INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 24, No. 3, p. 117-129, 2024
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Assessment of standing biomass and litter-fall production in reforested mangrove stands within Douala-Edea National Park (Cameroon)

Laurant Nyamsi-Moussian[1], Gordon N. Ajonina[2], Guillaume L. Essomè-Koum[2], Ernest F. Kottè-Mapoko[3], Boubakary[4], Alphonse Konango-Samè[1], Vanessa M. Ngo-Massou[5], Jean M. Emanè[1], Ndongo Din[*1]

[1]*Department of Botany, Faculty of Sciences, The University of Douala, Douala, Cameroon*

[2]*Department of Aquatic Ecosystems Management, Institute of Fisheries and Aquatic Sciences at Yabassi, The University of Douala, Douala, Cameroon*

[3]*Department of Fisheries Management, Institute of Fisheries and Aquatic Sciences at Yabassi, The University of Douala, Douala, Cameroon*

[4]*Department of Biological Sciences, Faculty of Sciences, The University of Maroua, Maroua, Cameroon*

[5]*Department of Biological Sciences, Higher Teacher's Training College, The University of Yaounde I, Yaounde, Cameroon*

Article published on March 17, 2024

Key words: Allometric equation, Blue carbon, Ecological balance, Ecological engineering, *Rhizophora* ssp.

Abstract

Ecological restoration is considered like the practical and sustainable management option for degraded mangroves. The ecological status of reforested mangrove areas (RMAs) in Douala-Edea National Park (DENP) is not well understood, despite extensive restoration projects. This study aims to estimate standing biomass and litterfall production in three RMAs located in Bolondo and Yoyo II. In each RMA and it natural vegetation, five 10m × 10m permanent sampling plots (PSPs) were established. Thirty PSPs were established equally in RMAs and natural vegetation. Height and diameter measurements were recorded, and allometric equations were used to estimate above-ground biomass (AGB) and below-ground biomass (BGB). In addition, 150 litter traps (1m × 1m) were evenly distributed across the PSPs to collect monthly litterfall, which was dried, sorted, and weighed. Mean abundances, diameters, and heights were: 4000±200 ind./ha, 1.2±0.5 cm, and 1.8±0.3 m; 3280±238.74 ind./ha, 2.58±0.85 cm, and 5.64±1.87 m; 2160±240.83 ind./ha, 2.93±1.4 cm, and 3.34±1.26 m for 3-year, 6-year and 11-year RMAs respectively. AGB, BGB, and annual litterfall biomass were: 11.98±0.76 kg/ha, 13.88±1.3 kg/ha, and 40.78±7.42 g/m²/year for 3-year RMAs; 61.18±2.16 kg/ha, 55.19±1.92 kg/ha, and 397.75±75.79 g/m²/year for 6-year RMAs; and 55.25±2.93 kg/ha, 47.8±1.31 kg/ha, and 576.23±106.75 g/m²/year for 11-year RMAs, respectively. These values correspond to approximately 12.31±2.19, 52.08±1.6, and 46.26±1.1 kgC/ha of total carbon sink and 18.27±3.48, 179.09±4.44, and 259.3±8.89 kgC/ha/year of total annual litterfall carbon sink. Although 6-year RMAs showed higher AGB and BGB than natural vegetation, the values remained lower overall. In contrast, 11-year RMAs exhibited higher annual litterfall production, indicating progress towards ecological balance.

***Corresponding Author:** Ndongo Din ✉ din.ndongo@yahoo.com

Introduction

Globally, mangroves cover an area of 137,000 km² (Spalding and Leal, 2021). These tropical coastal forest ecosystems are renowned for their high biomass productivity and carbon sequestration capacity (Alongi, 2011; Chowdhury *et al.*, 2023). On average, a minimally disturbed mangrove sequesters 1087±584 MgC/ha (Sasmito *et al.*, 2020). The conservation of mangroves is crucial for the well-being of local human communities and the fight against global warming (Din *et al.*, 2016; Kathiresan *et al.*, 2021).

However, mangroves are under threat from both natural and human-induced pressures, leading to a reduction in vegetation cover (Golberg *et al.*, 2020; Emanè *et al.*, 2021). Between 1996 and 2016, the rate of deforestation of mangroves was estimated at 4.3 % (Spalding and Leal, 2021). During the period of 2000-2012, almost 1646 km² of the world's mangrove area disappeared. Along its western Atlantic coast, Cameroon has 1113 km² of mangroves (Hamilton and Casey, 2016). Over the last two decades, these mangroves have been subject to increased anthropisation, which has led to a considerable decrease in vegetation cover (Din *et al.*, 2017). The mangroves in Douala-Edea National Park (DENP) are also affected by this issue. According to Ajonina and Usongo (2001), the annual regression rate of these mangroves was estimated to be 53 ha before 2000. Similarly, Findi and Wantim (2022) observed a regression rate of 58.38 % between 2011 and 2015 using satellite image analysis. For at least three decades, these mangroves have been the primary source of firewood used for smoking fish in various fishing camps and surrounding households (Ajonina, 2008).

In response to this ecological disaster, various options for mangrove conservation have been implemented worldwide, including restoration. Mangrove restoration refers to a set of human actions aimed at re-establishing ecological processes that accelerate the recovery of forest structure, ecological functioning, and biodiversity to levels typical of climax forest (Elliott *et al.*, 2013). According to Worthington and Spalding (2018), over 190,147 km² of mangroves were restored globally by 2018. In Central Africa, Ajonina *et al.* (2016) reported that over 500 ha of degraded mangroves were reforested before 2017. Reforestation of degraded mangroves in Cameroon officially began in 2009 and continues to this day. In 2023, Planète-Urgence's NGO implemented the planting of 40,000 seedlings in the mangroves of Bolondo fishing camp village located in DENP, with the involvement of governmental organizations and other partners (Planète-Urgence, 2023).

Mangrove restoration projects face numerous obstacles worldwide, often resulting in partial or complete failure (López-Portillo *et al.*, 2017; Worthington and Spalding, 2018; Ellison *et al.*, 2020; Lhosupasirirat *et al.*, 2023). These failures not only cause ecological damage but also result in significant financial losses, with the average cost of restoring one hectare in Central Africa estimated at US$ 3200 (Ajonina *et al.*, 2016). Lee *et al.* (2019) identified the absence of a comprehensive database for monitoring and assessment restoration projects as a major obstacle to mangrove restoration efforts.

There is a lack of information on the structure and functioning of restored mangrove areas along the African Atlantic coast (Zabbey and Tanee, 2016). To our knowledge, in Cameroon, there is only one specific study on mangrove restoration which is limited to determining the main abiotic factors that influence the growth of seedlings in nurseries (Boubakary *et al.*, 2019). No published scientific study has yet been conducted on the monitoring and assessment of standing biomass and litterfall production of reforested mangrove areas in the DENP. However, quantifying the biomass of reforested areas would be crucial for safeguarding mangroves in the DENP and for improving climate change mitigation strategies (Malik *et al.*, 2020). Furthermore, it is essential to incorporate the monitoring of objectively verifiable indicators of ecosystem functioning, such as litterfall production into any restoration project (Dahdouh-Guebas and Cannicci, 2021). To contribute improvement of mangrove restoration projects in DENP, this study aims to assess the impact of mangrove reforestation through the estimation of both standing biomass carbon stock and litterfall production of three reforested mangrove areas with reference to their respective adjacent good natural stands.

Materials and methods

Study site

The study site is located in the mangrove areas of the Douala-Edea National Park (DENP), which lies between latitudes 3°14′ N-3°50′ N and longitudes 9°34′ E-10°03′ E. Mangroves occupy 39202.2 ha of the DENP, or 14.91% of its surface, and belong to mangroves of the Cameroon Estuary (Fig. 1). The research was conducted in the mangrove areas adjacent to two fishing camps (Bolondo and Yoyo II) in the Mouanko district (Fig. 1). The climate is equatorial and belongs to the Cameroonian domain. It is characterised by a short dry season (December to February) and a long rainy season (March to November with peak rainfall in September). The annual mean temperature is around 26.7°C (Ngo-Massou *et al.*, 2016). Additionally, the tide follows a semi-diurnal pattern. Five characteristic mangrove species (*Avicennia germinans* (Linn.) Stearn, *Nypa fruticans* (Thurnb.) Wurmb, *Rhizophora harrisonii* Leechman, *Rhizophora mangle* Linn. and *Rhizophora racemosa* Meyer) are abundant, associated with two other species (*Ficus* sp. and *Raphia* sp.) (Ajonina, 2008).

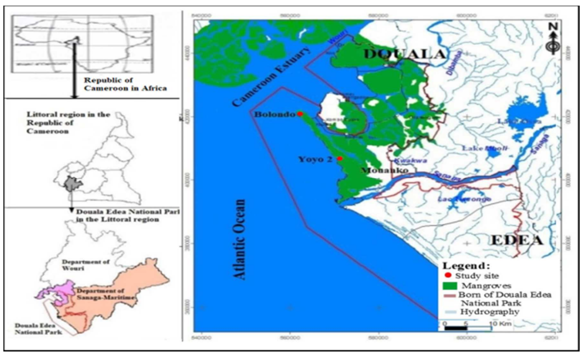

Fig. 1. Location of studied sites (Modified from Ajonina and Chuyong, 2011).

Data collection

Study design

Data were collected in three reforested mangrove areas (RMAs) of different ages in two fishing camp village: Bolondo (one RMA of 6 years old) and Yoyo 2 (one RMA of 3 years old and other of 11 years old). In each RMAs, 5 Permanents Sampled Plots (PSPs) of 100 m² (10 m × 10 m) were installed. In addition, 5 PSPs were established in the natural vegetation adjacent to each RMA to serve as a reference. A total of 30 PPEs were installed, 15 in the three reforested areas and 15 in the adjacent natural vegetation. The reference sites were chosen based on the studies conducted by both Bosire *et al.* (2006) and Wang'ondu *et al.* (2014) in the Gazi Bay of Kenya, Ferreira *et al.* (2015) in Jaguaribe River in Brazil, Pradisty *et al.* (2022) in the Perancak River in Indonesia.

Measurements

All fieldwork was conducted during low tide. In each PSP, plant species were inventoried and height was determined either by using a graduated stick or a Suunto PM-5360-degree clinometer. Diameter at breast height (DBH) was measured using a Vernier caliper for young trees and a forestry diameter tape for older trees.

Litterfall collection

Litterfall refers to all organic debris from plants that decompose on the surface of the ground. To estimate litterfall production, five litter traps of 1 m² (1 m × 1 m) were installed in each PSP (Pradisty *et al.*, 2022) (Table 1). The traps were made using polyester sieves with a pore size of 0.5 mm and they were set up to collect as much litterfall as possible from each PSPs. Two installation methods were used in the field depending on the average height of the individuals: (1) for the 5 PSPs in which the height of individuals was less than 3 m, traps were suspended by stakes at an average height of 1.5 m from the ground (Fig. 2A); (2) for the other 25 PSPs in which the height of individuals was more than 3 m, the five litter traps were suspended on branches of the trees (Fig. 2B).

Table 1. Main information about PSP and litter traps

Site	Sampled area	Vegetation type	Area (ha)	Initial theorical density of reforested mangroves (individuals/ha)	Age of vegetation (in years)	Number of PSP	Number of litter traps
Bolondo	Bol-Plant1	Reforested	0.6	3333	6	5	25
	Bol-Nat1	Natural	ND	-	ND	5	25
Yoyo II	Yoy-Plant1	Reforested	1	2500	11	5	25
	Yoy-Nat1	Natural	ND	-	ND	5	25
	Yoy-Plant2	Reforested	2	4444	3	5	25
	Yoy-Nat2	Natural	ND	-	ND	5	25
Totals	6	2	-	-	-	30	150

Bol: refers to the name of the Bolondo study location; Nat: indicates natural stands; ND: Not Determined; Plant: indicates reforested stands; Yoy: refers to the name of Yoyo II study location.

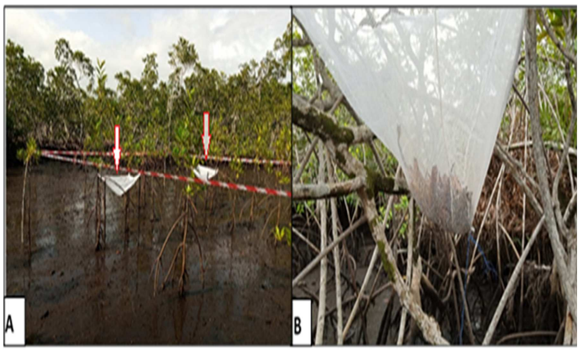

Fig. 2. Installation of litter traps in PSPs: A. for individuals less than 3 m high (traps indicated by arrows); B. for individuals more than 3 m high

Fig. 3. Litterfall treatments: A. Collection of samples in the field, B. Oven drying, C. Twigs weighing, D. Flowers weighing

The collection was conducted monthly for a period of 12 months, from October 2020 to September 2021. Biological samples were collected, labelled, and stored in plastic zip bags before being transported to the laboratory (Fig. 3A). The samples were then repackaged in A4 paper envelopes, labelled accordingly, and oven-dried at 70°C until a constant mass was achieved (Fig. 3B). The average drying time was 72 hours. The plant parts were dried and sorted into flowers, leaves, twigs, and seed-fruits. They were then weighed using a Zhi Heng Digital Jewelry Scale, model ZH-8256, to the nearest 0.01 g (Fig. 3C-D).

Data analysis

Vegetation structure

The study utilized data from plant species inventories and individual measurements to calculate several vegetation indices in accordance with (Kauffman and Donato, 2012). These indices include Abundance (A), Densities (D), basal area of woody species i (STi), average diameter (dm), average height (Hm), and Complexity Index (CI). To compare the vegetation structure, individual diameters and heights were divided into 5 classes. The diameter classes were (in cm): <3, [3-5[, [5-7[, [7-10[and >10 while the height classes were (in m): <3, [3-5[, [5-7[, [7-10[and >10.

Estimation of standing biomass and carbon stock of reforested mangrove areas

In Permanent Sampling Plots (PSPs), three biomass compartments were estimated: above-ground biomass (AGB), below-ground biomass (BGB), and litterfall production (refer to section 1.2.2). The standing biomass value was calculated as the sum of above-ground and below-ground biomass (Kamruzzaman *et al.*, 2017).

Allometric equations

AGB and BGB rates of each individual PSP were estimated using the following specific allometric equations:

AGB (Fromard *et al.*, 1998):

A. germinans: AGB = $0.14(DBH)^{2.4}$;

Rizhophora spp.: AGB = $0.1282(DBH)^{2.6}$;

BGB (Komiyama *et al.*, 2008):

General equation: BGB = $0.199\times\rho^{0.899}$ $(DBH^{2.22})$. ρ: wood density of considered species. For *A. germinans*: ρA: 0.661 g/cm^3; for *Rhizophora* spp.: ρR = 0.883 g/cm^3.

The selected allometric equations were based on the diameter ranges of the sampled individuals in reforested areas, which are similar to those used for their design. To estimate biomass per hectare, the PSP-derived values were extrapolated. Carbon stocks for above-ground, below-ground, and litterfall were estimated by multiplying AGB, BGB, and litterfall production by their respective carbon concentration coefficients: 0.5, 0.39, and 0.45, as outlined by Kauffman and Donato (2012).

Statistical analysis

Statistical tests, including ANOVA and t-tests, were conducted to compare parameter values between reforested mangrove areas (RMAs) and their corresponding adjacent natural vegetation. Descriptive statistics and significance tests were performed using the 'R Commander' package of R software version 4.1.3. Histograms and biomass variation curves were generated using Excel 2013. The study considered RMAs of various ages and their corresponding adjacent natural vegetation in the form of treatments, with their PSPs considered as replicates.

Results and discussion

Status of vegetation of RMA

Composition plant species and density

In the sampled areas, a total of three species from two genera and two families were identified. Two species of the Rhizophoraceae family, *Rhizophora mangle* L. and *Rhizophora racemosa* Meyer, were found in the Reforested Mangrove Areas (RMAs), while *Avicennia germinans* (L.) Stern (Acanthaceae) and *R. racemosa* were identified in the adjacent natural vegetation. All sampled areas, except for Bol-Nat1, were monospecific. The study found that the abundances of RMAs were 4000±200 ind./ha, 3280±238.74 ind./ha and 2160±240.83 ind./ha for the 3-year, 6-year and 11-year mangrove stands respectively. These abundances showed a negative trend with respect to the ages of vegetation, mean diameters, mean heights and complexity indices (Table 2). This trend could be explained by a progressive increase in competition between individuals for environmental resources, which would lead to a reduction in woody individual abundance over time. The abundance of RMAs decreases with the age of vegetation in the Gazi Bay in Kenya and in the Rufiji Delta in Tanzania, as observed by Kairo *et al.* (2008) and Monga *et al.* (2022).

Distribution of diameters and heights

The mean diameters of individuals were 1.20±0.5 cm, 2.58±0.85 cm, and 2.93±1.4 cm for RMAs aged 3 years (Yoy-Plant2), 6 years (Bol-Plant1), and 11 years (Yoy-Plant1), respectively (Table 2). The Student's statistical test showed no significant difference between the diameters of individuals in the RMAs Bol-Plant1 and Yoy-Plant1 (Table 2). The majority of individuals in the RMAs were concentrated in the <3 cm class (Yoy-Plant2 (100%), Bol-Plant1 (63.63%), and Yoy-Plant1 (59.09%)) (Fig. 4). Concerning the higher extremity, only individuals from adjacent good natural stands had representatives in last two intervals.

The heights of individuals in Yoy-Plant2, Bol-Plant1, and Yoy-Plant1 were 1.8±0.3 m, 5.64±1.87 m, and 3.34 ±1.26) m, respectively (Table 2). The Student's t-test did not reveal any significant difference between the heights of individuals in the RMAs Bol-Plant1 and Yoy-Plant1. The distribution of height classes shows that the individuals of RMAs had heights below 10 m (Fig. 5).

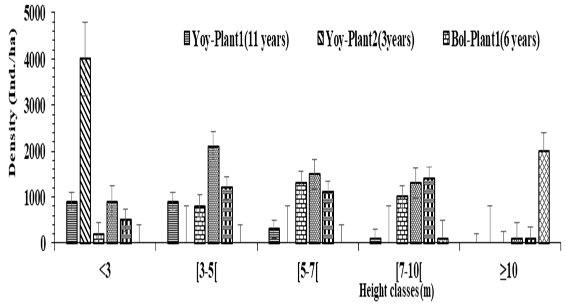

Fig. 4. Distribution of Diameter classes

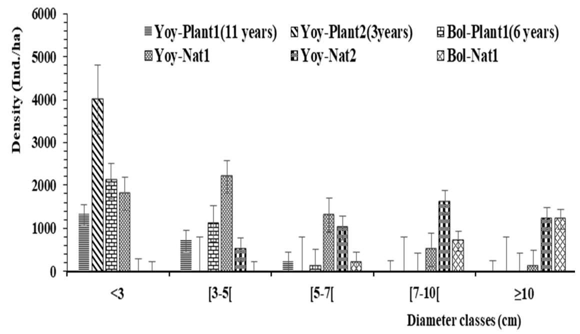

Fig. 5. Distribution of height classes

On average, individuals from the adjacent natural stands were taller than those from the corresponding RMAs (Table 2). This is likely due to the older age of the adjacent vegetation compared to the reforested vegetation. Notably, the average height of individuals in the 6-year-old RMA (Bol-Plant1: 5.64±1.87 m) was greater than that of the 11-year-old RMA (Yoy-Plant1: 3.34±1.26 m). The results obtained in this study differ from previous ones, which could be due to the use of different plant species for reforestation at the two sites. The mean height and diameter of individuals in the 3-year-old RMA are similar to those found in a 3-year-old *R. racemosa* RMA in Kono Creek, Nigeria (Zabbey and Tanee, 2016).

The increase in height and diameter of individuals of the same species is correlated and is a function of the RMA's age. The finding is comparable to the seedling growth in Perancak estuary in Bali, Indonesia (Pradisty *et al.*, 2022). In the same RMA of *Rhizophora mucronata* Lam. in Kenya, the mean heights of individuals were 4.70±0.20 m and 8.40±1.10 m at 8 and 11 years, respectively (Bosire *et al.*, 2006; Kairo *et al.*, 2008). The complexity index values did not vary proportionally with the age of vegetation in the reforested areas. However, the index values of the reforested areas (Yoy-Plant2 (0.40×10^{-3}), Bol-Plant1 (3.54×10^{-3}) and Yoy-Plant1 (1.14×10^{-3})) were lower than those of their respective adjacent natural stands (Yoy-Nat2 (76.1×10^{-3}), Bol-Nat1 (390×10^{-3}) and Yoy-Nat1 (32.95×10^{-3})).

Standing biomass and carbon stock

Above-ground biomass (AGB) and below-ground biomass (BGB)

The above-ground biomasses (AGB) of the RMAs did not strictly vary with the age of the vegetation although the smallest value was for the youngest RMA (Table 3). The one-tailed Student's t-test with the same variance showed no significant difference between AGB and below-ground biomasses (BGB) of 6-year-old and 11-year-old RMAs ($p > 0.05$).

The respective AGB and BGB of adjacent good natural stands (Yoy-Nat2 (2653.13±608.91 kg/ha and 1289.07±422.02 kg/ha), Bol-Nat1 (6857.94±563.07 kg/ha and 2907.77±1111.95 kg/ha) and Yoy-Nat1 (575.64±57.72 kg/ha and 362.78±73.72 kg/ha) were higher than those of the RMAs (Yoy-Plant2 (11.98±0.76 kg/ha and 13.88±1.3 kg/ha), Bol-Plant1 (61.18±2.16 kg/ha and 55.19±1.92 kg/ha) and Yoy-Plant1 (55.25±2.93 kg/ha and 47.8±1.31 kg/ha) (Table 3). Additionally, statistical test revealed a significant difference at the 5% threshold in biomass between the two vegetation types.

The age of the vegetation is positively correlated with the total standing biomass of RMAs in Douala Edea National Park (DENP). This correlation can be explained by the difference in diameter between individuals of the two types of vegetation sampled, as stem diameter growth is also positively correlated with vegetation age. This observation is similar to that of Hieu *et al.* (2017) in Vietnam and Monga *et al.* (2022) in Tanzania. Monga *et al.* (2022) obtained total carbon biomass values of 13.65; 20.13; and 57.53 MgC/ha for 5-, 10-, and 15-year-old RMAs, respectively. In contrast, Ferreira *et al.* (2015) estimated a biomass of 60.43 Mg/ha for a 5-year-old *R. mangle* RMA in Potenji estuary in Brazil.

Table 2. Specific composition and structure parameters of the vegetation of the sampled areas

Site	Sampled area	Vegetation type	Age (years)	Specific composition	D (ind./ha)	BA_i (m^2)	dm (cm)	Hm (m)	CI
Bolondo	Bol-Plant1	Reforested	6	*R. racemosa*	3280 ±238.74	19.03×10^{-3}	^{a}2.58 ±0.85	^{b}5.64 ±1.87	3.54×10^{-3}
	Bol-Nat1	Natural	ND	*R. racemosa* *A. germinans*	2060 ±610.74	462.57×10^{-3} 151.30×10^{-3}	15.95 ±11.13	15.27 ±4.79	390×10^{-3}
Yoyo II	Yoy-Plant1	Reforested	11	*R. mangle*	2160 ±240.83	15.56×10^{-3}	^{a}2.93 ±1.4	^{b}3.34 ±1.26	1.14×10^{-3}
	Yoy-Nat1	Natural	ND	*R. racemosa*	5920 ±630.08	113.38×10^{-3}	4.46 ±2.16	4.93 ±2.36	32.95×10^{-3}
	Yoy-Plant2	Reforested	3	*R. racemosa*	4000 ±200	5.55×10^{-3}	1.2 ±0.5	1.8 ±0.3	0.40×10^{-3}
	Yoy-Nat2	Natural	ND	*R. racemosa*	4260 ±952.89	316.98×10^{-3}	8.48 ±4.74	5.58 ±2.44	76.1×10^{-3}

BA: Specific basal area; CI: Complexity Index; D: Density; dm: Average diameter; Hm: Mean height; ND: Not Determined. For the parameters dm and Hm, areas with identical letters did not show significant differences between them at the Student's t-test at the 5% threshold: a ($p = 0.63$), b ($p = 0.49$).

Table 3. Biomass and carbon stock of study sites

Site	Sampled area	Vegetation type	Age (years)	AGB (kg/ha)		BGB (kg/ha)		Total (kg/ha)	
				Biomass	Carbon stock	Biomass	Carbon stock	Biomass	Carbon stock
Yoyo II	Yoy-Plant2	Reforested	3	11.98 ±0.76	5.99 ±0.37	13.88 ±1.3	6.31 ±2.17	25.86 ±1.86	12.31 ±2.19
	Yoy-Nat2	Natural	ND	2653.13 ±608.91	1326.56 ±304.45	1289.07 ±422.02	502.73 ±164.58	3942.21 ±1029.7	1829.3 ±468.51
Bolondo	Bol-Plant1	Reforested	6	^{a}61.18 ±2.16	30.56 ±0.85	^{b}55.19 ±1.92	21.52 ±0.75	116.32 ±3.62	52.08 ±1.6
	Bol-Nat1	Natural	ND	6857.94 ±563.07	3428.97 ±281.54	2907.77 ±1111.95	1134.03 ±433.66	9765.71 ±1658.73	4563 ±707.76
Yoyo II	Yoy-Plant1	Reforested	11	^{a}55.25 ±2.93	27.62 ±1.4	^{b}47.8 ±1.31	18.64 ±0.51	103.05 ±2.05	46.26 ±1.1
	Yoy-Nat1	Natural	ND	575.64 ±57.72	287.82 ±28.86	362.78 ±73.72	141.48 ±28.75	938.43 ±130.07	429.31 ±57

ND: Not Determined. For a given parameter, the areas with identical letters did not show significant differences between them at the Student's t test at the 5% threshold: a ($p = 0.84$), b ($p = 0.93$).

The biomass values of above-ground and below-ground of a 12-year-old *R. mucronata* RMA in the Gazi Bay, Kenya were 106.7±24 t/ha and 24.9±11.4 t/ha respectively, as reported by Bosire *et al.* (2008). These values are significantly higher than those of the 11-year-old *R. mangle* RMA in DENP. The difference in biomass between the two ages can be attributed to the species used for reforestation and the evaluation method employed, as explained by Kairo *et al.* (2008). The greater biomass of the natural vegetation in RMA at DENP suggests that the RMAs have not yet fully restored the functional properties of the pre-existing ecosystem.

Biomass and carbon stock of litter fall in the sample area

Litter fall composition

In all sampled vegetation, litterfall was composed of: branches, leaves, flowers and seeds.

Table 4 shows the annual distribution of the different components in the sampled plots. It can be seen that the proportion of dry leaf biomass is higher in the sampled areas irrespective of the stand type and age of the RMA. For the RMAs, the proportions of leaves were 93.08% (Yoy-Plant2), 95.93% (Bol-Plant1), 80.61% (Yoy-Plant1), while those of the corresponding natural vegetation were: 67.84% (Yoy-Nat2), 82.43% (Bol-Nat1), and 90.97% (Yoy-Nat1) (Fig. 6). In contrast, the proportion of dry fruit-seed biomass was zero only for the 3-year-old RMAs. In this and many other studies on litterfall production from mangroves, the proportion of leaves was dominant (Ntyam *et al.*, 2014; Wang'ondu *et al.*, 2014; Mchenga and Ali, 2017; Kamruzzaman *et al.*, 2019; Pradisty *et al.*, 2022).

Table 4. Components and production of litterfall in three reforested areas of different ages and in their respective adjacent vegetation

Site	Sampled area	Vegetation type	Age (years)	Composition of plant species	Litterfall components	Average total annual production (g/m²/year)		Average monthly biomass production (g/m²/month)
						Dry biomass	carbone stock	
Yoyo2	Yoy-Plant2	Reforested	3	*R. racemosa*	Flowers	1.20 ±0.4	0.54±0.09	0.10±0.22
					Fruits/seeds	0	0	0
					Leaves	37.96±6.46	17.08±2.77	3.23±1.25
					Twigs	1.62±1.52	0.73±0.63	0.135±0.09
					Total	40.78±7.42	18.27±3.48	3.47±1.32
	Yoy-Nat2	Natural	ND	*R. racemosa*	Flowers	122.10±59.62	54.94±25.04	10.17±6.45
					Fruits/seeds	91.44±111.94	41.15±49.25	7.62±14.22
					Leaves	630.57±83.19	283.76±37.41	52.55±16.16
					Twigs	85.37±30.63	38.42±12.86	7.11±8.49
					Total	929.48±203.38	418.27±9.5	77.45±22.12
Bolondo	Bol-Plant1	Reforested	6	*R. racemosa*	Flowers	12.61±9.37	5.68±4.02	1.05±0.65
					Fruits/seeds	1.47±3.12	0.66±1.43	0.12±0.08
					Leaves	381.56±65.98	171.7±29.69	31.80±10.04
					Twigs	2.11±2.62	0.95±1.15	0.18±0.00
					Total	397.75±75.79	179.09±4.44	33.15±10.14
	Bol-Nat1	Natural	ND	*Avicennia germinans* and *R.*	Flowers	13.39±2.78	6.03±1.27	1.12±1.51
					Fruits/seeds	88.27±14.03	39.72±6.43	7.36±14.57
					Leaves	595.91±11.96	268.16±5.32	49.66±20.14
					Twigs	25.36±8.43	11.41±3.77	2.11±3.44
					Total	722.93±28.34	325.32±11.67	60.25±26.89
Yoyo2	Yoy-Plant1	Reforested	11	*R. mangle*	Flowers	40.09±20.19	18.04±9.06	3.38±2.85
					Fruits/seeds	49.23±48.78	22.15±21.52	4.1±5.9
					Leaves	464.51±50.64	209.03±22.88	38.71±13.87
					Twigs	22.40±16.35	10.08±7.17	1.88±1.35
					Total	576.23±106.75	259.3±8.89	48.07±19.62
	Yoy-Nat1	Natural	ND	*R. racemosa*	Flowers	15.65±3.88	7.04±1.68	1.30±0.53
					Fruits/seeds	11.69±6.85	5.26±3.11	0.97±4.79
					Leaves	654.39±75.38	294.47±30.89	54.53±18.29
					Twigs	37.58±4.47	16.91±1.98	3.13±5.66
					Total	719.31±70.89	323.69±8.43	59.93±19.51

ND: Not Determined.

Total annual Litter fall production

The dry litter fall biomass varied in the same direction as the age of the RMAs: Yoy-Plant3 (40.78±7.42 g/m²/year), Bol-Plant1 (397.75±75.79 g/m²/year), Yoy-Plant1 (576.23±106.75 g/m²/year). The litterfall biomasses of the RMAs were significantly lower than those of the respective natural vegetation: Yoy-Nat2 (929.48±203.38 g/m²/year), Bol-Nat1 (722.93±28.34 g/m²/year), Yoy-Nat1 (719.31±70.89 g/m²/year). Furthermore, Turkey HSD multiple comparison tests between the average monthly dry litterfall production between the different pairs of RMAs and their respective adjacent good natural stands showed a significant difference.

Litterfall production in mature mangroves worldwide has been estimated to be between 2 and 16 t/ha/year (Ntyam *et al.*, 2014). The results obtained in this work (Yoy-Plant2 (0.4 t/ha/year), Bol-Plant1 (3.97 t/ha/year), Yoy-Plant1 (5.76 t/ha/year)) where in this range, except for the 3-year-old RMA (Yoy-plant2). These litterfall productions show that these two ecosystems would contribute to the restoration of ecosystem functionality (Bosire *et al.*, 2008). Furthermore, the litterfall production of the 11-year-old RMA (Yoy-Plant1) showed no significant difference from the adjacent good natural stands. This result is similar to that observed for *R. mucronata* RMA older than 11 years in the Gazy Bay. As litterfall production is an important ecological function of the vegetation, these two mangrove stations would function similarly in their respective ecosystems. This would imply that the productivity of the reforested areas would be able to match that of the natural stands from a certain age under favourable conditions (Wang'ondu *et al.*, 2014).

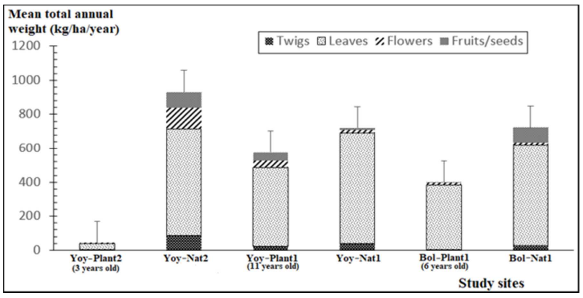

Fig. 6. Distribution of the proportions of annual productions of litter fall components by site

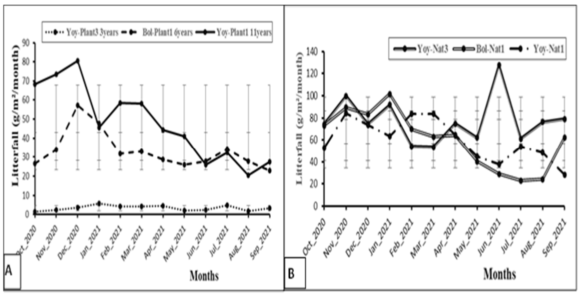

Fig. 7. Variation in monthly production of dry biomass of litterfall: A. In the three reforested areas of different ages; B. In the adjacent good natural stands

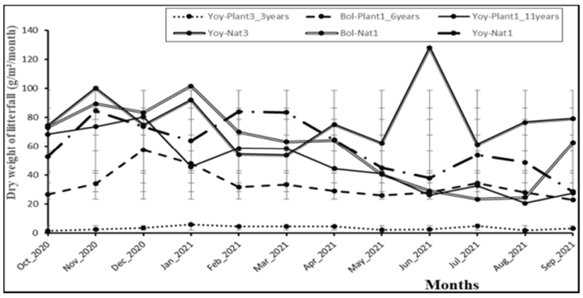

Fig. 8. Comparison of litterfall dry mass between reforested mangrove and their respective adjacent good natural stands

Monthly litterfall production and factors of variation

Similar to the annual production, the monthly dry litterfall biomass varied with the age of the plantation. Fig. 7A shows that on the one hand, the variation of the dry litterfall biomass is similar throughout the year in the 3- and 6-years old RMAs and, on the other hand, the older RMA showed the higher dry litterfall biomass. Furthermore, there was a significant difference between the monthly dry biomass values for RMAs of different ages ($F = 38.86$; $P = 2.38291 \times 10^{-09}$). In contrast, the dry biomass values for the natural vegetation of each RMAs respectively showed very similar variations over time and their dry biomass values were not significantly different at the 5% threshold ($F= 2.49$; $P= 0.098$) (Fig. 7B).

The comparison of mean dry litterfall biomass values between each RMA and its respective adjacent good natural stands shows that the dry litterfall biomasses of the adjacent good natural stands were higher than those of the RMAs (Fig. 8). However, the mean monthly dry litterfall biomass values of the 6-year-old RMA (Bol-Plant1) were similar to those of its adjacent good natural stands (Bol-Nat1), but the one-way Student's t-test with different variances showed a significant difference between these two sets of values at the 5% threshold ($t= -3.37$; $p = 0.0022$). Furthermore, the one-way Student's t-test with equal variances showed that there was no significant difference between the monthly biomass means of the two plots Yoy-Plant1 (11 years) and Yoy-Nat1 ($t= -1.516$; $p = 0.0716$).

The superposition of the monthly variations of dry biomass presented in Fig. 8 and the annual variation of the seasons in the locality allows to show that dry biomass of litterfall decreases with increasing rainfall. Furthermore, maximum litterfall production was recorded during the dry season (November 2020 to February 2021), while minimum production was recorded during the months of heavy rainfall (June 2021 to August 2021) with the exception of Yoy-Nat1 PSP in which there was a significant fall in twigs during June 2021 (Fig. 9A).

The litterfall production of the RMAs of the DENP varied with both age and season. The litterfall production in the RMAs of DENP increases with decreasing rainfall, which is similar to the observations made in several other mangroves, including the Perancak mangroves in Bali, Indonesia, Sundarbans in India, and Zanzibar mangroves in Tanzania (Mchenga and Ali, 2017; Pradisty *et al.*, 2022). This could be explained by the fact that there is a reduction in freshwater supply in estuary which is accompanied by an increase in the salinity of the environment and the plants adapt to this saline stress by losing leaves and some branches to reduce water loss (Ntyam *et al.*, 2014).

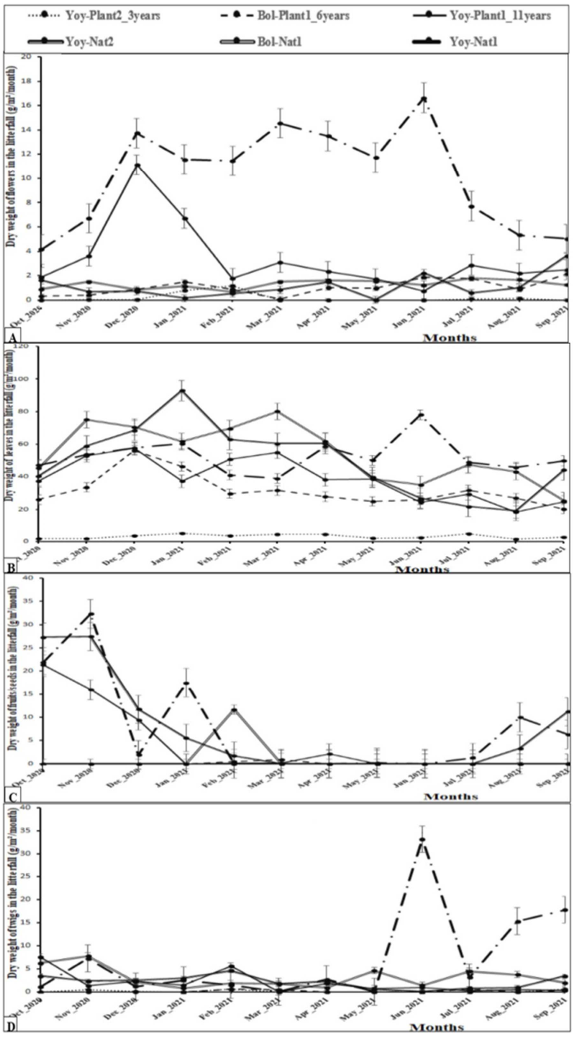

Fig. 9. Monthly variation in dry biomass of litterfall components: A. Branches; B. Leaves; C. Flowers; D. Fruits-seeds.

The dry twig biomass collected for the 3- and 6-year-old RMAs was discontinuous and very low throughout the year (Fig. 9A). In contrast, the biomass of twigs in the 11-year-old RMA was higher than in the other two RMAs and remained consistent throughout the year. Additionally, its variation closely resembled that of adjacent natural stands. The annual variation in fruit/seed dry biomass exhibited similar characteristics to that of the twigs, except for the months of maximum and minimum biomass collection (Fig. 9A-D).

The dry biomass of collected leaves and flowers was continuous throughout the year in the respective adjacent good natural stands and in the 11-year-old RMA (Fig. 9B-C). The biomass of collected flowers was negligible throughout the year in the 3-year-old RMA, while the biomass variation in the 6-year-old RMA was similar to that of its adjacent natural stands (Fig. 9C). Leaf biomass production was continuous throughout the year for all PSPs, and it was the dominant component of litterfall composition (Fig. 9B). Mangrove litterfall production worldwide is generally influenced by air temperature, insolation, rainfall, forest succession stages (i.e. pioneer plants, young forests, mature forests), forest management (e.g. selective pruning or harvesting), and anthropogenic disturbance (e.g. coastal development) (Kamruzzaman *et al.*, 2019; Pradisty *et al.*, 2022).

Conclusion

The estimation of standing biomass and litterfall production of three reforested mangrove sites of DENP showed that *Rhizophora* was the plant genus used for reforestation in the sampled RMAs. The average diameter, height, standing biomass, and litter production were positively correlated with the age of the reforested areas. As the areas aged, litter production approached that of the adjacent natural vegetation. Reforestation of the disturbed mangrove of the DENP would be a significant ecological success indicator for the short term. This would make a significant contribution to the safeguarding of these ecosystems. However, it is important to note that the allometric equations used in this study were developed based on vegetation data that are not originate from the African Atlantic coast. Developing original allometric equations for these ecosystems would improve the accuracy of the estimates.

Acknowledgments

The authors would like to express their gratitude to the Cameroon Wildlife Conservation Society (CWCS) for providing the necessary materials to accomplish this work in the field.

References

Ajonina GN, Usongo L. 2001. Preliminary Quantitative Impact Assessment of Wood Extraction on the Mangroves of Douala-Edea Forest Reserve, Cameroon. Tropical Biodiversity **7**, 137–149. https://www.researchgate.net/publication/313056745

Ajonina GN. 2008. Inventory and Modelling Mangrove Forest Stand Dynamics Following Different Levels of Wood Exploitation Pressures in the Douala-Edea Atlantic Coast of Cameroon, Central Africa. PhD thesis, Albert-Ludwigs-Universität, Germany, 215.

Ajonina G, Chuyong G. 2011. Vulnerability assessment of mangrove forest stands from anthropogenic wood exploitation pressures and sea level rise impacts following a re-census survey and analysis of eight years old permanent sample plots in the Douala-Edea Estuary, Cameroon. Technical Report, 1-27. http://doi.org/10.13140/RG.2.2.36502.24644

Ajonina GN, Aya FA, Diame A, Armah AK, Camara S, Amegankpoe C, Zabbey N, Kaya P. 2016. Overview of Experience of Mangrove Reforestation in West and Central Africa. In Ogunsanwo OY, Akinwole AO, eds., 38th Annual Conference of FAN. Forestry Association of Nigeria **17,** 12-21. https://www.researchgate.net/publication/314243276

Alongi DM. 2011. Carbon Payments for Mangrove Conservation: Ecosystem Constraints and Uncertainties of Sequestration Potential. Environmental Sciences Policy **14,** 462–470. https://doi.org/10.1016/j.envsci.2011.02.004

Bosire JO, Dahdouh-Guebas F, Walton M, Crona BI, Lewis RR, Field CD, Kairo JG, Koedam N. 2008. Functionality of Restored Mangroves: A review. Aquatic Botany **89**, 251–259. https://doi.org/10.1016/j.aquabot.2008.03.010

Bosire JO, Kairo JG, Wartel S, Kazungu J, Koedam N. 2006. Success Rates of Recruited Tree Species and their Contribution to the Structural Development of Reforested Mangrove Stands. Marine Ecology Progress Series **325**, 85–91. https://doi.org/10.3354/meps325085

Boubakary, Essomè-Koum, GL, Nyamsi-Moussian L, Konango-Samè A, Kottè-Mapoko EF, Motto IS, Massako F, Din N. 2019. Mangrove Ecosystems Rehabilitation in Cameroon: Effects of Two Abiotic Factors on the Growth of *Rhizophora* Seedlings. Journal of Marine Biology and Environmental Sciences **1**, 1–6. https://doi.org/https://doi.org/10.36266/JMBES/101

Chowdhury A, Naz A, Maiti SK. 2023. Variations in Soil Blue Carbon Sequestration between Natural Mangrove Metapopulations and a Mixed Mangrove Plantation: A Case Study from the World's Largest Contiguous Mangrove Forest. Life **13,** 1-11. https://doi.org/10.3390/life13020271

Dahdouh-Guebas F, Cannicci S. 2021. Mangrove Restoration Under Shifted Baselines and Future Uncertainty. Frontier in Marine Science **8,** 8-11. https://doi.org/10.3389/fmars.2021.799543

Din N, Ngo-Massou VM, Essomè-Koum GL, Ndema-Nsombo E, Kottè-Mapoko E, Nyamsi-Moussian L. 2017. Impact of Urbanization on the Evolution of Mangrove Ecosystems in the Wouri River Estuary (Douala Cameroon). In Finkl CW, Makowski C Ed. Coastal Wetlands : Alteration and Remediation. Coastal Research Library, Springer **8,** 81–131. https://doi.org/10.1007/978-3-319-56179-0

Din N, Ngo-Massou VM, Essomè-Koum GL, Kottè-Mapoko EF, Emane JM, Akongnwi AD, Tchoffo R. 2016. Local Perception of Climate Change and Adaptation in Mangrove Areas of the Cameroon Coast. Journal of Water Resource and Protection, 608–618.

Elliott S, Blakesley D, Hardwick K. 2013. Restauration des Forêts Tropicales: un guide pratique. Sonne N Ed. Royal Botanic Garden, Kew, 344. https://www.forru.org/sites/default/files/public/publications/resources/forru-0000152-0003.pdf

Ellison AM, Felson AJ, Friess DA. 2020. Mangrove Rehabilitation and Restoration as Experimental Adaptive Management. Frontier in Marine Science **7,** 1–19. https://doi.org/10.3389/fmars.2020.00327

Emanè JM, Essomè-Koum GL, Ngotta-Biyon J, Ekodeck, GE, Tomedi-Eyango M, Din N. 2021. Effects of Anthropogenic Pressures on the Structure of Floristic Components of Mangroves in the Cameroon Estuary. Examines in Marine Biology and Oceanography **4**, 1–7. https://doi.org/10.31031/EIMBO.2021.04.00057

Ferreira AC, Ganade G, Jose Luiz de Attayde. 2015. Restoration Versus Natural Regeneration in a Neotropical Mangrove : Effects on Plant Biomass and Crab Communities. Ocean and Coastal Management Journal **110,** 2002-2009. https://doi.org/10.1016/j.ocecoaman.2015.03.006

Findi EN, Wantim MN. 2022. Using Remote Sensing and GIS to Evaluate Mangrove Forest Dynamics in Douala-Edea Reserve, Cameroon. Journal of Materials and Environmental Science **13**, 222–235.

Fromard F, Puig H, Mougin E, Marty G, Betoulle JL, Cadamuro L. 1998. Structure, Above-Ground Biomass and Dynamics of Mangrove Ecosystems: New Data from French Guiana. Oecologia **115,** 39-53.

Goldberg L, Lagomasino, D, Thomas, N. 2020. Global Declines in Human-driven Mangrove Loss. Global Change Biology. **26,** 1-32. https://doi.org/10.1111/gcb.15275

Hamilton SE, Casey D. 2016. Creation of a High Spatio-Temporal Resolution Global Database of Continuous Mangrove Forest Cover for the 21st Century (CGMFC-21). Global Ecology Biogeography **25**, 729-738. https://doi.org/10.1111/geb.12449

Hieu PV, Dung LP, Tue NT, Omori K. 2017. Will Restored Mangrove Forests Enhance Sediment Organic Carbon and Ecosystem Carbon Storage. Regional Studies in Marine Science https://doi.org/10.1016/j.rsma.2017.05.003

Kairo JG, Lang'at JKS, Dahdouh-Guebas F, Bosire JO, Karachi M. 2008. Structural Development and Productivity of Replanted Mangrove Plantations in Kenya. Forest Ecology and Management **255,** 2670-2677. https://doi.org/10.1016/j.foreco.2008.01.031

Kamruzzaman M, Osawa A, Deshar R, Sharma S, Mouctar K. 2017. Species Composition, Biomass, and Net Primary Productivity of Mangrove Forest in Okukubi River, Okinawa Island, Japan. Regional Studies in Marine Science **12,** 19-27. https://doi.org/10.1016/j.rsma.2017.03.004

Kamruzzaman M, Kalayan B, Sumonta PK, Ahmed S, Osawa A. 2019. Litterfall Production, Decomposition and Nutrient Accumulation in Sundarbans Mangrove Forests, Bangladesh. Forest Science and Technology, 1-9. https://doi.org/10.1080/21580103.2018.1557566

Kathiresan K. 2021. Mangroves: Types and Importance. In Rastogi RP, Gupta DK, Phulwaria M, Ed. Mangroves: Ecology, Biodiversity and Manegement, Springer, 1-31. https://doi.org/10.1007/978-981-16-2494-0

Kauffman JB, Donato DC. 2012. Protocols for the Measurement, Monitoring and Reporting of Structure, Biomass and Carbon Stocks in Mangrove Forests. Working Paper 86. CIFOR, Bogor, Indonesia, 1-40. www.cifor.org

Komiyama A, Jin O, Poungparn S. 2008. Allometry, Biomass and Productivity of Mangrove Forests : A Review. Aquatic Botany **2094,** 1-10. https://doi.org/10.1016/j.aquabot.2007.12.006

Lee SY, Hamilton S, Barbier EB, Primavera J, Lewis RR. 2019. Better Restoration Policies Are Needed to Conserve Mangrove Ecosystems. Nature Ecology and Evolution **3**, 870-872. https://doi.org/10.1038/s41559-019-0861-y

Lhosupasirirat P, Dahdouh-Guebas F, Hugé J, Wodehouse D, Enright J. 2023**.** Young Voices and Visions for the Stakeholder Perceptions on Community-Based Ecological Mangrove Restoration (CBEMR): a Case Study in Thailand. Society for Ecological Restoration **31**, 1–14. https://doi.org/10.1111/rec.13894

López-Portillo J, Lewis RRI, Shing VHR, Lee Y. 2017. Mangrove Ecosystems : A Global Biogeographic Perspective Structure, Function, and Services. In Rivera-Monroy VH, Lee SY, Kristensen E, Twilley RR Ed. Mangrove Ecosystems: A Global Biogeographic Perspective: Structure, Function, and Services, 301–345. https://doi.org/10.1007/978-3-319-62206-4

Malik A, Jalil AR, Arifuddin A, Syahmuddin A. 2020. Biomass Carbon Stocks in the Mangrove Rehabilitated Area of Sinjai District, South Sulawesi, Indonesia. Geography, Environment, Sustainability **2012,** 32–38. https://DOI-10.24057/2071-9388-2019-131

Mchenga ISS, Ali AI. 2017. Mangrove Litter Production and Seasonality of Dominant Species in Zanzibar, Tanzania. Journal of East African Natural History **106,** 5-18. https://doi.org/https://www.ajol.info/index.php/jeanh/article/view/162370/151879

Monga E, Mangora MM, Trettin CC. 2022. Impact of Mangrove Planting on Forest Biomass Carbon and other Structural Attributes in the Rufiji Delta, Tanzania. Global Ecology and Conservation **35,** 1-12. https://doi.org/10.1016/j.gecco.2022.e02100

Ngo-Massou VM, Kenne M, Dongmo AB. 2016. Effect of Anthropogenic Activities on Mangrove Crab Diversity in Cameroon Atlantic Coast. International Journal of Research Studies in Biosciences **4,** 1-12. http://dx.doi.org/10.20431/2349-0365.0404001

Ntyam OCS, Armah AK, Ajonina GN, Wiafe G, Adomako J, Nyarko E, Obiang BO. 2014. Importance of Mangrove Litter Production in the Protection of Atlantic Coastal Forest of Cameroon and Ghana. In The Land/Ocean Interactions in the Coastal Zone of West and Central Africa, Estuaries of the World, Diop S, Barusseau JP, Descamps C. Ed. Springer International, 123-137. https://doi.org/10.1007/978-3-319-06388-1

Planète-Urgence. 2023. Projet Cameroon Mangrove Ecosystem Restoration and Resilience. Web page available by: https://planete-urgence.org/en/projet-camerr-cameroon-mangrove-ecosystem-restoration-and-resilience/

Pradisty NA, Sidik F, Bimantara Y, Susetya IE, Basyuni M. 2022. Litterfall and Associated Macrozoobenthic of Restored Mangrove Forests in Abandoned Aquaculture Ponds. Sustainability **14,** 2-19. https://doi.org/10.3390/su14138082

Sasmito SD, Sillanpää M, Hayes MA, Bachri S, Saragi-Sasmito MF, Sidik F, Hanggara B, Mofu WY, Rumbiak VIR, Hendri, Taberima S, Suhaemi, Nugroho JD, Pattiasina TF, Widagti N, Barakalla, Rahajoe JS, Hartantri H, Nikijuluw V, Jowey RN, Heatubun CD, Ermgassen P, Worthington T, Howard J, Lovelock CE, Friess DA, Hutley LB, Murdiyarso D. 2020. Mangrove Blue Carbon Stocks and Dynamics are Controlled by Hydrogeomorphic Settings and Land-Use Change. Global Change Biology, 1-6. https://doi.org/10.1111/gcb.15056

Spalding M, Leal M. 2021. The State of the World's Mangroves 2021 (M. Spalding and M. Leal Ed. Global Mangrove Alliance. https://doi.org/www.mangrovealliance.org

Wang'ondu VW, Bosire JO, Kairo JG, Kinyamario JI, Mwaura FB, Dahdouh-Guebas F, Koedam N. 2014. Litterfall Dynamics of Restored Mangroves (*Rhizophora mucronata* Lamk. and *Sonneratia alba* Sm.) in Kenya. *Restoration Ecol*ogy **22,** 824–831. https://doi.org/10.1111/rec.12149

Worthington T, Spalding M. 2018. Mangrove Restoration Potential: A Global Map Highlighting a Critical Opportunity (UICN (ed.)). UICN, University of Cambridge, The Nature Conservancy, 1-34. https://doi.org/10.17863 /CAM.39153

Zabbey N, Tanee FBG. 2016. Assessment of Asymmetric Mangrove Restoration Trials in Ogoniland, Niger Delta, Nigeria: Lessons for Future Intervention, 245–257.