below ground, under a given set of conditions. Forest biomass can be used to measure the carbon sequestration capacity of forest

Table 2. Mangrove species found in the study

Mangrove name	Species name
Black mangrove	*Rhizophora mucronata*
Beropa	*Sonneratia alba*
White mangrove	*Rhizophora apiculata*
Tongke cokke	*Bruguiera gymnorrhiza*
Buli	*Xylocarpus granatum*
Api-api bulu	*Avicennia lanata*

Table 1. Mangrove biomass allometric equation

Species name	Mangrove equation	Source
Rhizophora mucronata	$B = 0.1466 \times DBH^{2.3136}$	(Dharmawan &and Samsoedin, 2012)
Sonneratia alba	$B = 0.3841 \times \rho \times D^{2.101}$ (ρ = 0.078)	(Kauffman and Donato, 2012)
Rhizophora apiculata	$B = 0.043 \times D^{2.630}$	(Amira, 2008)
Bruguiera gymnorrhiza	$B = 0.0754 \times (D)^{2.505}$	(Kauffman and Donato, 2012)
Xylocarpus granatum	$B = 0.251 \times \rho \times D^{2.46}$ (ρ = 0,528)	(Komiyama et al., 2005)
Avicennia lanata	$B = 0.1814 \times DBH^{2.2825}$	(Hasidu et al., 2022)
Ceriop tagal	$B = 0.529 \times DBH^{2.04}$	(Kangkuso et al., 2018)

Note: B is biomass (kg/m^2), D is diameter (cm), ρ is wood density (g/cm^2), and diameter at breast height (DBH) is the measurement point of the tree stand (bole) at a height of 1.3 meters.

plants, as carbon accounts for 47% of biomass (SNI, 2011). Allometric equations are used in a non-destructive way to estimate biomass.

The total biomass potential (Figure 2) was determined by the different station points, which indicated that the total biomass in station 1 was greater than that in stations 2 and 3. This was due to the larger stem diameter factor in station 1 compared to the diameter of the tree trunks in the other stations. Mandari et al. (2016), tree diameter also affects the value of biomass because the value of biomass increases with the size of the tree diameter. This finding is in accordance with the findings of the theory. This station has a biomass of 341.88 tons/hectare so it has a higher biomass. The biomass produced by each station in the study site is as follows: station 1 produced 341.88 tons/hectare, station 2 produced 296.29 tons/hectare, and station 3 produced 285.64 tons/hectare. Thus, the total biomass produced was 923.81 tons/hectare.

Potential carbon stock

The biomass approach was used to determine the biomass of vegetation in the mangrove forest area, assuming that 47% of the biomass is stored as carbon. This process is obtained from the equation of the coefficient values a and b (SNI, 2011).

Based on the different locations of the stations (Figure 3), the potential carbon stock in station 1 is higher compared to stations 2 and 3. This is because station 1 has a larger trunk diameter compared to the diameter of trees in other stations. Thus, these trees are able to store larger amounts of carbon stocks than trees with smaller diameters. Station 1 has a larger biomass content with a carbon stock of 160.68 tons/hectare. The biomass produced by each station in the study site is as follows: station 1 produced 160.68 tons/hectare, station 2 produced 139.26 tons/hectare, and station 3 produced 134.25 tons/hectare. The total carbon stock content that can be generated is 434.19 tons/hectare. This result is significant with carbon reserves in mangrove forest stands in Bedono Village, Demak, Central Java, which contain 190.257 tons/hectare (Azzahra, 2020). Meanwhile, peat forest land cover can have a total carbon stock content of 1.371 tons/hectare (Anshari et al., 2022).

Carbon dioxide (CO_2) sequestration potential

Carbon dioxide sequestration in mangrove forest stands is determined by the annual growth of vegetation biomass in the mangrove forest, which is determined by the equation of the coefficient values a and b. The biomass is then multiplied by the carbon dioxide sequestration conversion factor (1.4667), which is based on the photosynthesis equation.

Carbon dioxide uptake in mangrove forest areas in three different station locations (Figure 4), station 1 has the ability to absorb carbon dioxide 30.51 tons/hectare/year, station 2 is able to absorb 26.44 tons/hectare/year, and station 3 is able to absorb 25.49 tons/hectare/year. The mangrove forest has the capacity to absorb a total of 82.45 kilograms of carbon dioxide/hectare annually. The results of this study show that the carbon absorption capacity of Rawa Aopa Watumohai National Park exceeds the carbon absorption capacity of the Takalar Lama Village Mangrove Forest, Mappakasunggu District, Takalar Regency, which has a carbon absorption value of 30.29 tons/hectare (Daud, 2020). The diameter of trees in the mangrove forest of Rawa Aopa Watumohai National Park is generally larger than the diameter of trees

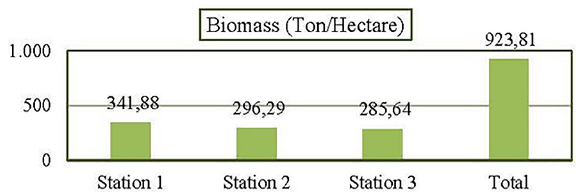

Figure 2. Total biomass potential

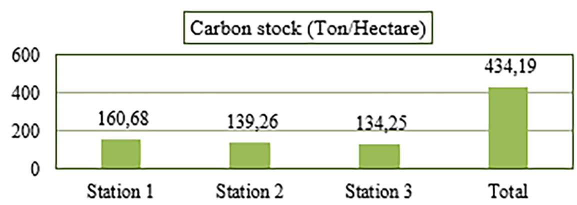

Figure 3. Potential total carbon stock in mangrove forests

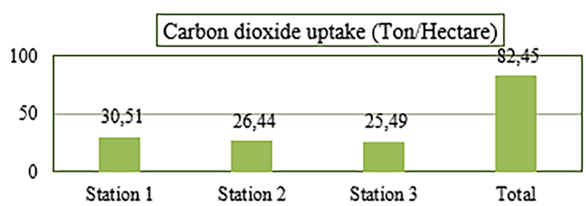

Figure 4. Total carbon dioxide uptake of mangrove forest

in the mangrove forest of Takalar Lama Village. Adinugroho et al. (2016) concluded that if the stand consists of species with high wood density and a relatively large number of individuals, then the potential biomass and carbon content of the stand will increase proportionally with the diameter of the trees that compose it. This is also very different from the results of carbon dioxide absorption in Abdul Latief Forest Park, which produces 4.75 tons/hectare annually (Sribianti et al., 2022).

Oxygen production

Trees are one of the oxygen providers on the earth's surface (Bayu et al., 2014). Trees are considered the lungs of the world because of their ability to absorb carbon dioxide and produce oxygen through the process of photosynthesis. The carbon sequestration value is multiplied by the equivalent number of carbon dioxide to oxygen to achieve oxygen production.

Oxygen production of mangroves in Rawa Aopa Watumohai National Park, Tinanggea District, was measured at three station locations (Figure 5). Station 1 has a total oxygen production value of 26.11 tons/hectare/year, Station 2 has a value of 22.63 tons/hectare/year, and Station 3 has a value of 21.81 tons/hectare/year. The Mangrove Area of Rawa Aopa Watumohai National Park in Tinanggea District produces a total annual oxygen production of 70.54 tons/hectare/year. Oxygen production in this forest stand is still higher than the oxygen production produced by paring bamboo forest stands in Tompobulu District, Maros Regency, which is around 30.73 tons/hectare/year (Daud et al., 2018).

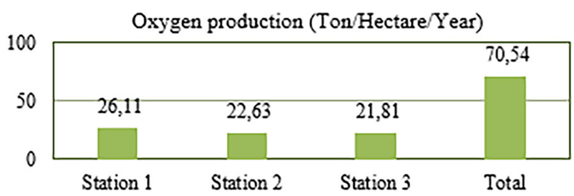

Figure 5. Total oxygen production yield

Biomass, carbon stock, CO_2 sequestration

Average CO_2 sequestration and average oxygen production/hectare in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District was determined using biomass data and average carbon stocks. Based on the calculation results of Table 3, the average CO_2 absorption in mangrove forest areas at station 1, station 2, and station 3 is 18.21 tons/hectare, 13.82 tons/hectare, and 11.12 tons/hectare, respectively. The total amount of CO_2 absorption for all station locations is 43.15 tons/hectare. Meanwhile, the average oxygen production/hectare at station 1, station 2, and station 3 were 15.58 tons/hectare, 11.82 tons/hectare, and 9.52 tons/hectare, respectively. The total oxygen production/hectare for all station locations was 36.92 tons/hectare.

Biomass in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District (Table 4), at station 1, station 2, and station 3 were 341.88 tons/hectare, 296.29 tons/hectare, and

Table 3. Potential biomass, carbon stocks, CO_2 uptake and average oxygen production in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District

No	Station location	Average biomass (tons/hectare)	Average carbon stock (tons/hectare)	Average CO_2 uptake (tons/hectare)	Average oxygen production (tons/hectare)
1	Station 1	12.42	5.84	18.21	15.58
2	Station 2	9.42	4.43	13.82	11.82
3	Station 3	7.58	3.56	11.12	9.52
Total		29.42	13.83	43.15	36.92

Table 4. Potential biomass, carbon stocks, CO_2 uptake and total oxygen production in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District

No	Station location	Total biomass (tons/hectare)	Total carbon reserve (tons/hectare)	Total CO_2 uptake (tons/hectare)	Total oxygen production (tons/hectare)
1	Station 1	341.88	160.68	501.43	1.338.83
2	Station 2	296.29	139.26	434.57	1.160.29
3	Station 3	285.64	134.25	418.95	1.118.59
Total		923.81	434.19	1.354.95	3.617.71

285.64 tons/hectare, respectively. With a total area of 3006 hectares, the area has a biomass potential of 923.81 tons/hectare. This result is greater than the biomass in mangroves in Tallo River, Makassar, which is 252.44 tons/hectare (Rahman et al., 2017). Carbon reserves at stations 1, 2, and 3 in the Rawan Aopa Watumohai National Park Mangrove Area, Tinanggea District, were 160.68 tons/hectare, 139.26 tons/hectare, and 134.25 tons/hectare, respectively. Overall, the carbon stock stored in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District is 434.19 tons/hectare. This result is significant with carbon reserves in mangrove vegetation of Ketapang Beach, Batu Menyan Village, amounting to 300.97 tons/hectare (Kusuma et al., 2023). Carbon dioxide in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District which is able to be absorbed at station 1, station 2, and station 3 are 501.43 tons/hectare, 434.57 tons/hectare, and 418.95 tons/hectare respectively. The total carbon dioxide absorbed in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District is 1,354.95 tons/hectare. This result is significant with carbon uptake in the Tread Mangrove Area in Tugurejo Village Semarang, which contains 1,463.22 tons/hectare (Yaqin et al., 2022). The results of the calculation of oxygen production produced at station 1, station 2, and station 3 in the Mangrove Area of Raawa Aopa Watumohai National Park, Tinanggea District, were 1,338.83 tons/hectare, 1,160.29 tons/hectare, and 1,118.59 tons/hectare, respectively. Mangrove areas in Raawa Aopa Watumohai National Park, Tinanggea District, produce a total of 3,617.71 tons of oxygen/hectare. This result is greater than the oxygen production at 1385.92 tons/hectare (Rifandi, 2020).

The results of oxygen production (Table 5) from the location of the research station show that station 1 has an oxygen production value of 81.47 tons/hectare/year, station 2 has an oxygen production value of 70.61 tons/hectare/year, and station 3 has an oxygen production value of 68.07 tons/hectare/year. Mangrove forest areas in Rawa Aopa Watumohai National Park have the capacity to produce 220.14 tons of oxygen/hectare annually. Daud et al. (2018) found that the oxygen potential of paring bamboo stands in Tompobulu District, Maros Regency was 30.73 tons/hectare/year, smaller than the oxygen production in the mangrove forest area of Rawa Aopa Watumohai National Park. The average annual oxygen production for each sampling station in the Rawa Aopa Watumohai National Park Mangrove Area in Tinanggea District for station 1 was 26.11 tons/hectare; for station 2 was 22.63 tons/hectare; for station 3 was 21.81 tons/hectare; and for the overall average oxygen production was 70.54 tons/hectare.

Analysis of the value of environmental services from carbon dioxide (CO_2) sequestration

The value of environmental services resulting from CO_2 sequestration can be determined by multiplying the value of CO_2 sequestration by the corresponding carbon price. The Green Climate Fund (GCF) has provided USD 7.5 million to the Directorate General of PSKL, as part of its USD 93 million commitment. The payment is made through a result-based payment (RBP) scheme, which is one of the carbon trading schemes. Carbon units sequestered by forest areas form the basis of the result-based payment, which is intended to prevent forests from becoming greenhouse gases that contribute to climate change. The carbon price in social forestry areas is USD 2.9/ton, with a commitment of USD 93 million (Forest Digest, 2024). Table 6 shows the value of CO_2 sequestration and environmental services.

Based on Table 4, the value of environmental services related to CO_2 absorption in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District is for station 1 amounting to USD 84.47/hectare/year, for station 2 amounting to USD 73.20/hectare/year, and for

Table 5. Total carbon stock, average oxygen production, total oxygen production in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District

No	Station location	Annual carbon reserve (tons/hectare/year)	Average O_2 production (tons/hectare)	O_2 production (tons/hectare/year)
1	Station 1	9.78	26.11	81.47
2	Station 2	8.47	22.63	70.61
3	Station 3	8.17	21.81	68.07
Total		26.42	70.54	220.14

Table 6. The value of environmental services from CO_2 sequestration in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District

No	Station location	CO_2 uptake (tons/hectare/year)	Value of CO_2 sequestration environmental services (IDR/hectare/year)	Total CO_2 uptake (tons/hectare)	Value of CO_2 sequestration environmental services (IDR/hectare)
1	Station 1	30.51	1.340.571	501.43	22.030.020
2	Station 2	26.44	1.161.798	434.57	19.092.194
3	Station 3	25.49	1.120.040	418.95	18.405.972
Total		82.45	3.622.410	1.354.95	59.528.188

Note: 1 USD$ = IDR 15,175 (Exchange rate of IDR and dollar, September 30, 2024).

station 3 amounting to USD 70.57/hectare/year. The total value of this environmental service for all research stations is USD 228.24/hectare/year. The value of CO_2 absorption environmental services in the Mangrove Area of Rawa Aopa Watumohai National Park, Tinanggea District is much greater than the value of CO_2 absorption in sapling-level stands in the mangrove forest of Takalar Lama Village, Takalar Regency, which is around USD 12.49/hectare/year (Sribianti, 2021). The annual CO_2 absorption environmental service value of the Rawa Aopa Watumohai National Park Mangrove Area in Tinanggea District based on three different locations, namely station 1, station 2, and station 3 respectively, is USD 209.06; USD 181.18; and USD 174.67. The total annual environmental service value for all research stations was USD 3,750.83.

CONCLUSIONS

The Mangrove Area of Rawa Aopa Watumohai National Park District has abundant opportunities to produce biomass, store carbon, absorb CO_2, and produce oxygen. All stations have the following average potential: 29.42 tons/hectare, 13.83 tons/hectare, 43.15 tons/hectare, and 36.92 tons/hectare. Total annual O_2 production was 220.14 tons/hectare, total annual carbon stock was 26.42 tons/hectare, and total annual CO_2 sequestration was 82.45 tons/hectare.

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