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Aboveground Blue Carbon Stock Assessment of Bakhawan Eco-Park Mangrove Plantation in New Buswang, Kalibo, Aklan, the Philippines

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Abstract

The purpose of this study was to determine the aboveground biomass density, blue carbon stock, and monetary value of the mangroves at Bakhawan Eco-Park Mangrove Plantation in New Buswang, Kalibo, Aklan. There were 21, 45 × 45-meter sampled plots established, equivalent to 5% sampling intensity of the plantation's total area. The number of sample plots was distributed in proportion to the area of the plantation in the specific year it was established. The quadrant and random sampling methods were used. All trees in a quadrant were identified, and the biomass density was calculated using the wood density of various mangrove species. Carbon stock was calculated by multiplying the biomass density by 0.46 or 0.5. The monetary value of C was calculated using the benefits transfer method at $5/ton. The results showed that the plantation established in 1990 had the highest biomass density (Mg/ha) and carbon stock (Mg/ha) with 132 Mg/ha and 66.02 Mg/ha, while the plantation established in 2015 had the lowest biomass density and carbon stock (Mg/ha) with 69.98 Mg/ha and 34.99 Mg/ha. Overall, the estimated total monetary value of Bakhawan Eco-Park of 250 hectares mangrove plantation in New Buswang, Kalibo, Aklan is PhP 2994771.63.

Keywords

Biomass Density, Monetary Value, Mangrove Species, GSP Device, KASAMA

1. Introduction

The Mangrove was globally recognized for being highly important in terms of ecological, economic, social, and cultural due to the variety of goods and benefits it provides. Mangroves provide benefits such as coastal protection from strong winds and waves, as well as the preservation of fisheries and biodiversity in coastal and estuarine water masses [1]. The area covered by mangroves has decreased from 6,025,000 ha in 2010 to 5,329,000 ha in 2015 [2]. Many mangrove stands are on the verge of extinction as a result of conversion to aquaculture ponds, agricultural farms, oil palm plantations, and settlement areas [3] [4]. Mangroves were also overlooked in national forest conservation and biodiversity protection plans due to a lack of understanding of their ecological and economic values [5]. Given the difficulties in mangrove conservation, a collaborative research project was launched to synthesize the best practices and challenges in mangrove rehabilitation in the Philippines. Numerous planting efforts implemented were unsuccessful due to the lack of science-based approach guidelines [6] [7].

Bakhawan Eco-Park, which spans 250 acres, was founded in 1990. The goal of this reforestation project was to reduce floods and storm surges in the local community while also providing a source of income for the locals. The Kalibo Save The Mangrove Association (KASAMA), a non-governmental organization, began the reforestation project with the creation of 50 hectares of reclaimed land in Barangay New Buswang with the assistance of the Kalibo, Aklan local government, and the Department of Environment and Natural Resources (DENR). Furthermore, Bakhawan Eco-Park is the most successful mangrove reforestation project in the Philippines and the main tourist attraction in Kalibo. Mangrove rehabilitation is critical in many tropical countries, including the Philippines, to address climate change. Mangroves serve as both CO_2 sources and sink into the atmosphere [8].

By sequestering atmospheric CO_2, mangrove species can reduce the amount of excess carbon in the air, lowering the amount of greenhouse gas that contributes to global warming. Greenhouse gases can account for up to 26% of the greenhouse effect [9]. Nonetheless, carbon storage is a critical ecosystem service provided by mangroves. Carbon storage and sequestration have recently been identified as one of the environmental services provided by mangrove forests [10] [11] [12]. To address this gap in Bakhawan Eco-Park aboveground carbon stock inventory are important to gain a scientific understanding of mangrove ecosystems and in relation to human activities, it may contribute to sustainable management and conservation of mangrove forest. The main objective of this study is to assess the aboveground blue carbon stock of the Bakhawan Eco-Park mangrove plantation. Specifically, this study aims to 1) determine the aboveground biomass density and carbon stock of mangroves (Mg/ha); 2) provide the estimated monetary value of the aboveground carbon stock of mangroves in the Bakhawan Eco-Park mangrove plantation.

2. Review of Related Literature

In Southeast Asia, mangrove forests grow along the tidal seas. Mangroves provide a habitat for a wide variety of biodiversity, including aquatic and terrestrial insects, fish, crustaceans, mammalian, amphibian, reptilian, and avian species. Mangrove forests have very high levels of above-ground biomass (AGB) as well as very high levels of below-ground biomass (BGB), resulting in carbon storage levels comparable to those measured in dense Amazon rainforests [9]. These forests provide important ecosystem goods and services to the region's dense coastal populations while also supporting important biosphere functions. Mangroves are threatened by both natural and anthropogenic stressors, but the current state and dynamics of the region's mangroves are unknown [13]. Despite their ecological and socioeconomic value, mangrove forests in South Asia are being lost or degraded due to both natural (e.g. coastal erosion, disturbances from tropical cyclones and tsunamis) and anthropogenic factors (conversion to other land use, over-harvesting, pollution, decline in freshwater availability, flooding, and reduction of silt deposition) factors [14] [15] [16] [17] [18]. Mangroves are increasingly being affected by climatic fluctuations, including those caused by human activity [19]. Simultaneously, mangroves are gaining recognition for their role in food provision, coastal protection (e.g., from large storms), biodiversity reserves, and as a large carbon store [10] [20].

Mangrove forest, which accounts for 0.4% of the world's forests, is the most threatened tropical forest ecosystem [21]. Asia experienced massive loss, with a 1.9 million ha deficit recorded since 1980, at a rate of 102,000 ha per year 1. Approximately half of the Philippines' original mangrove forest has vanished since its discovery in the early 1900s. Two major causes of this decline are the overharvesting of mangrove trees for fuelwood and pole, as well as the massive expansion of aquaculture ponds over mangrove domains [22]. Local communities play critical roles in reducing deforestation. They must be actively involved in developing policies and plans for sustainable forest management and programs to strengthen their commitment to forest conservation efforts and ensure equitable access to forest benefits [23]. Unfortunately, current mangrove harvesting policies are punitive; as a result, people who planted mangroves are disillusioned by the loss of harvesting rights [24] [25] [26].

2.1. Status of Philippines Mangrove

The Philippines is a 36,300-kilometer-long archipelago with mangrove forests, sea grass beds, and coral reefs. These marine habitats provide food and other goods and services to more than half of the country's 1500 towns and 42,000 villages. There are approximately 30 - 40 species of major and minor mangroves in the Philippines, belonging to 15 families [27] [28]. Mangroves are mostly found in the tropics and subtropics [29]. A more recent estimate reduces this to around 153,577 hectares, but the majority of this is found in Palawan, which is about 41,830 hectares [30]. The average biomass of the country's mangrove forest is around 401.8 Mg/ha, with approximately 176.8 Mg/ha of carbon stored [31]. These figures are roughly half of the carbon stored by an old growth, which ranges from 370 to 520 Mg/ha [32]. *Rhizophora*-dominated mangrove stands, in particular, have high biomass and carbon density [33].

2.2. Mangrove

Mangrove is a type of forest that grows along tidal mudflats and shallow water coastal areas, extending inland along rivers, streams, and tributaries with brackish water. The primary producer in the mangrove ecosystem is mangrove trees, which interact with associated aquatic fauna, and social and physical factors of the coastal environment. There are 47 true mangroves and associated species from 26 different families in the mangrove flora. True mangroves grow in mangrove habitats, but associated species can also be found in beach forests and lowland areas. A useful field guide to some Philippine mangrove species has been published by the Department of Environment and Natural Resources (DENR), Region 7 [34]. Mangrove communities are made up of biotic components such as plants, animals, and microbial organisms that are well adapted to intertidal environments. However, none of these can be identified as a community in a mangrove ecosystem without the presence of actual mangrove plants (trees and shrubs), implying that true mangrove vegetation is the most important component of the ecosystem. Mangrove vegetation defines the landscape and participates in the ecological processes that occur in this ecosystem, either directly or indirectly [35]. Furthermore, mangrove forests are an important ecosystem because they enrich coastal waters by producing commercial forest products, protect coastlines from storms and floods, and provide habitat, breeding, and spawning grounds for marine fisheries. Furthermore, by slowing water flow and sedimentation, mangrove forests can improve nutrient levels. This process deposits nutrients from a variety of sources, including agricultural leaching [36]. Mangrove forest survival and ecosystem health are critical to the long-term productivity and stability of coastal environments in the Philippines [37]. Mangroves help to produce fisheries, which provide food and a living for millions of coastal residents. They also protect the coastline from natural disasters like typhoons, storm surges, coastal erosion, and rising sea levels. Their ability to perform ecological functions, however, is dependent on the extent and health of the forest's ecosystem [38].

2.3. Mangrove's Plantation and Rehabilitation Initiatives

Governments, nongovernmental organizations, and aid agencies are now enthusiastically promoting mangrove reforestation and management throughout South and Southeast Asia, and increasingly in Africa, the Caribbean, and Latin America. Moreover, local people are frequently viewed as potential partners in such reforestation efforts, and it is widely assumed that their participation will improve reforestation success by cultivating local stewardship of newly planted forests [39].

Southern Luzon has the most extensive mangrove areas in the country, but it is also the most vulnerable to anthropogenic impact and natural disasters. Mangrove planting is a regular activity in all of its provinces. Planting sites are typically along the shoreline and use *Rhizophora* species [40]. The low survival rate is usually attributed to poor species-substrate matching as well as poor planting location and timing. Like most mangrove rehabilitation programs in the country, most mangrove planting activities in the region are more of afforestation' (which affects existing nearby habitats such as seagrass beds and mudflats) than reforestation of denuded mangrove areas [41]. However, mangrove planting for coastal protection has primarily occurred in the Visayas region of the central Philippines, where the numerous islands are more vulnerable to typhoons than the larger islands of Luzon to the north and Mindanao to the south. Mangroves were planted in Negros in the 1930s and 1940s, and in Bohol in the 1950s and 1960s, primarily for wood supply and typhoon protection [42] [43] [44]. To halt deforestation, DENR established a tenure program known as the Community-Based Forest Management Agreement (CBFMA) with the local community. Thinning or selective cutting was then permitted for domestic use but not for commercial purposes. This tenure program also resulted in the formation of a formal organization known as the Banacon Fisherfolks and Mangrove Planters Association, or BAFMAPA. Since regular funds for plantation development were established, CBFMA has further bolstered the local community's mangrove-planting tradition. With vast areas of plantations today, there is also a strong local interest in commercially harvesting them for additional income. The DENR, on the other hand, remains steadfast in its cutting ban due to the enduring rule of Republic Act 7161 [23].

We view these challenges as opportunities for new and larger constituencies to be involved in rehabilitation and restoration. Restored mangrove ecosystems can be purposefully designed and engineered to provide valuable ecosystem services, adapt to climatic changes, and create platforms for educating no-specialists about the successes and failures of restored mangrove ecosystems. The single most important factor in designing a successful mangrove restoration project is determining the normal hydrology (depth, duration, and frequency, as well as tidal flooding) of existing natural mangrove plant communities ([*i.e.*,] a reference site) in the area in which you wish to do restoration [45]. The actual planting of mangrove propagules is frequently used but rarely required unless the goal is a monoculture or forest plantation, or if stem-density targets must be met faster than natural regeneration would allow [46] [47] [48].

2.4. Carbon Stock

Climate change is a major challenge of the twenty-first century as a result of the continuous release of greenhouse gases into the atmosphere. Carbon dioxide is one of the primary gases responsible for this climatic anomaly. Carbon dioxide in the atmosphere traps and radiates heat that is leaving the atmosphere [49]. Mangrove ecosystems are potentially well suited to these climate change mitigation strategies due to their large carbon stocks and the numerous other critical ecosystem services they provide [50]. Because of its potential role in CO_2 sequestration, mangrove restoration has recently been considered a climate change adaptation and mitigation strategy [51].

Carbon stock assessment, according to [52], is an important step in carbon accounting and the consideration of land use options and strategies to promote carbon sequestration. Changes in carbon stock as a result of land use change dynamics may result in either carbon emission or sequestration. Forest ecosystems have been identified as playing important roles in climate change phenomena due to their ecological CO_2 based on this premise [8]. As a result, estimating carbon stocks and changes in carbon stocks in various forest carbon pools in relation to carbon trading has become critical [53].

3. Material and Methods

3.1. Materials

In the conduct of the study, different materials were used such as a camera, record book, ballpen, straw lace, compass, Diameter tape, scientific calculator, and tree caliper for the collection of data. Quadrant samples were located using a GPS device in obtaining the coordinates and elevation.

3.2. Methods

3.2.1. Location and Site Description

Bakhwan Eco-Park, with a total land area of 250 hectares of mangrove forest plantation, was geographically located between 11.7180˚N and 122.3857˚E in New Buswang, Kalibo, Aklan. Mangrove species such as Bakauan Babae (*Rhizophora mucronata*), Bakauan Lalaki *(Rhizophora apiculate*), Bakauan Bato (*Rhizophora stylosa*), Kulasi (*Lumnitzera racemose*), Pagatpat (*Sonneratia alba*), Api-api (*Avicennia officinalis*), and Tagibi (*Xylocarpus granatum*) were found throughout the plantation. KASAMA managed this Eco-Park in collaboration with the DENR, NGOs, and local governments.

3.2.2. Site Selection and Sampling Method

Site selection was based on the age and area of the plantations through a quadrant sampling method laid out with 45 × 45 meters (2025 m^2). There are six (6) subdivided areas separated by five (5) years of age. Each area was divided into plots with a sampling intensity of 5%.

To avoid bias the plots were sampled using random sampling and quadrant sampling. There were established four (4) plots in the area of 50 hectares, One (1) plot in Ten (10) hectares, Two (2) plots in 20 hectares, and eight (8) plots in 100 hectares.

3.2.3. Data Collection

Mangrove species were identified in the quadrant. Mangrove species with a diameter of 10 cm or greater were used as sample plants to calculate carbon stock

(**Table 1**). A measuring tape was used to measure the diameter at breast height (DBH) at 1.37 m above the ground.

- For prop-rooted species (*Rhizophora* spp.), stem diameter was often measured above the highest prop root [54] [55].

Dead-standing trees were also recorded with the same measurement as living trees. However, the decay status of dead trees was recorded based on the description below:

Status 1: small branches and twigs were retained; resemble a live tree except for the leaves.

Status 2: No twigs or branches may have lost a portion of large branches.

Status 3: Few or no branches, standing stem only: maybe broken-topped. These require a different approach to biomass estimation.

1) Biomass Density (Mg/ha)

Aboveground biomass for mangrove species and mangrove association was calculated using the allometric equation by [55].

$$\text{Aboveground biomass density}\left(\text{Mg/ha}\right) = 0.251(D)^{2.46}$$

where: P = is the wood density of the species

D = is the diameter at breast height

All tree biomass for each plot was summed to get the total biomass expressed in Mg/plot and converted into hectares (Mg/ha).

2) Aboveground Blue Carbon Stock Determination

All Biomass density (Mg/ha) was covered to the equivalent amount of carbon by multiplying the biomass density by 0.46 or 0.5, which was the average C content value based on [57].

All trees of carbon stock for each plot were summed to get the total carbon stock expressed in Mg/plot and converted into hectares (Mg/ha).

3) Carbon Stock (Mg/ha) of Mangrove Plantation

The total carbon stock (Mg/ha) of the mangrove plantation was determined by multiplying the amount of carbon stored per hectare of its total area.

4) Estimation of Monetary Value of Carbon Stock

The economic value of aboveground carbon stock was estimated using the benefits transfer method.

Table 1. Wood density of different mangrove species [56].

Common name	Scientific name	Family name	Wood density (g/cm^3)
Api-api	*Avicennia officinalis*	Acanthaceae	0.72
Bakauan Babae	*Rhizophora mucronata*	*Rhizophor*aceae	0.82
Bakauan Bato	*Rhizophora stylosa*	*Rhizophor*aceae	0.84
Bakauan Lalaki	*Rhizophora apiculata*	*Rhizophor*aceae	0.85
Kulasi	*Lumnitzera racemosa*	Combretaceae	0.87
Pagatpat	*Sonneratia alba*	Lythraceae	0.51

The value of aboveground carbon stock was based on the assumption that the average value per ton C is US$ 5.00 based on the estimation of the carbon benefits association with tree planting [58] [59]. This value is within the range of the values reported particularly in the countries of Asia with almost similar socio-economic conditions in the Philippines and judged as the most appropriate value as follows:

Current carbon value for mangrove plantation:

$$\text{CCVp} = \text{CCS}(\text{Mg/ha}) \times \text{Pv} \times \text{Pd}$$

where:

CCVp = current carbon amount (plantation)

CCS = current carbon benefits (Mg/ha)

Pv = average value of ton carbon (US$) for plantation

Pd = Peso Dollar exchange rate which is ₱50.88/US$ 1 as of November January 2018.

5) Total Monetary Value of Mangrove Plantation

The total monetary value of a mangrove plantation was determined by multiplying the amount of carbon stored per hectare of every mangrove plantation by its total area.

3.2.4. Data Analysis

Data from the field were tabulated and analyzed using mean and average. Simple statistics and comparisons of computed data were used to interpret and analyze the data gathered.

4. Results and Discussion

4.1. Aboveground Biomass Density of Mangrove Species

As shown in **Table 2**, the average biomass of mangrove species at different ages of plantation with five (5) years age gap.

The highest biomass density was observed in 1990, with an average of 132.03 Mg/ha, while the lowest amount of biomass density was observed in 2015, with an average biomass of 69.98 Mg/ha. Lower biomass density was observed in 2015 due to its lower species composition, which included only three mangrove species and was newly planted in comparison to other plantations. However, higher

Table 2. Average biomass density (Mg/ha) of mangrove plantation.

Year Planted	Age	Biomass density (Mg/ha)
1990	27	132.03
1995	22	126.96
2000	17	77.97
2005	12	71.09
2010	7	92.07
2015	2	69.98

biomass density was observed in the year 1990 with a 27-year-old plantation, which was affected by species composition, age of plantation, diameter at breast height, and wood density; the same observation was made by [26] in his study on a 40-year old plantation, which contains 823.7 Mg/ha biomass density. [60] demonstrated in their study in a 27-year-old plantation in Samar, Philippines, with 282.64 Mg/ha biomass density, which was comparatively higher than the result of this study (132.03 Mg/ha) due to the larger research area and higher species composition.

The second highest biomass density was obtained in the year 1995 with a 22-year old plantation having an average biomass density of 126.96 Mg/ha, followed by the year 2010 (92.07 Mg/ha), the year 2000 (77.97 Mg/ha) with 17-year old plantation and year 2005 with an average biomass density of 71.09 Mg/ha with 12-year old plantation. The observation third highest biomass density with a 7-year-old plantation was obtained in the year 2010 since it was mainly composed of Pagatpat (*Sonneratia alba*) and Api-api (*Avicennia officinalis*) species, having an average biomass density of 158.75 Mg/ha and 108.50 Mg/ha respectively. The literature revealed that Pagatpat and Api-api species has also the ability to grow faster [60].

4.2. Aboveground Carbon Stock of Mangrove Species

The aboveground carbon stock of mangrove plantations ranged from 34.99 to 66.02 Mg/ha, as shown in **Table 3**. It has been discovered that the oldest plantation (27 years old) established in 1990 has a higher carbon stock stored than the newly established plantation in 2015 (with 2 years of age).

Plantation established in the year 1990 stored the highest average amount of 66.02 Mg/ha carbon for the reason that it was the oldest plantation in the area composed of five species of mangrove having an average diameter range of 10 - 35 cm (**Table 3**). It was followed by a 1995 plantation with the second highest carbon stock of 63.48 Mg/ha. In the year 2000, the amount of carbon stored was

Table 3. Average carbon stock (Mg/ha) of mangrove plantations at different ages.

Mangrove Plantation					
Year Planted	Age	Area (ha)	Biomass density (Mg/ha)	Carbon Stock (Mg/ha)	Total Carbon (Mg/ha/plantation)
1990	27	50	132.03	66.02	3301.00
1995	22	10	126.96	63.48	634.80
2000	17	20	77.97	38.99	779.80
2005	12	20	71.09	35.14	702.80
2010	7	100	92.07	46.04	4604.00
2015	2	50	69.98	34.99	1749.50
Total		**250**	**570.10**	**284.55**	**11771.90**

TC = Carbon stock multiplied by the total area of the plantation.

38.99 Mg/ha, which was influenced by a lower average number of individuals per species, which was 830 per ha. Plantations established in 2005, on the other hand, had an average carbon stock of 35.14 Mg/ha, which was lower than in the year 2000. Despite having the same plantation area of 20 hectares, it was influenced by its age and the number of individuals per hectare. Furthermore, the lowest carbon stock was obtained in 2015, at 34.99 Mg/ha. It was influenced by the plantation's age and the lower number of mangrove species, which included *Rhizophora stylosa*, *Rhizophora apiculata*, and *Sonneratia alba* found that the carbon stock of a 40-year-old plantation was estimated to be 370.7 Mg/ha, which is higher than the result of this study (66.02 Mg/ha carbon stored by a 27-year-old plantation). This is due to the differences in plantation year and diameter class. The plantation established in 2010 can store a total carbon of 4604 Mg/ha in a 100-ha area, followed by the plantations established in 1990 and 2015 in 50-ha areas with 3301 and 1749.5 Mg/ha, respectively. A 20-ha area yielded 779.8 and 702.8 Mg/ha in the years 2000 and 2005, respectively. While the lowest carbon stored was 634.8 Mg/ha in 1990 in a 10-ha area.

In total, the Bakhawan Eco-Park mangrove plantation stored 11771.90 Mg/ha of carbon over a 250-ha area. The results show that the higher the biomass values and plantation area, the greater the amount of carbon stored. Furthermore, varying topography, hydrologic regime, erosion, and exposure to currents may be significant factors for faster growth and survival of mangrove forests, thereby affecting carbon stock [60]. Reduced emissions from deforestation and forest degradation, as well as sustainable forest management and the conservation and enhancement of forest carbon stocks (REDD+), are critical components of global efforts to mitigate climate change. Because of their large ecosystem carbon stocks, mangroves have potential value in climate change mitigation strategies and carbon mitigation programs such as (REDD+).

4.3. Estimated C Benefits Monetary Value

The monetary value of carbon benefits was calculated using the average value of C per ton, which is US$ 5.0 [58] [59]. As shown in **Table 4**, these values were used to calculate the monetary value of C benefits in mangrove plantations. The highest monetary value calculated was in 1990, with a monetary amount of PhP 16,795.49 per hectare due to the highest C stored among other plantation ages (**Table 4**). 1995, 2010, 2000, 2005, and 2015 were the years that followed. The lowest value was calculated in 2015, with a monetary value of PhP 8901.46.

The values in **Table 4** for different years of the plantation were solely based on services rendered in capturing C and did not include any other direct benefits that could be derived. The estimated total amount of carbon stored by a 100-hectare plantation established in 2010 will be PhP 1.1 M. The carbon stock values obtained in the smaller 50-hectare plantation established in 2015, on the other hand, will be the lowest estimated amount of PhP 445072.8 because the results were primarily influenced by species composition, age, and diameter at

Table 4. The estimated monetary value of carbon stored.

Mangrove Plantation				
Year Planted	Area (ha)	Carbon stock (Mg/ha)	Monetary value (PhP/ha)	Total Monetary Value (PhP/ha/plantation area
1990	50	66.02	16,795.50	839,774.4
1995	10	63.48	16,149.31	161,493.12
2000	20	38.99	9919.06	198,381.12
2005	20	35.14	8939.62	178,792.32
2010	100	46.04	11,712.58	1,171,257.6
2015	50	34.99	8901.46	445,072.8
Total	**250**	**284.66**	**72,417.53**	**2,994,771.36**

1 kg = 5US$, *1US$ = PhP 50.88. TMV = monetary value multiplied by the total area of the plantation.

breast height. The estimated total monetary value of Bakhawan Eco-250 Park's hectares of mangrove plantation in New Buswang, Kalibo, Aklan was PhP 2994771.36. The observed variation in the total monetary value of carbon was influenced by the plantation's age and size.

5. Conclusion and Recommendations

The Bakhawan Eco-Park mangrove plantation provides the most important service in climate change mitigation, storing an average of 11771.90 Mg/ha carbon worth PhP 2994771.36. This study recommended expanding and increasing the area of the mangrove plantation to store more carbon in mitigating climate change and providing disaster protection. To conduct enrichment planting to improve growth and productivity, as well as to apply silvicultural practices such as thinning and pruning to improve the growth performance of mangrove species, which will provide an alternative source of income. Further research on the belowground carbon stock is in order to have data on the belowground carbon stock and continuous monitoring of the aboveground carbon stock of Bakhwan Eco-Park mangrove plantation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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