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Short-Communication

The Role of Urban Forests as Carbon Sink: A Case Study in the Urban Forest of Banda Aceh, Indonesia

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ABSTRACT

Forests have a role as carbon sinks and come under the spotlight when the world is facing the climate change problem. Urban forests have functions as the most effective carbon sinks. Banda Aceh City only has 7.15 ha of urban forest, and the vegetation that grows in the urban forest is essential for carbon emissions reduction. This study aimed to determine the potential tree biomass and carbon sink value in the BNI Urban Forest, Banda Aceh City, Indonesia. This study used vegetation analysis by inventory method with the census sampling method. The diameter of all trees was measured, and tree biomass, carbon stocks, and carbon sequestration were calculated. This study identified 16 tree species in the BNI Urban Forest with a total of 318 individuals, showing *Casuarina equisetifolia* as the most dominant tree (163 trees). The above-ground biomass, carbon stock, and carbon sequestration by the vegetation in the BNI Urban Forest were 24.66 tons/ha, 11.59 tons/ha, and 42.51 tons/ha, respectively. This study presented the vegetation conditions and the potential of carbon sequestration, which can be used to monitor and evaluate the benefits of the existence of urban forests in Banda Aceh.

1. Introduction

Forests have a significant role in the survival and life of living things. Therefore, forest management is essential. It is helpful to know the extent of utilization and use of forest areas (De Groot et al. 2019). The following points are strongly related to the application of forest ecosystem service functions that will have a good impact on the environment: (1) forests have a role as a carbon sink and begin to be in the spotlight when the earth is faced with the problem of global climate change caused (Subhan et al. 2021; Wahanisa 2015), (2) awareness of the importance of protecting and preserving the environment has increased along with global climate change, which has become a world issue in recent years (Hyde et al. 2022), and (3) global warming, caused by large quantities of carbon dioxide (CO_2) gas in the atmosphere (Skytt et al. 2020), triggering an increase in the earth's temperature due to the current greenhouse effect (Xu and Cui 2021).

The effort to reduce greenhouse gas concentrations (emissions) in the atmosphere is to reduce the release of CO_2 into the air (Fenton 2017). For this reason, the amount of CO_2 in the air must be controlled by increasing the amount of CO_2 uptake by plants as much as possible and suppressing the release of greenhouse gas as low as possible. Naturally, the release of CO_2 into the atmosphere occurs through various mechanisms such as the respiration of living things, decomposition of organic matter, and combustion of biomass (Marchi et al. 2016). In addition, plants absorb CO_2 during photosynthesis to convert CO_2 into oxygen (O_2) (Sharkey 2021).

Banda Aceh City has an urban forest named BNI Urban Forest that was initiated after the tsunami in 2004 with a large existing urban forest of about 7.15 ha (Alfida et al. 2016). Urban forests are part of green open spaces, which function as the most effective carbon sinks and can reduce greenhouse gas emissions in the atmosphere (Lee et al. 2021; Mahmoudi et al. 2022). Besides adding to the city's beauty, the existence of urban forests can also absorb CO_2 in the air through the photosynthesis process, which can contribute to climate change mitigation (Devisscher et al. 2022; Mukhlison 2013). The different types of trees will have different abilities to absorb CO_2 in the air. Therefore, the selection of species that meet the criteria for selecting urban forest types (Conway and Vecht 2015; Morakinyo et al. 2020; Sun et al. 2022; Wu et al. 2021) and information on the amount of carbon stored by these types is important for urban forest planners to plan the development of urban forests and to absorb a high amount of carbon (Barona et al. 2022; Petri et al. 2019).

Banda Aceh City only has one urban forest as green open spaces and it has an essential role as a carbon sink. However, no previous study on carbon stock estimation and carbon sequestration was conducted on this site. Therefore, this study aimed to determine the potential carbon stocks and carbon sequestration in the BNI Urban Forest, Banda Aceh.

2. Materials and Methods

2.1. Study Area

This research was carried out from July 2021 to October 2021 in the BNI Urban Forest, Banda Aceh City (5.584585, 95.351010), with a total area of 7.15 ha. The research location was in Tibang Village, Syiah Kuala District, Banda Aceh City, with a study area of 5.48 ha (**Fig. 1**).

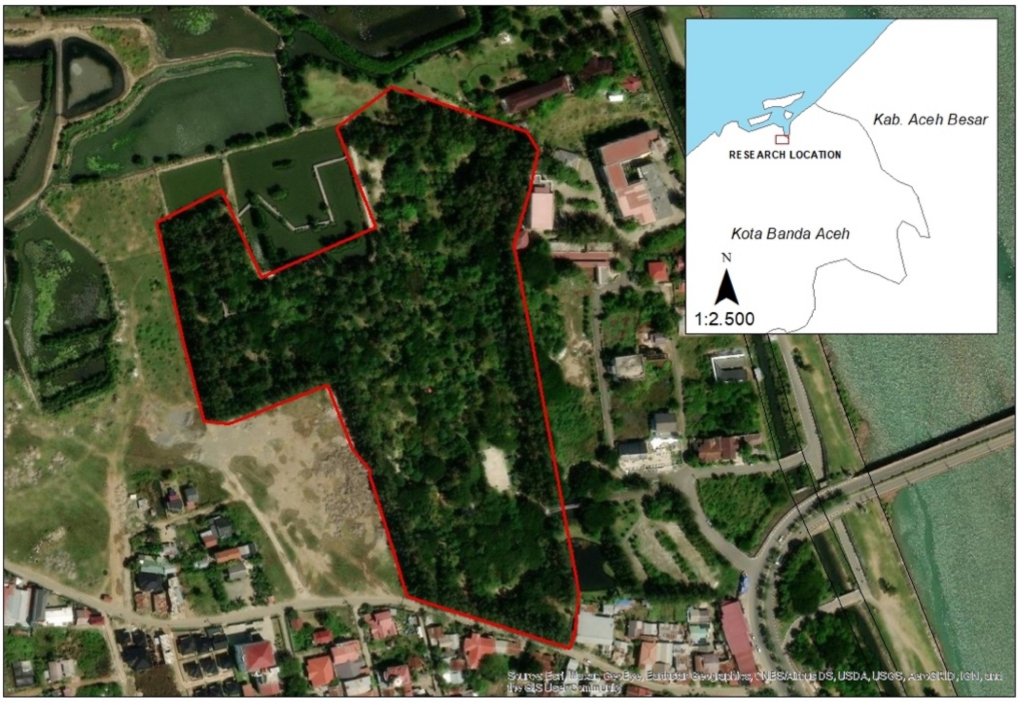

Fig 1. Research location in BNI Urban Forest, Banda Aceh, Indonesia.

2.2. Materials

The tools used were a global positioning system (GPS) tracker, roll meters (50 m), phiband for measuring tree diameter at breast height (DBH), camera, and tally sheet. The objects observed were all the trees in BNI Urban Forest Banda Aceh.

2.3. Methods

The research was conducted utilizing the vegetation analysis inventory method (Muslih et al. 2021; Ng et al. 2021). In addition, the census sampling method was carried out by recording all species and numbers of trees above ground.

2.3.1. Data collection

The data of all species and numbers of trees in the BNI Urban Forest Banda Aceh were collected. Trees that became the object of this study were trees having a DBH of more than 20 cm. Data collection was carried out using the vegetation inventory method (Rahmadwiati et al. 2022) and identifying plant diversity (Sugianto et al. 2021).

2.3.2. Data analysis

The data from the field was then calculated, including the tree diameter, tree biomass, carbon stocks, and carbon sequestration.

2.3.2.1. Tree biomass

Tree biomass is determined based on the allometric formula for tropical wood species in Indonesia (Krisnawati et al. 2012). The allometric used is allometric for mixed trees because tree stands in urban forests are highly varied.

$$AGB = -2{,}75 + 2{,}591 * In(D) \quad (1)$$

where AGB is above-ground biomass (kg), and D is tree diameter.

2.3.2.2. Carbon stocks potential

After obtaining the biomass amount, the carbon content of the biomass was calculated using Equation 2 (Badan Standardisasi Nasional 2011):

$$Cb = AGB \text{ x } \%\ C\ organic \quad (2)$$

where Cb is the carbon content of biomass (kg), AGB is above-ground biomass (kg), and *% C organic* is a percentage value of carbon content (0.47).

The carbon stock was then calculated using Equation 3 (Badan Standardisasi Nasional 2011):

$$C = \frac{\Sigma C_b}{A} \quad (3)$$

where C is potential carbon stock (ton/ha), C_b is carbon content of biomass (ton), and A is research area (ha).

2.3.2.3. Carbon sequestration

Carbon sequestration was calculated by multiplying the carbon content of biomass by the carbon conversion factor (Ali et al. 2022; Toochi 2018).

$$CO_2 = Cb \times 3.67 \qquad (4)$$

where CO_2 is carbon sequestration, Cb is the carbon content of biomass (ton/ha), and 3.67 is the conversion of element C to CO_2.

3. Results and Discussion

3.1. Tree Composition

The BNI Urban Forest Banda Aceh previously was only empty land caused by the impact of the tsunami in 2004. In 2011, the government developed the area into a cleaner and more organized urban forest as one of the green open spaces that continues to change until now. Currently, the benefits of the BNI Urban Forest Banda Aceh have been felt by the people of Banda Aceh City with the available biodiversity, improved water and soil quality, and the BNI Urban Forest Banda Aceh which is now greener and more beautiful. So that it can be said that the existence of trees that grow there enters into plants a value that can be felt (Muslih et al. 2022). Subhan et al. (2022) explained that the existence of a well-maintained urban forest would become a habitat for animals such as primates, reptiles, and birds.

Trees grow in groups consisting of 16 tree species with a total of 318 individuals. The BNI Urban Forest Banda Aceh area is dominated by *Casuarina equisetifolia*. The composition of species and number of trees in the BNI Banda Aceh can be seen in **Table 1**.

Table 1. Species composition and number of trees in BNI Urban Forest Banda Aceh

No.	Species	Family	Number of tree (individual)	Percentage (%)
1	*Acacia mangium*	Mimosaceae	6	1.9
2	*Pterocarpus indicus*	Fabaceae	15	4.7
3	*Tamarindus indica*	Fabaceae	13	4.1
4	*Pithecellobium dulce*	Fabaceae	7	2.2
5	*Ficus benjamina*	Moraceae	3	0.9
6	*Casuarina equisetifolia*	Casuarinaceae	163	51.3
7	*Delonix regia*	Fabaceae	2	0.6
8	*Senna siamea*	Fabaceae	5	1.6
9	*Lannea grandis*	Anacardiaceae	2	0.6
10	*Sterculia foetida*	Malvaceae	22	6.9
11	*Swietenia mahagoni*	Meliaceae	3	0.9
12	*Azadirachta indica*	Meliaceae	1	0.3
13	*Hura crepitans*	Euphorbiaceae	8	2.5
14	*Albizia chinensis*	Fabaceae	3	0.9
15	*Samanea saman*	Fabaceae	60	18.9
16	*Hibiscus tiliaceus*	Malvaceae	5	1.6
	Total		318	100

The most dominant tree was *C. equisetifolia* with 163 individuals (51.3%). This species is the dominant tree because BNI Urban Forest Banda Aceh is located in a coastal area where sea pine has good growth potential on nutrient-poor land. The least number is *Azadirachta indica*, with only 1 individual (0.3%). Based on the Republic of Indonesia Government Regulation Number 63 of 2002, one of the urban forests' functions is to improve and maintain the microclimate and aesthetic value following its function. Based on its topographical location in coastal areas, many *C. equisetifolia* trees are found. *C. equisetifolia* has a function in efforts to improve the microclimate, therefore improving the lighting conditions of sunlight, air pressure, and relative humidity (Harjadi 2017).

The second most dominant species in the BNI Urban Forest Banda Aceh is *Samanea saman*. This tree strongly supports the need for shade trees and producers of fresh urban air for visitors who carry out activities in the area. According to Sumardi and Widyastuti (2013), the urban forest needs trees that grow large and shady to support social functions, environmental conservation, and aesthetics. It is the reason shady trees are more commonly found in urban forests.

3.2. Tree Biomass and Carbon Stock

Table 2 shows that the amount of biomass in the Banda Aceh City Forest area is 24,669.18 kg/ha. In addition, the potential carbon stock is 11,594.51 kg/ha, and CO_2 sequestration is 42.51 tons/ha. The largest tree biomass and carbon stock were found in *C. equisetifolia*, while the smallest tree biomass and carbon stock were found in *A. indica*. This number will continue to increase along with the growth and development of trees (Ledheng et al. 2022) because the vegetation in the BNI Urban Forest Banda Aceh is still under maintenance.

Table 2. The result analysis of biomass, carbon stocks, and carbon sequestration

No.	Species	Number of Tree (individual)	AGB (kg)	C (kg)	CO_2 (ton)
1	*Acacia mangium*	6	1,991.65	936.08	3.43
2	*Pterocarpus indicus*	15	5,246.78	2,465.99	9.04
3	*Tamarindus indica*	13	4,006.77	1,883.18	6.91
4	*Pithecellobium dulce*	7	1,945.35	914.31	3.35
5	*Ficus benjamina*	3	1,307.89	614.71	2.25
6	*Casuarina equisetifolia*	163	67,717.95	31,827.43	116.70
7	*Delonix regia*	2	392.15	184.31	0.68
8	*Senna siamea*	5	2,809.63	1,320.53	4.84
9	*Lannea grandis*	2	682.19	320.63	1.18
10	*Sterculia foetida*	22	7,348.12	3,453.62	12.66
11	*Swietenia mahagoni*	3	571.15	268.44	0.98
12	*Azadirachta indica*	1	229.48	107.86	0.40
13	*Hura crepitans*	8	2,739.90	1,287.75	4.72
14	*Albizia chinensis*	3	2,970.23	1,396.01	5.12
15	*Samanea saman*	60	33,423.34	15,708.97	57.60
16	*Hibiscus tiliaceus*	5	1,804.55	848.14	3.11
Total		318	135,187.12	63,537.95	232.97
kg/ha		-	24,669.18	11,594.51	-
Ton/ha		-	24.66	11.59	42.51

Notes: AGB is above-ground biomass, C is potential carbon stock, and CO_2 is carbon sequestration.

Several studies related to the estimation of carbon stocks have been carried out. For example, Baruna et al. (2017) conducted research in the Urban Forest of the Pontianak City Hall and reported a carbon stock of 70.27 tons/ha. It can be seen that the carbon stocks in the BNI Urban Forest Banda Aceh are very small when compared to the carbon stock in the Urban Forest of the Pontianak City Hall. The different characteristics of each region cause these differences. Several factors can influence genetic factors, location, soil conditions, stand density, and management practices applied by each manager.

The biomass content and potential carbon stocks contained in the BNI Urban Forest have different amounts. An unbalanced tree vegetation structure causes this, ranging from tree species, where they grow, cropping forms still piling up, and uneven planting locations. Reducing the number of trees per hectare does not reduce the amount of carbon sequestration per hectare (Matthews et al. 2020). It was due to a significant increase in stem diameter, some leaves, and some stomata. These differences significantly affect the conditions of CO_2 sequestration and stored carbon content.

3.3. Carbon Sequestration

The potential CO_2 sequestration in BNI Urban Forest Banda Aceh was 232.97 tons, or 42.51 tons/ha (**Table 2**). It can be seen that the largest CO_2 uptake of 116.70 tons was found in *C. equisetifolia*, with a total of 163 trees. Plants at the tree growth stage will produce a higher amount of biomass and carbon than plants at the sapling and pole stages. The results show that the amount of carbon stocks positively correlates with CO_2 sequestration.

The species with the lowest potential for CO_2 sequestration was *A. indica* due to the small tree number, young plant age, and small leaves that cause the process of CO_2 assimilation to be slightly hampered and tends to be ineffective. The amount of CO_2 the plant can absorb is affected by several factors, such as plant species, site conditions, and plant density. These factors significantly affect the amount of CO_2 sequestration by certain plants, impacting differences between plants. According to Zulkifli (2010), forests consisting of trees in the growth phase can absorb more CO_2, while mature forests with small growth can store carbon stock, but the ability to absorb excess CO_2 is limited. On the other hand, forests can absorb carbon for a long time by implementing sustainable forest management. Therefore, planting vegetation on vacant land or rehabilitating damaged forests will help absorb excess CO_2 in the atmosphere.

4. Conclusions

This study identified 16 tree species in the BNI Urban Forest Banda Aceh, consisting of 8 families with a total of 318 individuals. *Casuarina equisetifolia* was the most common type of tree were 163 trees (51.3%). The results revealed that the above-ground biomass, carbon stock, and carbon sequestration by the vegetation in the BNI Urban Forest were 24.66 tons/ha, 11.59 tons/ha, and 42.51 tons/ha, respectively. This study provided data related to the existing conditions of the vegetation and the potential of carbon sequestration, which can be used to monitor and evaluate the benefits of urban forests in Banda Aceh.

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