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Short Communication: Estimation of aboveground biomass and carbon sequestration in KGPAA Mangkunagoro I Grand Forest Park, Central Java, Indonesia

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Abstract. *Indriyani S, Sari SP, Negari SIT, Prambudi SA, Nur AAI, Kusumaningrum L, Indrawan M, Sunarto, Sugiyarto, Budiharta S, Setyawan AD. 2024. Short Communication: Estimation of aboveground biomass and carbon sequestration in KGPAA Mangkunagoro I Grand Forest Park, Central Java, Indonesia. Biodiversitas 25: 2257-2263.* Forests play an important role in climate change mitigation by absorbing carbon dioxide in the atmosphere and store it in the form of biomass. Valuation of carbon storage potential of a forest will provide insight on the importance of preserving it. This study aims to assess plant diversity and estimate aboveground biomass, carbon stocks, carbon dioxide sequestration potential, and the economic value of ecosystem services from carbon sequestration in KGPAA Mangkunagoro I Grand Forest Park, Central Java, Indonesia. We used a non-destructive method (i.e. allometric equation) in estimating aboveground biomass and carbon stock. We established 50 sampling plots to identify and measure trees (DBH >20 cm) and poles (10<DBH<20 cm). The results showed that there were 30 species from 20 families found in the observation plots. The potential aboveground biomass at the tree and pole level was 297.92 tons/ha and 57.22 tons/ha, respectively, while the total carbon stock for tree and pole was 140.02 tons/ha and 26.89 tons/ha, respectively. This was equivalent to carbon dioxide sequestration of 513.88 tons/ha and 98.70 tons/ha for trees and poles. The economic value of environmental services from carbon stock in the whole area of KGPAA Mangkunagoro I Grand Forest Park was estimated at IDR 21,289,040,253. The results of this research show that apart from playing a role in mitigating climate change by absorbing carbon, KGPAA Mangkunagoro I Grand Forest Park also has valuable economic value.

Keywords: Aboveground biomass, allometric equation, carbon sequestration, environmental service, grand forest park

Abbreviations: AGB: Above Ground Biomass, IDR: Indonesian Rupiah, USD: United States Dollar

INTRODUCTION

Global warming is currently one of the greatest global problems, characterized by the increase in the earth's temperature caused by the increase of greenhouse gases trapped in the atmosphere (Purnawan et al. 2020). Some researchers noted that the greenhouse gases, such as carbon dioxide (CO_2), are mainly contributed by increasingly human activities especially after the industrial revolution which began in nineteenth and the twentieth centuries (Dilmore and Zhang 2018). Industrial and transportation activities, such as fossil fuel combustion engines and coal-fired power plants, are the major source of CO_2 emissions to the atmosphere (Yoro and Daramola 2020). The accumulation of these gases triggers erratic climate patterns, such as extreme weather events, hotter temperature, long drought and heavy rainfall, which can affect the ecological, social, and economic dimensions of humans' life.

One strategy to mitigate global warming is by reducing carbon emissions emitted from various sources and enhancing carbon stock stored in various sinks. Carbon stock enhancement can be done by absorbing carbon dioxide in the atmosphere and store it in the form of vegetation biomass (Hastuti et al. 2017). Carbon sink in vegetation is considered as a Nature-Based Solution (NBS) in solving climate problem since it uses natural process through the absorption of carbon dioxide (CO_2) by vegetation via photosynthesis which is then converted into carbohydrates and stored as biomass. In this regard, the amount of stored carbon can be inferred from the biomass accumulated by vegetation. Thus, measuring the amount of carbon in vegetation, particularly in the trees, can indicate how much the carbon dioxide (CO_2) that has been absorbed (Drupadi et al. 2021).

Forests containing various plant species and vegetation types absorb and store more carbon than other land use types including agricultural lands. This is due to the presence of a great number of trees and vegetation with multiple canopies in the forests compared to agricultural lands which generally consist of annual crops (Kiat et al. 2020; Paradika et al. 2021). According to Adinugroho and Sidiyasa (2006), there is a strong positive correlation between tree diameter and height and biomass, meaning that the biomass contained in vegetation is strongly affected by the presence and abundance of large-sized trees. In the context of climate change mitigation, tree vegetation in forests can serve as a long-term carbon storage. The carbon storage mechanism in the growing plants is called carbon sequestration. Forests are one of major contributors of carbon sequestration because carbon from the atmosphere are absorbed in their dense vegetation. Not only sequestering a large amount of carbon, forests also provide various environmental services and serve as essential habitat of flora and fauna (Pamudji 2011).

In term of absorbing and storing carbon in the form of biomass, Saha and Bera (2020) estimated that forests store around 86% terrestrial aboveground biomass and 73% terrestrial soil carbon. The biomass accumulation in forest ecosystems also indicates forest productivity and sustainability (Pipite 2022). However, the capacity of forests in carbon sequestrations can decrease if forests are disturbed by human activities (Joshi and Singh 2020). Therefore, it is important to protect forest ecosystems to maintain their highest capacity in storing carbon as an effort to mitigate climate change. The protection of forest ecosystems can be manifested in various forms, but the most effective policy is by assigning it as conservation areas such as national parks, nature reserves, wildlife sanctuaries, botanical gardens and grand forest parks.

Grand forest park (or *Taman Hutan Raya* in Indonesian term) is a form of conservation area which has the potential to contribute in carbon storage. Based on the Government Regulation of the Republic of Indonesia Number 28 of 2011 concerning the Management of Nature Reserve Areas and Nature Conservation Areas Article 36, one of the roles of grand forest park is to sequester and store carbon along with other roles such as biodiversity conservation, research, scientific activities and education, culture, tourism, and recreation (Balitbangda 2020). KGPAA Mangkunagoro I Grand Forest Park has a high diversity consisting of a diversity of flora, fungi, bamboo, medicinal and food plants as well as fauna such as birds (Pertiwi et al. 2021). Based on Setiyawan (2019), the forest area in KGPAA Mangkunagoro I Grand Forest Park is managed by three institutions, namely *Taman Hutan Raya* (Tahura), State Owned Forest Company (*Perusahaan Hutan Negara Indonesia/Perhutani*), and *Lembaga Masyarakat Desa Hutan* (LMDH).

KGPAA Mangkunagoro I Grand Forest Park is a nature conservation area with an extent of 232.3 ha and is located on the slopes of Mount Lawu. This park is administratively located in Dukuh Sukuh, Berjo Village, Ngargoyoso Sub-district, Karanganyar District, Central Java Province, Indonesia. The KGPAA Mangkunagoro I Grand Forest Park contains various flora diversity, including pine (*Pinus merkusii*), resin (*Agathis dammara*), and quinine (*Cinchona pubescens*) (Widiyanto 2014). Vegetation within the KGPAA Grand Forest Park is essential in carbon sequestration, especially for species with large diameters and heights. Since there is a large number of trees with great size in KGPAA Mangkunagoro I Grand Forest Park, it is presumed that they store a significant amount of biomass, and therefore carbon storage which is beneficial for climate change mitigation. However, with the presence of tourism in the grand forest park, it is feared that there will be change in forest condition due to the construction of tourist facilities and impacts from visitor activities. If not monitored, these activities might result in carbon loss and affect the capacity of the forest in the grand forest park in storing carbon (Arfitryana et al. 2021). Therefore, observing the potential of environmental services based on carbon absorption in KGPAA Mangkunagoro I Grand Forest Park is necessary. Based on this rationale, this study aims to assess plant diversity, estimate biomass, carbon stocks, carbon dioxide sequestration, and environmental services in term of carbon sequestration in KGPAA Mangkunagoro I Forest Park. The results of this study are expected to enrich the existing literature about ecological study on environmental services, especially carbon sequestration and the economic valuation. Hopefully this research can be used as consideration for managers and community about the importance of KGPAA Mangkunagoro, so that it can increase awareness of preserving forests.

MATERIALS AND METHODS

Study area and period

KGPAA Mangkunagoro I Grand Forest Park, or Ngargoyoso Grand Forest Park, is an innate nature conservation area with extent of 231.3 Ha. This park is located on the slope of Mount Lawu, which is administratively located in Ngargoyoso Sub-district, Karanganyar District, Central Java Province, Indonesia (Figure 1). Geographically, KGPAA Mangkunagoro I Grand Forest Park is located at the coordinates of 7°37'20" S-7°38'33" S and 111°08'13" E-111°08'58" E. KGPAA Mangkunagoro I Grand Forest Park has a hilly and steep topography with altitudes between 1200-1640 m above sea level. The average rainfall is around 2921 mm/year with a type C climate based on Schmidt and Ferguson, suggesting that it has moderately wet climate with an average ratio of dry months to wet months (Q) of 0.45 with an average temperature of 23°C (Cahyono et al. 2020). To the north, KGPAA Mangkunagoro I Grand Forest Park is directly bordered by Munggur Village and Petak 8 R.P.H. Tambak; to the east, it is bordered by the North Lawu Protection Forest; to the west, it is bordered by Petak 12 R.P.H. Tambak, and to the south by Dukuh Plalar, Dukuh Pancot, and Dukuh Tengklik. Data collection was conducted from 21 June to 1 July 2023. Tools and materials used during data collection were tape line, stationery, documentation tools, and tally sheets.

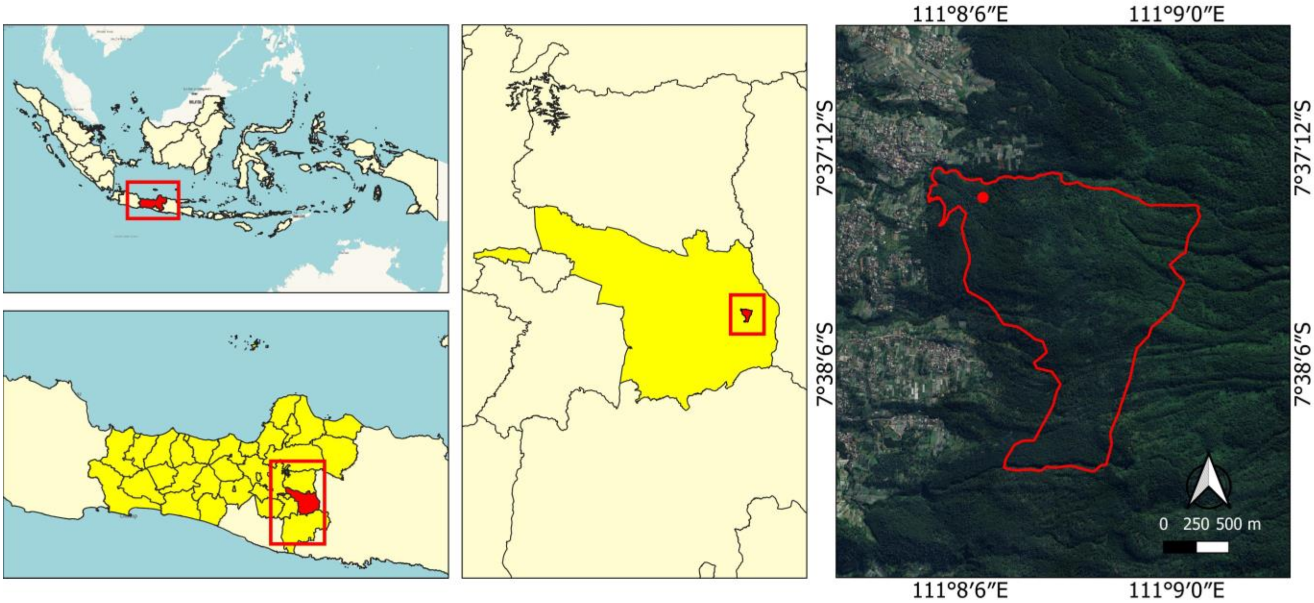

Figure 1. The research location is in the KGPAA Mangkunagoro I Grand Forest Park area, Ngargoyoso Sub-district, Karanganyar District, Central Java, Indonesia

Table 1. Allometric equations used to calculate above ground biomass in KGPAA Mangkunagoro I Grand Forest Park, Ngargoyoso Sub-district, Karanganyar District, Central Java, Indonesia

Species	Equation	References
Agathis dammara (Lamb.) Rich. & A.Rich.	$0.4725 \times D^{2.0112}$	(Wibowo et al. 2010)
Anthocephalus cadamba (Roxb.) Miq.	$0.014 \times D^{2.958}$	(Siarudin dan Indrajaya 2014)
Coffea sp.	$0.281 \times D^{2.6}$	(Arifin 2001)
Ficus benjamina L.	$0.027059 \times D^{2.86357}$	(Rodríguez et al. 2006)
Maesopsis eminii Engl.	$0.0363 \times D^{2.5131}$	(Samsoedin et al. 2016)
Pinus merkusii Jungh. & de Vriese	$0.1900 \times D^{2.2730}$	(Ahmad et al. 2014)
Schima wallichii (DC.) Korth.	$0.24 \times D^{2.072}$	(Li et al. 2018)
Shorea leprosula Miq.	$0.0726 \times D^{2.378}$	(Krisnawati et al. 2012)
Swietenia mahagoni (L.) Jacq.	$0.048 \times D^{2,3}$	(Adinugroho 2001)
Tree spikes	-4266348/(1 - 2792284 exp (-0.313677 H)	(Manuri et al. 2012)
Branching tree	$0.11 \times \rho \times D^{2.62}$	(Ketterings et al. 2001)
Unbranched tree	$3.14 \times \rho \times H \times D^2/40$	(Hairiah et al. 2001)
Coniferous tree	-1.17+2.119 x (In D)	(Brown 1997)
Broadleaf tree	$0.168 \times \rho \times D^{2.47}$	(Chave et al. 2005)

Note: D: Tree diameter, H: Tree height, ρ: Density

Data collection procedures

Vegetation sampling

Vegetation sampling in this study used non-destructive methods by measuring the circumference and height of trees to calculate tree biomass. This non-destructive method aims not to damage the environment because it does not cut down trees. Biomass calculation in this study was carried out by estimating Aboveground Biomass (AGB) using allometric formula (Darliana 2023, Table 1). We established sampling plot to document and measure the vegetation with size of 20 × 20 m for tree category and 10 × 10 m for pole category. In total, there were 50 plots established for vegetation sampling.

Estimating carbon stock and carbon dioxide sequestration

Estimating the value of carbon stock and carbon sequestration was carried out using a formula that refers to the National Standardization Agency (SNI 2011) as follows:

$$C_n = \frac{Cx}{1000} \; X \; \frac{10.000}{lsub\text{-}plot}$$

Where:
Cn: Carbon per hectare on each sub-plot (tons/ha)
Cx: Carbon per sub-plot (tons)
lsub-plot: total area of the sub-plot (m^2)

Sequestration of carbon dioxide: Carbon stock x 3.67

Estimation of the value of environmental services from carbon sequestration

Estimation of the value of carbon sequestration as a form of environmental services at the research site used the standard carbon price from the World Bank which valued of 10 USD per ton (Yulian et al. 2011). The calculation of the value of environmental services can be formulated as follows:

Value of environmental services: carbon sequestration (ton/ha) x total area (ha) x 10 USD

We used the exchange rate as per 5 July 2023 with 1 USD ~ IDR 15,118.

RESULTS AND DISCUSSION

Based on the results of the study, 30 species were found in the category of trees and poles across the sampling plots. Some species recorded included *P. merkusii, Schima wallichii* and *C. pubescens*. Tables 2 and 3 show the species, aboveground biomass, carbon stocks and carbon dioxide sequestrations at KGPAA Mangkunagoro I Grand Forest Park.

Table 2 shows that in pole category (vegetation with DBH= 10-20 cm) there were 26 species found with *P. merkusii* (pine) was the most common compared to other species. The accumulation of biomass in pine trees at the pole category referred to organic materials contained in pine trees including trunks, branches and leaf needles that can store biomass (Susila and Apriliani 2019). Pine trees produce significant biomass due to their size and relatively fast growth. The second species commonly encountered was *Araucaria cunninghamii* which belongs to the family Araucariaceae. This species has a fairly wide distribution and is a gymnosperm tree species with a tall and upright shape. The *A. cunninghamii* has a slow growth but is an effective carbon sink (Haruna 2020). The species at the pole category with the lowest abundance was *Shorea leprosula* which belongs to the Dipterocarpaceae family in which only 1 individual was found in the sampling plot. Humid environmental condition likely affects the low number rate of *S. leprosula* (Karlinasari et al. 2016).

The *P. merkusii* had the highest aboveground biomass at the pole level with 19.27 tons/ha, or equivalent to 9.05 tons/ha of carbon stocks. Pine also contributed to the largest amount of carbon dioxide uptake at the pole level at 40.04 tons/ha. The second species with the highest carbon stock value was Araukaria which had an aboveground biomass of 22.26 tons/ha, or equivalent to carbon stocks of 10.46 tons/ha and CO_2 sequestration equivalent to of 38.39 tons/ha. In contrast, *S. leprosula* had the lowest aboveground biomass at the pole level with 0.11 tons/ha or equivalent to a carbon stock of 0.05 tons/ha and carbon dioxide sequestration of 0.19 tons/ha. According to Rizki et al. (2016), the variation in biomass, carbon stocks and carbon dioxide sequestration among various species at the pole level in the research area provides information about the role of these species in climate change mitigation and carbon management in large forest ecosystems.

Table 2. List of species, Aboveground Biomass (AGB), carbon stock and carbon dioxide sequestered at the pole category

Local Name	Scientific Name	Family	AGB (tons/ha)	Carbon Stock (tons/ha)	CO_2 Sequestered (tons/ha)
Kenanga	*Cananga odorata* (Lam.) Hook.f. & Thomson	Annonaceae	0.22	0.10	0.37
Kayu tanganan	*Macropanax* sp.	Araliaceae	0.67	0.31	1.15
Araukaria	*Araucaria cunninghamii* Aiton ex A.Cunn.	Araucariaceae	22.26	10.46	38.39
Liwung	*Arenga pinnata* (Wurmb) Merr.	Arecaceae	0.86	0.41	1.49
Cemara gunung	*Casuarina junghuhniana* Miq.	Casuarinaceae	3.67	1.72	6.33
Kengkeng	*Weinmannia blumei* Planch.	Cunoniaceae	0.30	0.14	0.51
Paku pohon	*Cyathea contaminans* (Wall. ex Hook.) Copel.	Cyatheaceae	0.91	0.43	1.57
Meranti bunga	*Shorea leprosula* Miq.	Dipterocarpaceae	0.11	0.05	0.19
Oak batu	*Lithocarpus edulis* (Makino) Nakai	Fagaceae	1.67	0.78	2.88
Kayu manis	*Cinnamomum burmanni* (Nees & T.Nees) Blume	Lauraceae	0.73	0.34	1.26
Kayu manis jangan	*Cinnamomum zeylanicum* Blume	Lauraceae	0.35	0.16	0.60
Cempaka putih	*Magnolia x alba* (D.C) Figlar & Noot.	Magnoliaceae	0.28	0.13	0.48
Cempaka wangi	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	0.14	0.07	0.24
Kayu cedro	*Cedrela odorata* L.	Meliaceae	0.58	0.27	1.00
Mahoni afrika	*Khaya anthotheca* (Welw.) C.DC.	Meliaceae	0.32	0.15	0.55
Mahoni berdaun kecil	*Swietenia mahagoni* (L.) Jacq.	Meliaceae	0.29	0.14	0.51
Tali kuning	*Arcangelisia flava* (L.) Merr	Menispermaceae	0.24	0.11	0.41
Beringin	*Ficus benjamina* L.	Moraceae	0.58	0.27	0.99
Salam	*Syzygium polyanthum* (Wight) Walp.	Myrtaceae	0.13	0.06	0.23
Pinus	*Pinus merkusii* Jungh. & de Vriese	Pinaceae	19.27	9.05	33.23
Kayu afrika	*Maesopsis eminii* Engl.	Rhamnaceae	0.64	0.30	1.10
Jabon	*Anthocephalus cadamba* (Roxb.) Miq.	Rubiaceae	0.44	0.20	0.75
Kina	*Cinchona pubescens* Vahl	Rubiaceae	0.45	0.21	0.78
Kopi	*Coffea* sp.	Rubiaceae	0.68	0.32	1.17
Puspa	*Schima wallichii* (DC.) Korth.	Theaceae	0.89	0.42	1.54
Gaharu	*Aquilaria malaccensis* Lamk.	Thymelaeaceae	0.57	0.27	0.98
Total			57.22	26.89	98.70

Table 3. List of species, Aboveground Biomass (AGB), carbon stock and carbon sequestered at the tree category

Local name	Scientific name	Family	AGB (tons/ha)	Carbon stock (tons/ha)	CO_2 sequestered (tons/ha)
Kenanga	*Cananga odorata* (Lam.) Hook.f. & Thomson	Annonaceae	0.27	0.13	0.47
Damar	*Agathis dammara* (Lamb.) Rich. & A.Rich.	Araucariaceae	0.81	0.38	1.40
Cemara gunung	*Casuarina junghuhniana* Miq.	Casuarinaceae	0.01	0.003	0.01
Paku pohon	*Cyathea contaminans* (Wall. ex Hook.) Copel.	Cyatheaceae	0.08	0.04	0.15
Oak batu	*Lithocarpus edulis* (Makino) Nakai	Fagaceae	0.52	0.25	0.91
Sarangan	*Castanea argentea* (Blume) Blume	Fagaceae	0.51	0.24	0.88
Tanaman kayu manis	*Cinnamomum burmanni* (Nees & T.Nees) Blume	Lauraceae	0.27	0.13	0.47
Kayu manis jangan	*Cinnamomum zeylanicum* Blume	Lauraceae	0.52	0.24	0.89
Cempaka putih	*Magnolia x alba* (D.C) Figlar & Noot.	Magnoliaceae	0.29	0.14	0.51
Suren	*Toona sureni* (Blume) Merr.	Meliaceae	1.31	0.61	2.25
Mahoni afrika	*Khaya anthotheca* (Welw.) C.DC.	Meliaceae	0.20	0.09	0.34
Beringin	*Ficus benjamina* L.	Moraceae	0.59	0.28	1.01
Duwet putih	*Syzygium cumini* (L.) Skeels	Myrtaceae	0.52	0.24	0.90
Pinus	*Pinus merkusii* Jungh. & de Vriese	Pinaceae	286.15	134.49	493.58
Kayu afrika	*Maesopsis eminii* Engl.	Rhamnaceae	2.30	1.08	3.96
Kina	*Cinchona pubescens* Vahl	Rubiaceae	1.55	0.73	2.67
Puspa	*Schima wallichii* (DC.) Korth.	Theaceae	0.54	0.25	0.93
Gaharu	*Aquilaria malaccensis* Lamk.	Thymelaeaceae	1.47	0.69	2.54
Total			297.92	140.02	513.88

Table 4. Total aboveground biomass, carbon stock and carbon dioxide sequestration by tree and pole categories

Category	AGB (tons/ha)	Carbon stock (tons/ha)	Carbon dioxide sequestration (tons/ha)
Tree	297.92	140.02	513.88
Pole	57.22	28.73	105.51
Total	355.14	168.75	619.39

At the tree level (vegetation with a DBH of more than 20 cm), as many as 18 species were found with *P. merkusii* was the most dominant species. The *P. merkusii* is the only pine species with a wide distribution in Southeast Asia, such as Thailand, Vietnam, Malaysia and Indonesia (Sitompul 2019). The studied area was dominated mainly by pine species because there were rehabilitation programs in 1995-2000, suggesting the pine stands had ages of 23-25 years when this study was conducted (Cahyono et al. 2020). The pine stands in the KGPAA Mangkunagoro I Grand Forest Park were the results of silvicultural management that was applied before the establishment of the grand forest park. The second species commonly found was the African wood or *Maesopsis eminii*. African wood is a species that naturally grows and spreads in the tropics of East Africa and is first introduced in the West Java region (Samsoedin et al. 2016). African wood is a species that is included in the category of fast-growing species (Karlinasari et al. 2016). The dominance of species in an area indicates that physical and environmental conditions are suitable with the requirement of the species.

The carbon content of a forest is determined by biomass. Aboveground biomass is all above-surface living matter, including stems, branches, bark, seeds and leaves (Duncanson et al. 2019). The amount of vegetation biomass is influenced by the trunk diameter, tree height, density and specific wood gravity (Chairul et al. 2016). Pine had the highest aboveground biomass value at the tree level with 286.15 tons/ha, or equivalent to a carbon stock of 134.49. Pine also contributed to the largest carbon dioxide uptake at the tree level, amounting to 493.58 tons/ha. In Indonesia, based on research by Polosakan et al. (2014) in Gunung Halimun Salak National Park, the carbon stock for a 30-year-old pine stand is 96.5 tons/ha. Furthermore, Ijazah and Sancayaningsih (2015) also reported that the carbon stock for 30-year-old pine stands in Mangunan-Bantul amounted to 442.31 tons/ha. The carbon stock of pine stands obtained in this study was lower than the studies by Indrajaya in Java (2016) and Ijazah and Sancayaningsih (2015) but higher than that in Polosakan (2014). For pine tree carbon sequestration, Polosakan (2014) reported that the carbon dioxide sequestration of pine trees at the age of 30 years was 354.2 tons/ha. Furthermore, Indrajaya (2016) also reported that carbon dioxide absorption in 30-year pine stands was 612-896 tons/ha. African wood is the second species with the highest amount of aboveground biomass of 2.30 tons/ha, equivalent to carbon stocks of 1.08 tons/ha and CO_2 sequestration of valued at 3.96 tons/ha. Based on Samsoedin et al. (2016), the carbon stock of African wood at the age of 8 is 2.74 tons/ha, which is comparable with the result of our study. Almost the same value as the research conducted by Samsoedin et al. (2016).

Based on the research results in Ngargoyoso Grand Forest Park, tree-level vegetation had a higher aboveground biomass value than poles, where the tree level had an AGB value of 297.92 tons/ha, while the pole level had an AGB value of 57.22 tons/ha. The total AGB from the tree and pole level was 355.14 tons/ha. The magnitude of the AGB value is influenced by the large number of individuals in various strata of stands on trees found in each plot (Subhan et al. 2023). In this study, the carbon stock at tree level (140.02 tons/ha) is higher than that at the pole level (28.73

tons/ha). This is because the tree has a larger trunk diameter than the pole. The total carbon stock from trees and poles was 168.75 tons/ha. Based on the research by Sribianti et al. (2022) in Abdul Latief Grand Forest Park in Sinjai, South Sulawesi, Indonesia, trees had a higher carbon stock than the amount of carbon stock at other growth levels due to the larger diameter of the trunk compared to other stands. Similarly, in term of carbon dioxide sequestration, tree-level vegetation sequestered higher carbon dioxide compared to pole level. Based on Table 4, carbon dioxide sequestration at the tree level was 513.88 tons/ha, while at the pole level, it had a carbon uptake of 105.51 tons/ha. In total, the carbon dioxide sequestration in forest stands was 619.39 tons/ha. The results showed that carbon sequestration in Ngargoyoso Grand Forest Park, Karanganyar was higher than the results of research conducted by Aththorick et al. (2018) in the Bukit Barisan Karo Forest Park District, North Sumatra, Indonesia with a carbon absorption value of 20.76 tons/ha. That shows the average diameter of trees in the Ngargoyoso Grand Forest Park is greater than the Bukit Barisan Karo Forest Park.

The economic value of environmental services from carbon sequestration

The economic value of environmental services from carbon sequestration can be obtained by multiplying the average carbon sequestration value by the studied area, then multiplying it by the standard carbon price. The carbon price used here was based on the data of World Bank, which is 10 USD per ton carbon. Considering that the total area of Mangkunagoro I Grand Forest Park was about 231.3 ha (Cahyono et al. 2020), the total economic value of ecosystem services from carbon sequestration was IDR 21,289,040,253. The carbon sequestration value is one of the potentials to maintain and preserve the existence of the KGPAA Mangkunagoro I Grand Forest Park. Furthermore, the result of our study can be compared with other studies, including the research conducted by Sribianti et al. (2022) which showed that the value of CO_2 absorption in Abdul Latief Grand Forest Park was IDR 621,627,835 per year. In the research conducted by Juita et al. (2016) at Tanjungpura Pontianak University, the economic value of CO_2 absorption was IDR 29,896,803 per year.

In conclusion, KGPAA Mangkunagoro I Grand Forest Park in Ngargoyoso contained 30 species from 20 families with the most dominant species were *P. merkusii* and *A. cunninghamii*. The potential aboveground biomass at the trees and poles level was 297.92 tons/ha and 57.22 tons/ha, respectively while the potential carbon stock for trees and poles level was 140.02 tons/ha and 26.89 tons/ha, respectively. This is equivalent to carbon dioxide sequestration of 513.88 tons/ha and 98.70 tons/ha level for trees and poles, respectively. In addition, the economic value of environmental services from total carbon uptake in the forest vegetation in KGPAA Mangkunegoro I Grand Forest Park was estimated Rp. 21,289,040,253. The result of this study can be used as a consideration in managing KGPAA Mangkunegoro I Grand Forest Park, so the existing potential in the forest can be maintained and even improved.

REFERENCES

Adinugroho WC. 2001. Model Penaksiran Biomassa Pohon Mahoni (*Swietenia macrophylla*) di Kesatuan Pemangkuan Hutan Cianjur PT. Perhutani Unit III Jawa Barat. [Thesis]. Institut Pertanian Bogor, Bogor. [Indonesian]

Adinugroho WC. Sidiyasa K. 2006. Model pendugaan biomassa pohon mahoni (*Swietenia macroplhylla* King) di atas permukaan tanah. Penelitian Hutan dan Konservasi Alam 3 (1): 103-117. DOI: 10.20886/jphka.2006.3.1.103-117. [Indonesian]

Ahmad AG. Siregar CA. Siregar UJ. Arifin HS. 2014. Biomass estimation of *Pinus merkusii* Jungh et De Vriese Tapanuli strain at its natural distribution in North Sumatra. Indones For Rehab J 2 (2): 123-144. DOI: 10.9868/ifrj.2.2.123-133.

Arfitryana, Zulkarnaini, Warningsih T. 2021. Nilai ekonomi potensi jasa lingkungan menyerap karbon di Taman Wisata Alam Buluh Cina Kabupaten Kampar Provinsi Riau. Jurnal Ilmu Lingkungan 15 (1): 32-44. DOI: 10.31258/jil.15.1.p.32-44. [Indonesian]

Arifin J. 2001. Estimation of Carbon Storage on Different Forms of Land Use in Ngantang, Malang. [Thesis]. Universitas Brawijaya, Malang. [Indonesian]

Balitbangda Kutai Kartanegara. 2020. Kajian Teknis Pembentukan Kawasan Taman Hutan Raya Muara Siran Kabupaten Kutai Kartanegara. Universitas Mulawarman, Samarinda. [Indonesian]

Brown S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: A Primer. FAO, Rome.

Cahyono SA, Nugroho NP, Sepwantoro A, Kustiyarto Y, Aryhardi BA. 2020. Taman Hutan Raya KGPAA Mangkunagoro I: Potensi Tantangan dan Peluang. Mekar Abadi, Surakarta. [Indonesian]

Chairul, Muchktar E, Mansyurdin, Tesri M, Indra G. 2016. struktur kerapatan vegetasi dan estimasi kandungan karbon pada beberapa kondisi hutan di Pulau Siberut Sumatera Barat. Jurnal Metamorfosa 3 (1): 15-22. [Indonesian]

Chave J, Andalo C, Brown S et al. 2005. Tree allometry and improved estimation ofcarbon stocks and balance in tropical forests. Oecologia 145: 87-99. DOI: 10.1007/s00442-005-0100-x.

Darliana I, Wilujeng S, Nurmajid F. 2023. Estimasi cadangan karbon dan serapan karbon di Taman Maluku Kota Bandung. Paspalum 11 (1): 163-171. DOI: 10.35138/paspalum.v11i1.556. [Indonesian]

Dilmore R, Zhang L. 2018. Greenhouse gases and their role in climate change. In: Romanov V (eds). Greenhouse Gases and Clay Minerals: Enlightening Down-to-Earth Road Map to Basic Science of Clay-Greenhouse Gas Interfaces. Springer, Cham. DOI: 10.1007/978-3-319-12661-6_10.

Drupadi TA, Ariyanto DP, Sudadi. 2021. Pendugaan kadar biomassa dan karbon tersimpan pada berbagai kemiringan dan tutupan lahan di KHDTK Gunung Bromo UNS. Jurnal Agrikultur 32 (2): 112-119. DOI: 10.24198/agrikultura.v32i2.32344. [Indonesian]

Duncanson L, Armston J, Disney M et al. 2019. The importance of consistent global forest above ground biomass product validation. Surveys Geophys 40: 979-999. DOI: 10.1007/s10712-019-09538-8.

Hairiah K. Dewi S. Agus F. Velarde S. Ekadinata A. Rahayu S. van Noordwijk M. 2001. Measuring Carbon Stocks Across Land Use Systems: A Manual. World Agroforestry Centre (I.C.R.A.F.). S.E.A. Regional Office, Bogor.

Haruna MF. 2020. Analisis biomassa dan potensi penyerapan karbon oleh tanaman pohon di Taman Kota Luwuk. Jurnal Pendidikan Glasser 4 (2): 152-160. DOI: 10.32529/glasser.v4i2.742.

Hastuti AW, Suniada WKI, Islamy F. 2017. Carbon stock estimation of mangrove vegetation using remote sensing in Perancak Estuary, Jembrana District, Bali. Intl J Remote Sens Earth Sci 14 (2): 137-150. DOI: 10.30536/j.ijreses.2017.v14.a2841.

Ijazah M. Sancayaningsih RP. 2015. Penyimpanan Karbon pada Tegakan *Pinus merkusii* dan *Acacia auriculiformis* di Hutan Lindung Mangunan, Dlingo, Bantul, Daerah Istimewa Yogyakarta. [Skripsi]. Universitas Gajah Mada, Yogyakarta. [Indonesian]

Indrajaya Y. Sudomo A. 2016. Karbon tersimpan dalam biomassa hutan rakyat jamblang di Kabupaten Bantul dan Gunung Kidul, Yogyakarta. Prosiding SNaPP: Sains Teknologi 6 (1): 23-29. [Indonesian]

Joshi R. Singh H. 2020. Carbon sequestration potential of disturbed and non-disturbed forest ecosystem: A tool for mitigating climate change. Afr J Environ Sci Technol 14 (11): 385-393. DOI: 10.5897/AJEST2020.2920.

Juita S. Lumangkun A. Dewantara I. 2016. Penilaian ekonomi jasa lingkungan hutan kota pada Kawasan Universitas Tanjungpura Pontianak. Jurnal Hutan Lestari 4 (3): 380-386. [Indonesian]

Karlinasari L, Andini S, Worabai D, Pamungkas P, Budi SW, Siregar IZ. 2016. Tree growth perfomance and estimation of wood quality in plantation trials for *Maesopsis eminii* and *Shorea* spp. J For Res 29: 1157-1166. DOI: 10.1007/s11676-017-0510-8.

Ketterings QM, Coe R, Noordwijk MV, Ambagau Y, Palm CA. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above ground tree biomass in mixed secondary forests. For Ecol Manag 146: 199-209. DOI: 10.1016/S0378-1127(00)00460-6.

Kiat PE, Malek MA, Shamsuddin SM. 2020. Net carbon stocks change in biomass from wood removal of tropical forests in Sarawak. Malaysia. J King Saud Univ Sci 42 (13): 905-912. DOI: 10.1016/j.jksus.2019.09.012.

Krisnawati H. Adinugroho WC. Imanuddin R. 2012. Monograf Model-Model Alometrik untuk Pendugaan Biomassa Pohon pada Berbagai Tipe Ekosistem Hutan di Indonesia. Badan Penelitian dan Pengembangan Kehutanan, Bogor. [Indonesian]

Li S, Lang X, Liu W, Ou G, Xu H, Su J. 2018. The relationship between species richness and aboveground biomass in a primary *Pinus kesiya* forest of Yunnan, southwestern China. PLoS ONE 13 (1): e0191140. DOI: 10.1371/journal.pone.0191140.

Manuri S, Kumara I, Azwar W, Irwan M, Supriyanto, Firdaus M, Somala E. 2012. Inventarisasi Tegakan Hutan dan Cadangan di KPH Kapuas Hulu, Samarinda (I.D.). Forest and Climate Programe-German International Cooperation, Samarinda. DOI: 10.13140/2.1.1700.0964. [Indonesian]

National Standardization Agency (SNI). 2011. Standar Nasional Indonesia No. 7724 Tentang Pengukuran dan Penghitungan Cadangan Karbon - Pengukuran Lapangan untuk Penaksiran Cadangan Karbon Hutan (ground based forest carbon accounting). Jakarta. [Indonesian]

Pamudji WH. 2011. Potensi Serapan Karbon Pada Tegakan Akasia. [Skripsi]. Institut Pertanian Bogor, Bogor. [Indonesian]

Paradika GY, Kissinger, Rezekiah AA. 2021. Pendugaan cadangan karbon vegetasi di sempadan sungai pada Kawasan Hutan dengan Tujuan Khusus (KHDTK) Universitas Lambung Mangkurat. Jurnal Sylvia Sienteae 4 (1): 98-106. DOI: 10.20527/jss.v4i1.3098. [Indonesian]

Pertiwi YAB, Nufus M, Agustina A, Rahmadwiati R, Wicaksono RL, Nayasilana IN. 2021. Keanekaragaman, biomassa dan cadangan karbon bambu di Taman Hutan Raya KGPAA Mangkunagoro I. Jurnal Belantara 4 (2): 140-152. DOI: 10.29303/jbl.v4i2.816. [Indonesian]

Pipite A. 2022. Estimation of Aboveground Biomass (AGB) using allometric equation: Case study of Colo-ISuva Forest Park in Fiji. Earth Environ Sci Res Rev 5 (3): 137-147. DOI: 10.20944/preprints202206.0154.v1.

Polosakan R, Alhamd L, Rahajoe JS. 2014. Estimasi biomassa dan karbon tersimpan pada *Pinus merkusii* Jungh. & de Vriese di Hutan Pinus GN. Bunder, TN. G.N. Halimun Salak. Berita Biologi 13: 115-120. DOI: 10.14203/beritabiologi.v13i2.684. [Indonesian]

Purnawan EI, Jemi R, Triadi A, Perkasa P. 2020. Potensi karbon dan jasa lingkungan: Studi Hutan Lindung Gunung Bondang Kabupaten Murung Raya, Kalimantan Tengah, Indonesia. Daun 7 (2): 100-116. DOI: 10.33084/daun.v7i2.2006. [Indonesian]

Rizki GM, Bintoro A, Hilmanto R. 2016. Perbandingan emisi karbon dengan karbon tersimpan di Hutan Rakyat Desa Buana Sakti Kecamatan Batanghari Kabupaten Lampung Timur. Jurnal Sylva Lestari 4 (1): 89-96. DOI: 10.23960/jsl1489-96.

Rodríguez R, Jiménez J, Aguirre O, Treviño E. 2006. Estimación de carbono almacenado en un bosque de niebla en Tamaulipas, México. Ciencia-UANL 9: 179-187.

Saha S, Bera S. 2020. Carbon estimation in the under-shrub layer and the soil of a Dry Deciduous Forest of West Bengal (Easthern India). Trop Ecol 61 (4): 487-496. DOI: 10.1007/s42965-020-00108-3.

Samsoedin I, Sukiman H, Wardani M, Heriyanto NM. 2016. Biomass and carbon stock of *Maesopsis emenii* Engl. at Sukabumi District, West Java. Jurnal Penelitian Hutan Tanaman 13 (1): 73-81. DOI: 10.20886/jpht.2016.13.1.73-81.

Setiyawan KB. 2019. Modal sosial pengelolaan hutan rakyat: Studi Kasus Di Desa Berjo Ngargoyoso Karanganyar Jawa Tengah. Jurnal Sosial Ekonomi Pertanian 15 (2): 156-163. DOI: 10.20956/jsep.v15i2.6536. Indonesian]

Siarudin M, Indrajaya Y. 2014. Allometric equation of Jabon for estimating above ground biomass in private forests. Pakenjeng Sub District, Garut Regency. Jurnal Penelitian Hutan Tanaman 11 (1): 1-9. DOI: 10.20886/jpht.2014.11.1.1-9.

Sitompul HF. 2019. Analisis Vegetasi Tumbuhan Bawah pada Tegakan Alam *Pinus merkusii* Jungh Et De Vriese Strain Tapanuli di Kabupaten Tapanuli Utara, Provinsi Sumatera Utara. [Skripsi]. Universitas Sumatera Utara, Medan. [Indonesian]

Sribianti I, Sultan, Muthmainnah, Daud M, Nirwana, Abdullah AA, Sardiawan A. 2022. Estimasi Biomassa. Cadangan Karbon. Produksi O_2 dan nilai jasa lingkungan serapan CO_2 tegakan hutan di Taman Hutan Raya Abdul Latief. Jurnal Hutan Masyarakat 14 (1): 12-26. DOI: 10.24259/jhm.v14i1.18022. [Indonesian]

Subhan, Hanafi I, Rosalinda P, Muslih AM, Hayati D. 2023. Estimasi simpanan karbon hutan di Resort Pengelolaan Hutan (RPH) Alue Deulima Tahura Pocut Meurah Intan Aceh Besar. Jurnal Sumberdaya Hayati 9 (1): 30-38. DOI: 10.29244/jsdh.9.1. [Indonesian]

Susila R, Apriliani RN. 2019. Pendugaan cadangan karbon di Taman Hutan Raya Intan Dewata. Jurnal Wanamukti 22 (2): 94-103. DOI: 10.35138/wanamukti.v22i2.333.

Wibowo A, Ginoga K, Nurfatriani F, Indartik, Dwiprabowo H, Ekawati S, Krisnawati H, Siregar A. 2010. REDD+ & Forest Governance.Pusat Penelitian Sosial Ekonomi dan Kebijakan Kehutanan Kampus Balitbang Kehutanan, Bogor. [Indonesian]

Widiyanto H. 2014. Kajian Sensitifitas Kawasan Taman Hutan Raya (Tahura) K.G.P.A.A. Mangkunagoro I Karanganyar. [Thesis]. Sebelas Maret University, Surakarta. [Indonesian]

Yoro KO, Daramola MO. 2020. CO_2 emission sources, greenhouse gases, and the global warming effect. In: Rahimpour MR, Farsi M, Makarem MA (eds). Advances in Carbon Capture. Woodhead Publishing, Duxford, UK. DOI: 10.1016/B978-0-12-819657-1.00001-32.

Yulian EN, Syaufina L, Putri EIK. 2011. Valuasi ekonomi sumberdaya alam Taman Hutan Raya Bukit Soeharto di Provinsi Kalimantan Timur. Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan 1 (1): 38-38. DOI: 10.29244/jpsl.1.1.38. [Indonesian]