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Diversity and Potential Carbon Services of *In-Situ* Conservation Reserve in Gunung Sepuluh Timur Forest at Balikpapan, East Kalimantan

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ABSTRACT

Establishing an *in-situ* conservation reserve is one of the strategic approaches to conserving an ecosystem and protecting it from immediate threats, including deforestation and land-use conversion. Kalimantan is one of the islands in Indonesia that is currently threatened by deforestation. To protect East Kalimantan diversity, mainly in Balikpapan, an *in-situ* conservation reserve has been established in Gunung Sepuluh Timur (GST) forest. In contrast, the information on tree diversity and how the presence of tree community within the forest can benefit the ecosystem are still limited. This research aims to assess the potential benefits and carbon storage of the GST conservation forest. The assessment method applied tree, pole, and sapling surveys combined with forest cover analysis using GIS and NDVI (Normalized Difference Vegetation Index) approaches. The GST contained 56 tree species, 25 pole species, and 16 sapling species. Diversity (H') at tree stages was the highest (H' = 0.759; 95%CI: 0.64-0.88) and H' at sapling stages was the lowest (H' = 0.719; 95%CI: 0.51-0.92). The carbon service potential of GST forest was 87.04 t C/ha on average. It was estimated that the economic benefits of GST in sequestering carbon based on the compliance market rate were equal to US$ 189,758/year.

1. Introduction

One of the benefits that a forest can provide is forest carbon services. In this mechanism, carbon sequestered by a tree in the forest can be monetized. Forest carbon services have been growing in recent years worldwide, including a payment mechanism of €11.79 annually to finance sequestration service of 68,000/t CO_{2eq}. While 819 km^2 of forest used for carbon sequestration in rainforests can yield a yearly payment of US$65/ha. The price of carbon services varies from the lowest of US$1.2 to the highest of US$88/t CO_{2eq}. In Mexico's La Primavera reserve, Torres *et al.* (2013) observed that mean implicit carbon prices obtained ranged from US$6.79 to $15.67/t CO_{2eq} depending on respondents' surveying methodology and profile. Besides the benefits of vegetation diversity beyond its function as a carbon sequester, high vegetation species richness also has significant environmental functions (Muhlisin *et al.* 2021). Those environmental benefits include provisioning, regulating services like erosion control, and supporting ecosystem services like a higher diversity of primary consumers (Hall *et al.* 2020). Higher vegetation diversity is associated with more diverse pollinating bee species that can significantly contribute to the agricultural sector (Fründ *et al.* 2013; Isbell *et al.* 2011).

More recently, rainforests are increasing at threat by deforestation. One of the deforestation's main threats is clearing activities by settlement developers, logging, and mining company operations. For gaining more areas to support developer and company operation, a company has logged the nearby forest and reduced both flora and fauna living above ground (Curran *et al.* 2004; Fitzherbert *et al.* 2008; Vijay *et al.* 2016). Expansion of the company's areas within intact rainforests has deteriorated soil quality variables

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and impacted soil hydrology and forest biological properties due to the compaction processes of pile materials from underground layers and frequent uses of heavy equipment traffic during oil refinery operations (Sancayaningsih and Mosyaftiani 2015). According to Kumar and Pandey (2013), anthropogenic activities have led to the reductions of organic material content and deterioration of environmental variables ranging from negative impacts on pH, water holding capacity, salinity, texture, nutrient, and soil compaction, to the acceleration of erosion rate.

Balikpapan is a city located in East Kalimantan Province. This province is known for its biodiversity, vegetation, and rainforests. East Kalimantan includes the Southeastern parts of the island's central mountain ranges and has a total area of 21,144 km^2 which occupies about 11% of Indonesia's territory. East Kalimantan is also a wealthy province due to its rich reserves of natural resources, including forests, oil, gas, coal, and other minerals (Fatawi and Mori 2000). As the capital city of East Kalimantan, Balikpapan is also surrounded by rainforests. Nevertheless, due to rapid development and anthropogenic pressures, the rainforest in Balikpapan has steadily declined. One of the rainforest remnants in Balikpapan is the Gunung Sepuluh Timur forest. This forest is protected and conserved through the support- and cooperation involving city officials and a refinery unit of an oil company. Establishing an *in-situ* conservation reserve in Gunung Sepuluh Timur forest was in line with Law No. 26/2007 on Urban Space Planning, which requires that open green space make up at least 30% of the total urban area. Despite establishing a conservation reserve, information on tree diversity and how the existence of tree communities within the Gunung Sepuluh Timur forest can benefit the ecosystem are still limited. Then this research aims to assess the benefits and the last remaining carbon storage from the in-situ conservation reserve in the Balikpapan landscape through measurements of NDVI and carbon storage.

2. Materials and Methods

2.1. Study Site

The study was conducted in Gunung Sepuluh Timur forest (Figure 1), Balikpapan City, East Kalimantan Province, Indonesia with latitude from 1.26510 S to 1.27430 S and longitude of 116.80870 E and 116.82300 E. The forest is located near the coast and Balikpapan Bay in the West and has 45 ha. In the South and East, the forest is bordered by settlements of Balikpapan City, while in the West and North, the forest is bordered by oil refinery areas. As part of Law

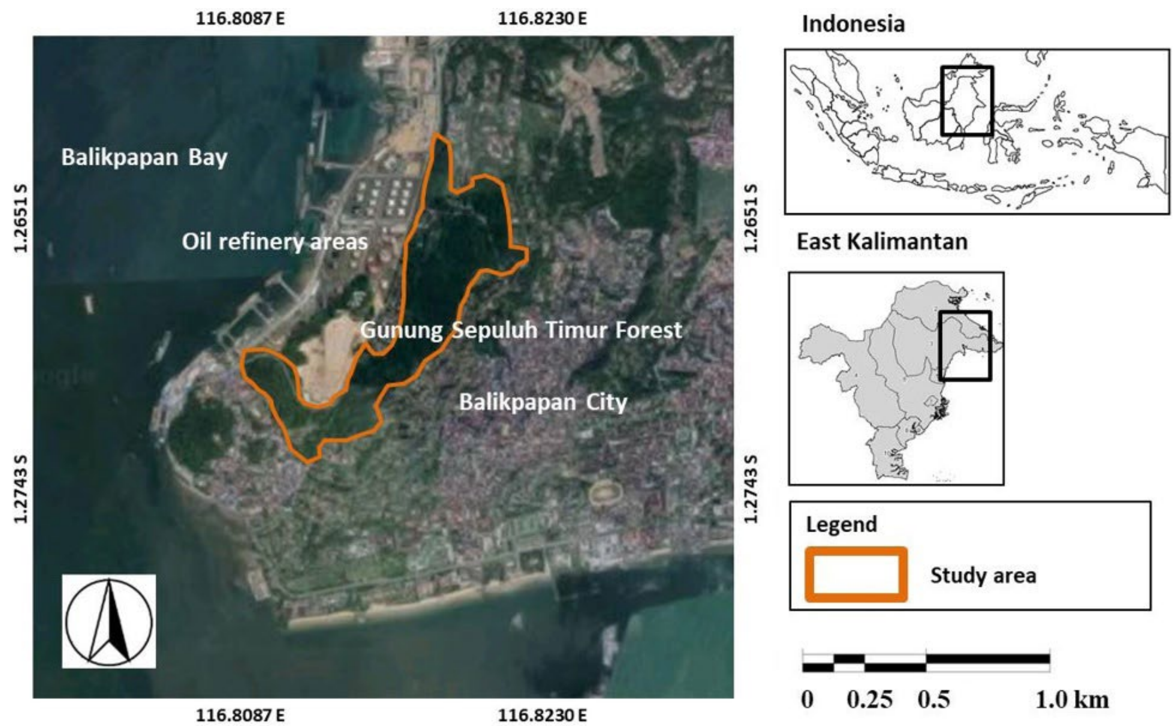

Figure 1. Map of the study site in Gunung Sepuluh Timur forest, Balikpapan City, East Kalimantan Province, Indonesia

No. 26/2007 on Urban Space Planning and ISO 14001 implementation, the oil company has collaborated with the forestry and environmental agency of Balikpapan to establish the forest as a conservation reserve. The altitude above sea level of the forest was 52 m, and the forest's biodiversity was categorized as lowland tropical biodiversity. The temperature was 26°C, with humidity of 94%, rainfall of 220 mm/month, and 16 days of rainy days per month (BMKG Samarinda 2021).

2.2. Forest Vegetation Survey

The forest vegetation surveys of the Gunung Sepuluh Timur forests were conducted following Fiqa *et al.* (2019). Vegetation analysis was carried out in the designated forest by making nested plots to record plants in three stages with a 20 x 20 m plot is for a tree (diameter at breast height/dbh ≥30 cm), a 10 x 10 m plot is for pole (30 cm> dbh >10 cm), and 5 x 5 m plot is for sapling (10 cm> dbh and height/h >1.5 m). Observations of vegetation based on their stages of three categories were done to determine the stability of the forest through the presence or absence of gaps in each phase of vegetation age. In the forest, ten sampling stations were located with three replicated nested plots, and in total, there were 30 plots for trees, poles, and saplings.

2.3. Forest NDVI

The method to measure NDVI (Normalized Difference Vegetation Index) of Gunung Sepuluh Timur forest was following Philiani *et al.* (2016), Kawamuna *et al.* (2017), and Sukojo and Arindi (2019). NDVI is described as a simple graphical indicator that can analyze remote sensing measurements, often from a space satellite platform, assessing whether the target being observed contains live green vegetation. The NDVI was measured by analyzing the wavelength of satellite images retrieved from Landsat 8 containing vegetation images and, in this study, isolated for forest cover. This measurement is possible since the cell structure of the vegetation leaves strongly reflects near-infrared light wavelengths ranging from 0.7 to 1.1 µm. The calculation of NDVI for each pixel of vegetation pixel was as follows:

The NDVI was denoted as 0 (no vegetation) to 1(high vegetation density). USING GIS, the NDVI values were then overlaid and mapped into Balikpapan City land cover layers. The forest covers are then categorized and classified by using NDVI as follows:

- if 0< NDVI <0.3 then forest covers <50%
- if 0.31< NDVI <0.4 then forest covers are 50–69%
- if 0.41< NDVI <1.0 then forest covers are 70–100%

2.4. Forest Data Analysis

2.4.1. Carbon Stock and Benefits

Carbon stock contained in the study site was measured following methods established by Widhi and Murti (2013) and Kanniah *et al.* (2014). In this method, NDVI values were used to estimate the carbon stock (ton/ha or t C/ha) following the below equation: C stock = (0.56) (197.55) (NDVI)1.39. The obtained C stock was then interpolated using GIS and set using Gunung Sepuluh Timur forest as map extent.

The benefit of estimated carbon stocks was calculated based on the monetary values of carbon stock per ton, as explained by the OECD (2021) and Fauzi and Siregar (2019). The price used was based on the Compliance Market with values of US$ 13.2/ton CO_{2eq} (Agung 2016). The equation to calculate the benefits from compliance markets is the total carbon/ha x constant (3.67) x US$ 13.2/ton CO_{2eq}.

2.4.2. Forest Vegetation Frequency

Forest vegetation data analysis was based on the frequency or numbers of occurrence of certain species for each stage (tree, pole, and sapling). The frequency denoted in % was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{(frequency of a species /}}{\text{total frequencies of all species)}} \times 100\%$$

2.4.3. Forest Vegetation Diversity

Forest vegetation diversity was assessed using Shannon-Wiener (H') indices (Asuk *et al.* 2018; Kasim *et al.* 2019; Rahmayanti *et al.* 2018). The H' was calculated as follows:

H' = Σ[Pi ln (Pi)], where Pi is the total number of tree species I in total individuals. The H range ranges from 0 (low diversity) to 1 (high diversity).

NDVI = near-invisible red wavelength - red wavelength / near-invisible red wavelength + red wavelength

2.4.4. ANOVA Test

One-way ANOVA test was used to test the effects of vegetation stage frequencies based on the stage differences (tree, pole, and sapling) on species frequency. The significance level was $p<0.05$.

3. Results

3.1. Forest Diversity and Frequency

There were 56 tree species, 25 pole species, and 16 sapling species. Figure 2 presents the diversity of plant species at the tree, pole, and sapling stages. Diversity (H') at tree stages was the highest (H' = 0.759; 95%CI: 0.64-0.88) and H' at sapling stages was the lowest (H’ = 0.719; 95%CI: 0.51-0.92). According to ANOVA, H’ was not significantly different (p = 0.829, F = 5.143) among stages. Meanwhile, the trees, pole, and sapling frequencies were significantly different (p = 0.000, F = 8.702). The calculation results show that although the tree has the highest number of tree species, the three stages have a lower frequency with a value of 1.69% (95%CI: 1.16-2.22%) (Figure 3). The second-largest frequency was owned by the pole stage with values of 3.58% (95%CI: 2.03-5.15%). In comparison, the sapling was the vegetation stage with the highest frequencies, with 5.53% (95%CI: 2.64-8.44%). It indicated that the vegetation in the sites was dominated mainly by a sapling. Figure 4 presents the rarefaction curves. The curve demonstrated that the observed plant species tend to increase as observed in tree, pole, and sapling stages and as a function of certain species' frequency

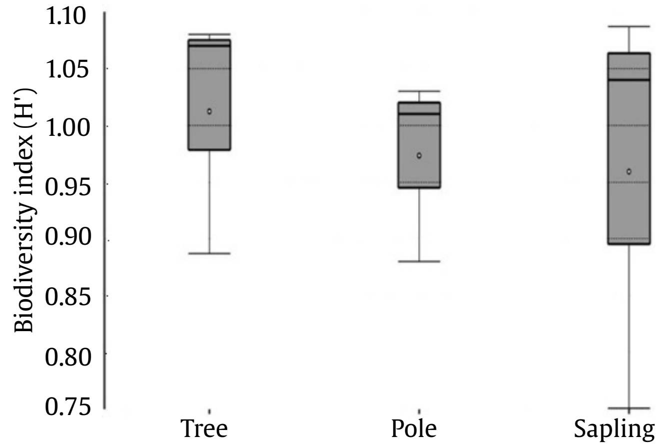

Figure 2. Average biodiversity indices (H’) of trees, poles, and saplings in Gunung Sepuluh Timur forest, Balikpapan, City, East Kalimantan Province, Indonesia

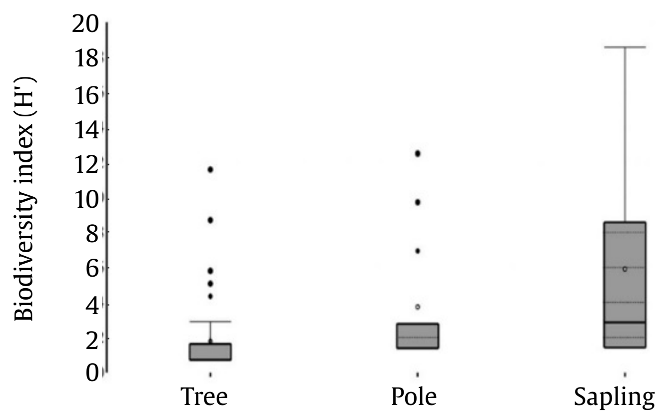

Figure 3. Average frequency (%) comparisons of trees, poles, and saplings in Gunung Sepuluh Timur forest, Balikpapan, City, East Kalimantan Province, Indonesia

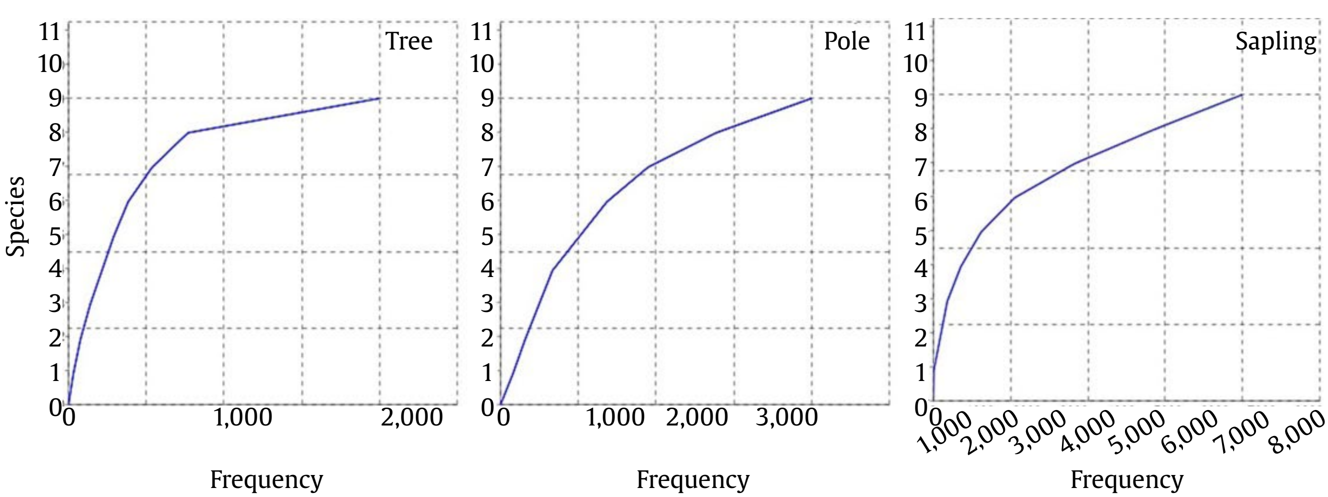

Figure 4. Rarefaction curve of trees, poles, and saplings in Gunung Sepuluh Timur

or numbers of occurrence. This indicates that further samplings and collections of more plant samples would recover more plant species. At the same time, the increasing trends were more significant at the tree stage than pole and sapling stages.

Among 56 identified tree species, *Cotylelobium melanoxylum* was the tree species with the highest frequency (11.59%), followed by *Syzygium* and *Schima wallichii* species (Figure 5). *Syzygium* was the species with the highest frequency (12.5%) for the pole community, followed by *Cotylelobium melanoxylum* and *Calophyllum nodusum* (Figure 6). For 16 sapling species, Syzygium (18%), *Calophyllum nodusum,* and *Litsea firma* were also the most dominant species (Figure 7). *C. melanoxylum* was ranked 6th among the species with the highest sampling frequencies.

3.2. Forest NDVI, Carbon Stock, and Benefits

Figure 8 represents the NDVI values of the *in-situ* conservation reserve in Gunung Sepuluh Timur forest. The conservation reserve has a higher NDVI than its surrounding landscapes. All reserve areas had NDVI values close to 1, indicating dense vegetation cover. As a comparison, some areas in the West and East have NDVI of less than one and even close to 0. In the West, those with low NDVI were the oil refinery areas. The areas in the East were the settlement areas part of Balikpapan City. Figure 9 shows the total carbon stocks of Gunung Sepuluh Timur forest. The values were derived from NDVI and calculated using an equation. Based on the calculation, the carbon service potential of GST forest was 87.04 t C/ha on average. High carbon stocks were observed in the North, East, and South parts of Gunung Sepuluh Timur forest with values closed to maximum values of 101.51 t C/ha. In contrast, lower carbon stocks were observed in central parts of the reserve, particularly those bordered directly by the oil refinery areas. The carbon stock was as low as 59.49 t C/ha in this part.

The economic benefits of Gunung Sepuluh Timur forest were expressed as the number of dollars that can be obtained from the total carbon stocks that this stock can store. The amount of money was obtained by converting the carbon stock per ton using rates of US$ 13.2/ton CO_{2eq}. This rate was following rates of compliance market of carbon stock. The final calculation obtained that for areas equal to 45 ha, the carbon storage service in Gunung Sepuluh Timur Forest has economic values equal to US$ 189,758/year.

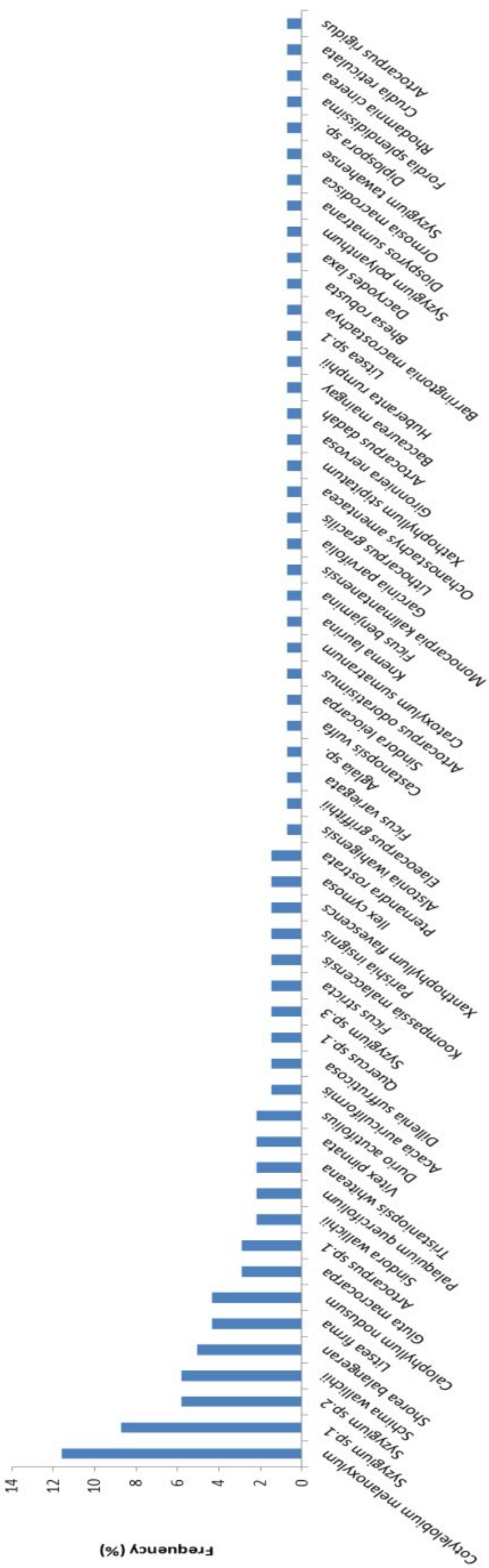

Figure 5. Frequency of 56 plant species at tree stage in Gunung Sepuluh Timur forest, Balikpapan City, East Kalimantan Province, Indonesia

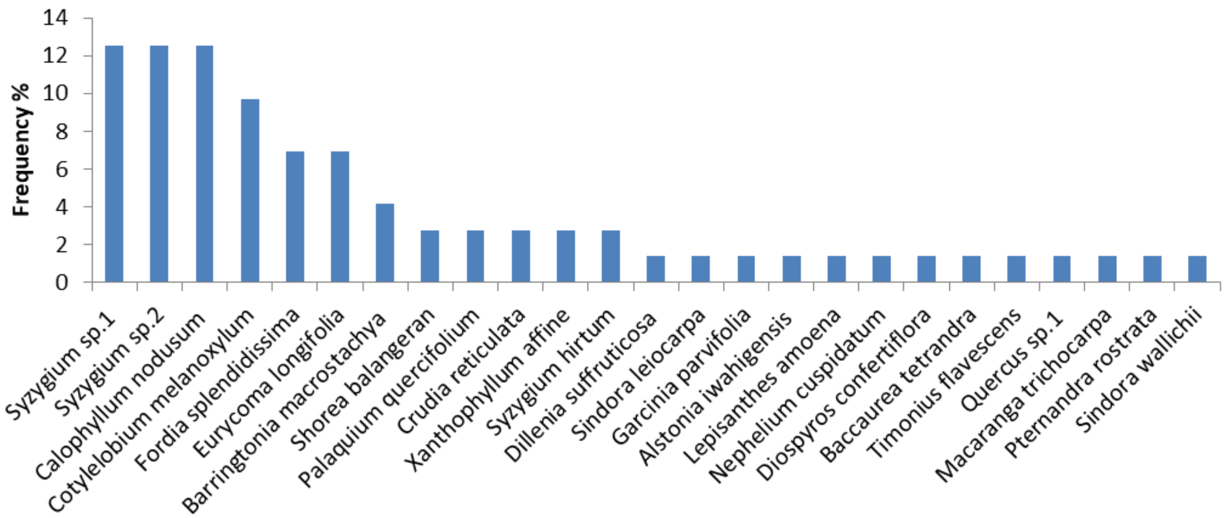

Figure 6. Frequency of 25 plant species at pole stage in Gunung Sepuluh Timur forest, Balikpapan City, East Kalimantan Province, Indonesia

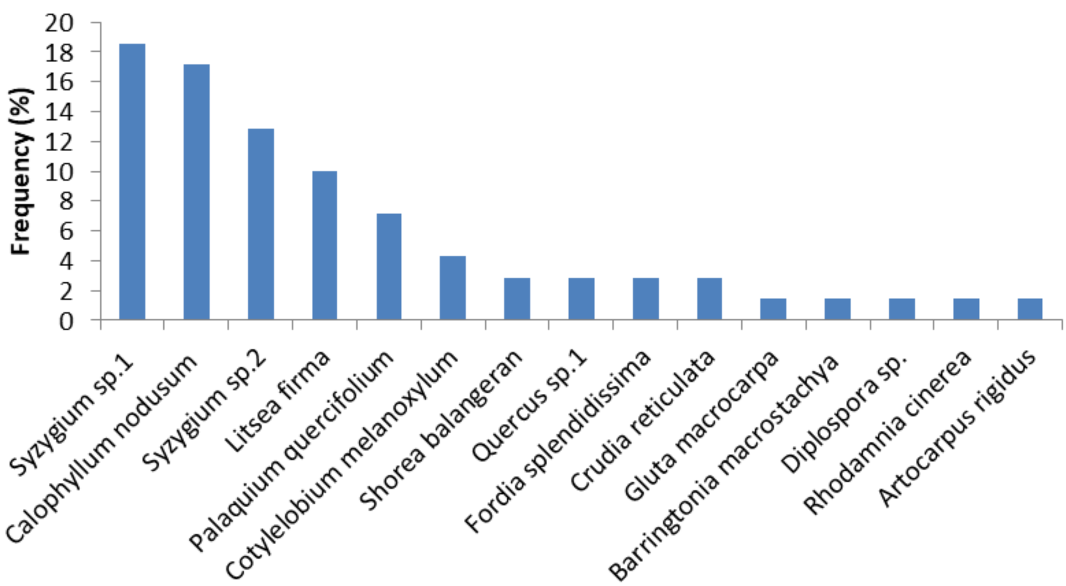

Figure 7. Frequency of 16 plant species at sapling stage in Gunung Sepuluh Timur forest, Balikpapan City, East Kalimantan Province, Indonesia

3.3. Forest Timber, Medicine, Food, and Decoration Benefits

Besides having benefits in sequestering carbon, trees in Gunung Sepuluh Timur forest also benefit timber, medicine, food, and decoration resources (Figure 10).

Thirty plant families had those benefits. Timber was the dominant benefit of the trees, followed by the medicine, food, and decoration benefits. There were 21 families recorded in the Gunung Sepuluh Timur forest, which has potential use for timber combined with other uses. Tree species that only have benefits for timber came from tree families of Calophyllaceae, Centroplacaceae, Dipterocarpaceae, Ebenaceae, and Sapotaceae. Several other families, including Dilleniaceae, Elaecarpaceae, Euphorbiaceae, Melastomataceae, Myristicaceae, Myrtaceae, Simaroubaceae, and Ulmaceae, were tree families that did not have timber benefits. Apocynaceae, Burseraceae, Clusiaceae, Fabaceae, Hypericaceae, Moraceae, Olacaceae, and Sapindaceae were tree families with more than two uses. Trees in Gunung Sepuluh Timur forest were also important sources for medicinal purposes. This can be seen since 21

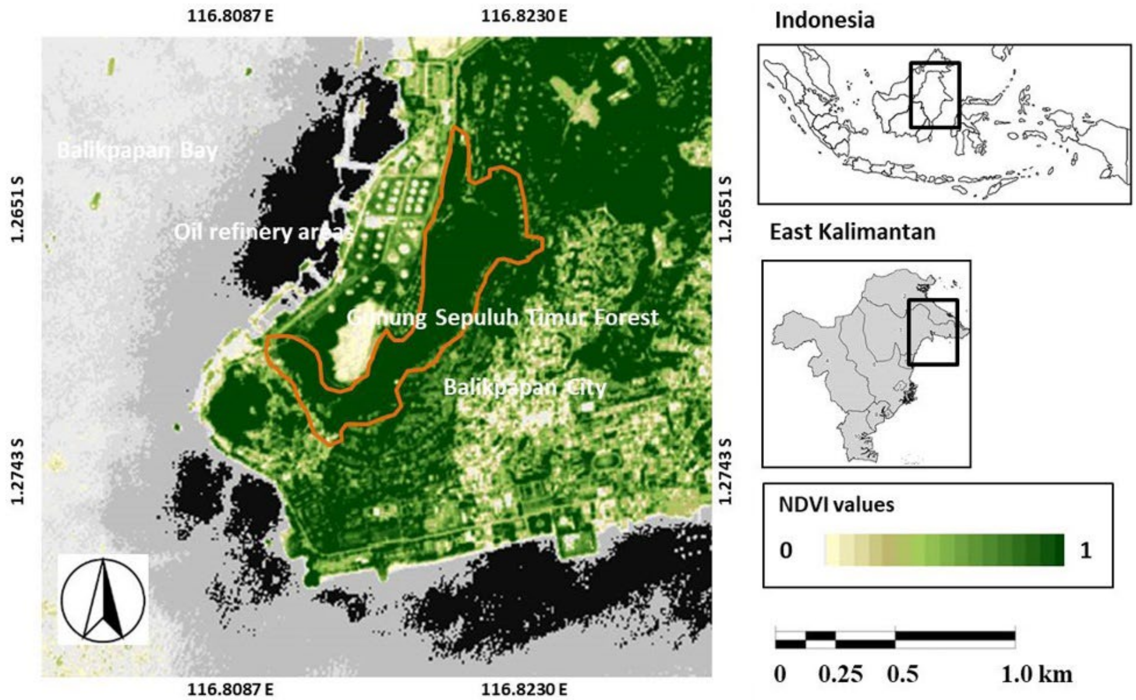

Figure 8. Map of NDVI values in Gunung Sepuluh Timur forest, Balikpapan City, East Kalimantan Province, Indonesia

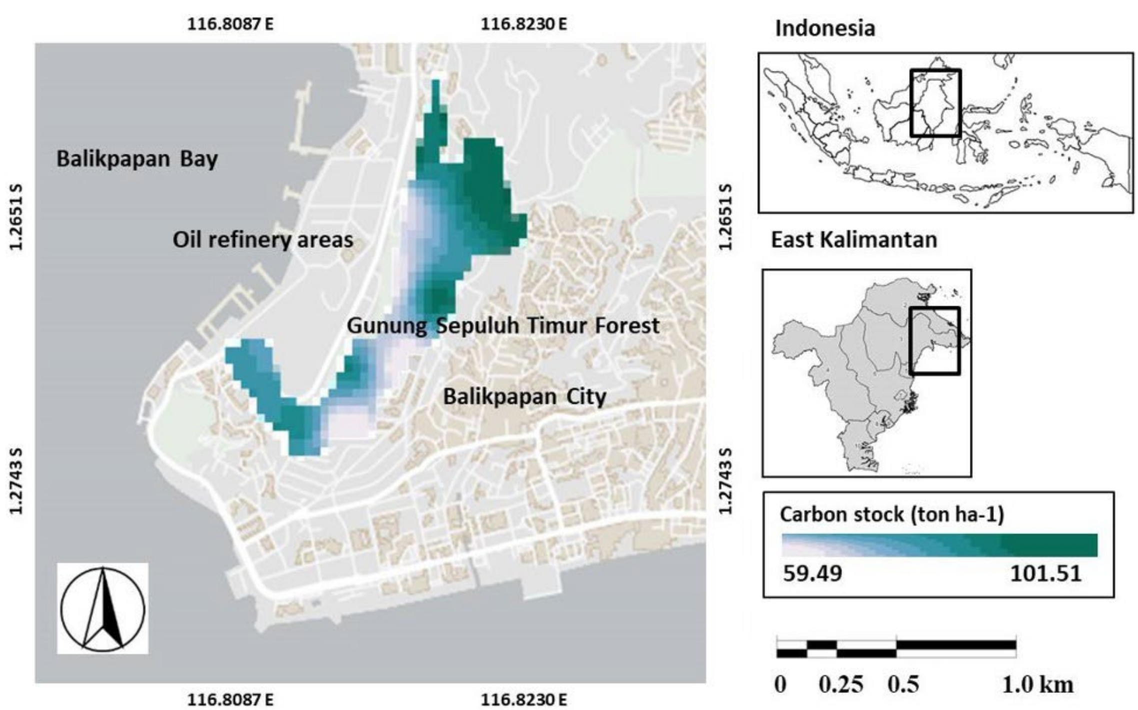

Figure 9. Map of carbon stock (ton/ha) in Gunung Sepuluh Timur forest, Balikpapan City, East Kalimantan Province, Indonesia

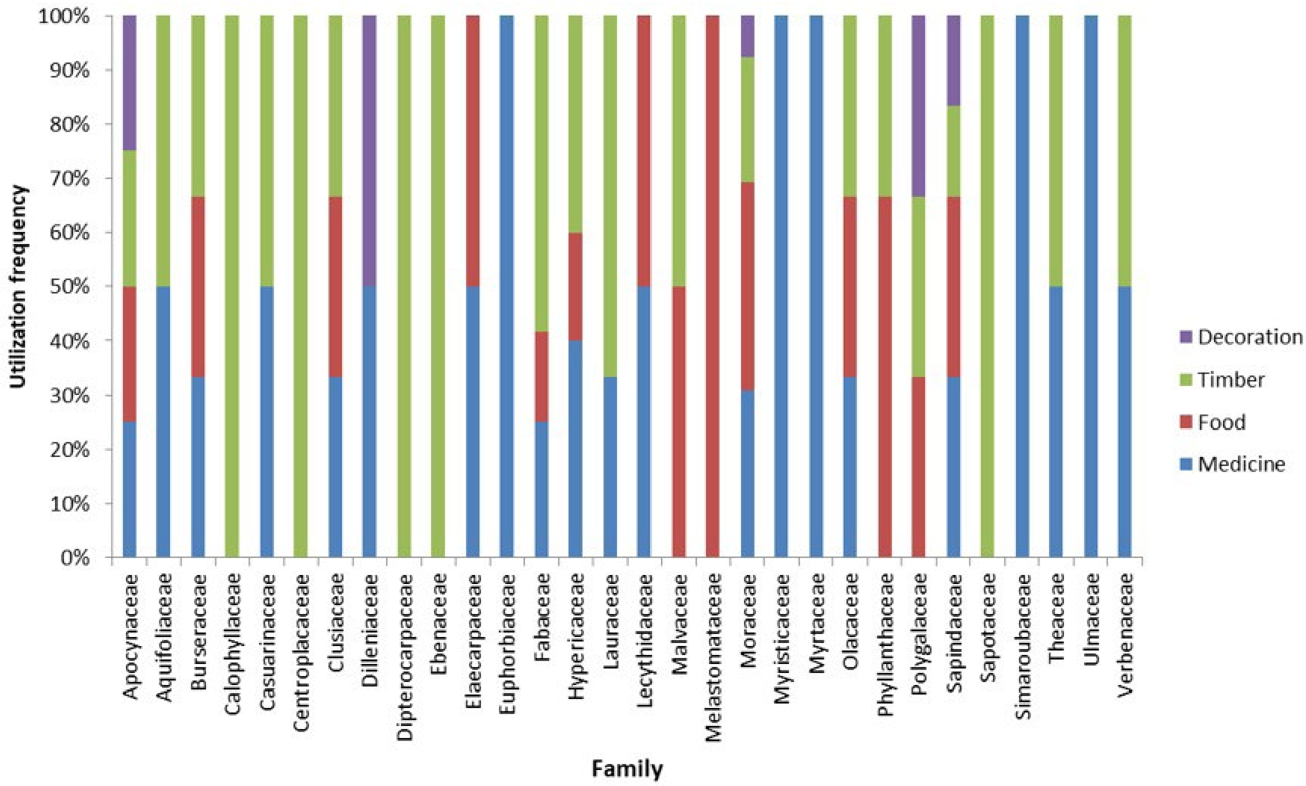

Figure 10. Timber, medicine, food, and decoration benefits of tree families in Gunung Sepuluh Timur forest, Balikpapan City, East Kalimantan Province, Indonesia

families, or 70% of tree families, provide medicinal ingredients.

4. Discussion

The H' value in this study is low since it is less than 1, indicating the dominance of some species. Despite low tree diversity, the vegetation in our study still has benefits, significant contributions, and important environmental services. The dominance of single species at the tree stage is characterized by a large diameter at breast height and can still contribute to carbon sequestration. In comparison to this study, He *et al.* (2013) confirmed that forests with single-species stands, H' is less than 1, also known as monoculture, had carbon storage of 314.59 t C/ha, or only 3.97% lower than forest stands with multiple tree species.

In this study, tree and sapling stages have a difference in diversity and abundance. Despite saplings' having a lower diversity, the results confirm that saplings have a higher frequency than trees and poles. Despite the lower frequency, saplings can still sequester carbon. In this study, saplings were growing in the vicinity of Gunung Sepuluh Timur forest since saplings require more sunlight for photosynthesis. The sunlight is abundant in the vicinity of the forest, which is more open with less canopy cover. The carbon stock in this vicinity equals 59.49 t C/ha. The results of this study are consistent with carbon stocks that can be sequestered by saplings, as observed in other studies. In forest stands in India, sapling stands can sequester carbon equals 56.59 t C/ha (Jhariya and Yadav 2018).

In this study, *Cotylelobium melanoxylum* was the most common plant species found to be abundant at tree and pole stages. In terms of economic values, *C. melanoxylum* had many benefits. According to Susilowati *et al.* (2019), for a longtime local people in Tapanuli, North Sumatera Province, Indonesia have used woods of *C. melanoxylon* as raw materials for constructing houses, bridges, and boats. The advantage of this wood species was related to its high quality, durability, and resistance to termites, a major threat to the woods, especially in tropical areas. Some parts of *C. melanoxylon* have been consumed for medical purposes. The bark of *C. melanoxylon* contained ampelopsin F., isoampelopsin F., ε-viniferin, vaticanol A, E, G, and lyoniresinol that important ingredients for traditional medicine (Matsuda *et al.* 2009). Pasaribu and Sipayung (2007) noted that the *C. melanoxylon's* bark also contains flavonoids that can be used as antidiabetic and have tannins and saponins compounds for antimicrobial.

Leaves of *C. melanoxylon* can also be used to treat wounds as practiced by the indigenous people.

The *C. melanoxylon* is always available at every plant stage, indicating this complete species occurrence. The high frequency of *C. melanoxylon* at the tree stage was in agreement with Susilowati *et al.* (2019). In Bona Lumban forest, North Sumatra, *C. melanoxylon* was also common tree species. In comparison, *C. melanoxylon* frequency was lower at the sapling stage. The low frequency of a certain sapling species indicates that this species has been facing certain environmental constraints. This condition might be a consequence of the disrupted seed dispersal, the vulnerability of the seed from decaying, or even the isolation process and characteristic changes in the soil. *C. melanoxylon* sapling was a specific microsite due to its preference for good drainage soil and good light intensity (Khurana and Singh 2001a, 2021b). While the canopy closure of Gunung Sepuluh Timur forest was high, as indicated by high NDVI values. This may reduce the light intensity needed by sapling and contribute to the lower density of *C. melanoxylon* at the sapling stage in the Gunung Sepuluh Timur forest.

Another potential species in the Gunung Sepuluh Timur forest was *Syzygium* sp. The abundance of this species at the tree stages was outnumbered by *C. melanoxylon*, while *Syzygium* sp. was abundant at the pole and sapling stages. The high abundance of *Syzygium* sp. at both stages indicated the potential of this species to be used. While *Syzygium* sp. has low timber value, considering its chemical contents, the chemical properties of this species show significant benefits. *Syzygium* sp. is known to have significant concentrations of bioactive compounds with biological activity proven to promote human health. The bioactive compounds were found in all parts of *Syzygium* sp., including the fruit, leaves, seeds, flowers, and stems (Pazzini *et al.* 2021). As confirmed by Zulcafil *et al.* (2020), the antidiabetic compounds of *Syzygium* sp. are safe to be consumed. The availability of *Syzygium* sp. at any stage indicates the sustainability of using this species for commercial medicinal purposes in the long term.

This result indicates the benefits of natural resources in this case of the in-situ conservation area of Gunung Sepuluh forest, which is in line with another research. Because Balikpapan was located near the coast, Balikpapan Bay, this city also has another important resource. Lahjie *et al.* (2019) have observed that the direct benefits of the natural products from the mangrove ecosystem of Balikpapan Bay can yield IDR 742,425,000/year or U.S. \$0.933/person/day from mangrove wood production alone. In comparison, the total income from fishing is IDR 1,019,056,640/year or U.S. \$1.28 person/day. The highest observed mangrove wood production was reached at the age of 25 years, and the highest value of mean annual increment (MAI) is 5.39 m^3/ha at the age of 40 years (Ratnasari and Sukojo 2017). This fact indicates the significant economic benefits of the Balikpapan landscape, including its *in-situ* conservation reserve located in Gunung Sepuluh Timur forest.

In Gunung Sepuluh Timur forest, most trees have benefits for medicinal and timber purposes, and only a few were used as food and decoration resources. This finding was in agreement with data in other forests. Medicine and timber resource seem to be the major benefits of forests in the tropical forest. Similar to the Gunung Sepuluh Timur forest results, trees in a conservation reserve in mining areas and East Kalimantan (Fiqa *et al.* 2019) were mainly dominated by timber and medicinal trees. In Kalimantan Forest, species found in the conservation area were potential for timber, either major or minor. Several trees recorded in this study were the most widely used tree for timber (Sheoran and Poonia 2010). Those timber trees include species from families of Calophyllaceae (Mohiuddin 2000), Centroplacaceae, Dipterocarpaceae (Rana *et al.* 2009), Ebenaceae (Wanda *et al.* 2019), and Sapotaceae (Deklerck *et al.* 2021).

Table 1 informs the benefits in the form of carbon stock in Gunung Sepuluh Timur forest that was comparable to the carbon stocks from other areas. The carbon stock in Gunung Sepuluh Timur forest

Table 1. Comparisons of forest carbon services and economic benefits (t C/ha = US\$13.20) (Agung 2016) from other locations

Location	Area	Carbon stock (t C/ha)	Total value (US\$/year)	Resources
Gunung Sepuluh Timur, East Kalimantan	45 ha	87.04	189,758	This study
Production forest, Kalimantan	na	119.43	na	Prayitni (2008)
Urban forest, Tangerang, Banten	2.5 ha	86.28	10,541	Nugraha (2011)
Pine forest, Halimun Salak National Park, West Java	7 ha	96.5	32,723	Polosakan *et al.* (2014)
Sekaroh protected forest, East Lombok	300 ha	244.87	3,504,824	Fauzi and Siregar, (2019)
Village forest, Bone, South Sulawesi	0.04 ha	7.25	14.048	Wiratman (2019)

was lower than the location in Sekaroh protected forest, East Lombok considering differences in forest status and size of forest. The search was a protected and isolated forest that could avoid any constraints and disruptions hindering seed dispersal and even tree growth. In contrast, Gunung Sepuluh Timur forest was surrounded by settlements and routine oil refinery activities, and this forest may experience any environmental disruptions and even logging. Another reason was the Sekaroh forest has a larger area about 300 ha than Gunung Sepuluh Timur (45 ha). Large landscapes contain larger catchment areas that are important to provide water resources to support vegetation (Jupri 2021; O'Connor 2001). Carbon stock in Gunung Sepuluh Timur forest was closed to the urban forest values in Banten. The forest in Banten shares some similarities with this study. Gunung Sepuluh Timur forest was an intact forest that has been surrounded and influenced by urbanization. Considering the geographical condition, Banten was located in a low land ecosystem, and this is similar to the Gunung Sepuluh Timur forest at an altitude of 52 m. This also indicates that forests in Gunung Sepuluh Timur and Banten were experiencing similar climates, resulting in similar carbon stocks.

In this study, the economic benefits of carbon stock were using rates estimated at US$13.20/t following Agung (2016). Carbon stock price is very dynamic. Until recently, there has been no fixed carbon stock price yet, and the prices were varied. Whereas, Pukkala (2020) has calculated the possible upper limit of carbon stock prices. The upper limit was estimated at €100/t or equal to US$119/t. Payment of €100/t or more will increase carbon sequestration by 70%. This is almost the most significant possible increase obtained through carbon subsidies.

In conclusion, Based on the results obtained in this study, the conservation reserve plays an important role in *in-situ* conservation. This is indicated by high plant species diversity in all vegetation stages ranging from tree to sapling. NDVI analysis also indicated high vegetation covers that lead to carbon stock potential. Calculation of economic benefits obtained from carbon storage in Gunung Sepuluh Timur forest yielded a value of US$ 189,758/year for 45 ha that can be obtained through carbon sequestration alone. Economic values of carbon stocks were not the only benefits obtained from Gunung Sepuluh Timur forest. The conserved trees in this forest also have value as resources for timber, medicine, food, and decoration purposes. Then the *in-situ* conservation reserve established in Gunung Sepuluh Timur forest has contributed significantly to the forest and society in Indonesia, particularly in East Kalimantan.

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