INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 24, No. 2, p. 62-72, 2024
http://www.innspub.net

RESEARCH PAPER | OPEN ACCESS

Logging effects on mangroves vegetation diversity in the Sanaga River estuary (Cameroon)

Alphonse Konango-Samè[1], Léopold G. Essomè-Koum[2], Boubakary[3], Ernest F. Kottè-Mapoko[4], Laurant Nyamsi-Moussian[1], Vanessa M. Ngo-Massou[5], Laurette Ngo-Nkot[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 Biological Sciences, Faculty of Sciences, University of Maroua, Maroua, Cameroon*

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

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

Article published on February 08, 2024

Key words: Anthropogenic disturbance index, Diversity indices, Douala-Edea National Park, Mangrove degradation, Variable score

Abstract

In recent decades, there has been a significant reduction in mangrove vegetation cover. Anthropogenic activities are increasingly affecting this ecosystem, even in protected areas. This study aimed to assess the impact of logging on the floristic composition and structure of mangrove vegetation in the Sanaga river estuary. The study was conducted in six mangrove areas of the Douala-Edea National Park. Plots measuring 25m x 25m were established every 20m along open transects perpendicular to the main tidal channels to inventory all species. Trees with a circumference greater than 15cm were identified and their heights were measured in each plot. The number and circumference of all stumps were also identified. The impact of logging was characterised by stump abundance, number of associated species, and density of *Acrostichum aureum* and *Nypa fruticans*. Seven of the eight characteristic mangrove species of the African Atlantic coast were encountered, with the exception of *Conocarpus erectus*. Out of the six investigated sites, three were slightly disturbed and three were moderately disturbed. The Shannon-Weaver diversity index ranged from 1.13 to 1.88, while the mean abundance varied from 400 ± 67.9 to 656 ± 90.5 ind. ha^{-1}. The mean diameter ranged from 7.8 ± 6.7 to 22.5 ± 11cm, and the mean height of trees ranged from 4.8 ± 2.8 to 17.5 ± 8.2m. Many young individuals are being exploited (diameter of the stumps less than 10 cm) . Human activities have impacted the structure of the mangroves, with logging being the main cause of degradation of this ecosystem.

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

Introduction

Deforestation is a significant problem faced by developing countries, resulting in permanent alterations to their ecosystems. The combination of high population growth and poverty is driving people to occupy low-cost open spaces, intensifying pressure on resources and contributing to the modification of many natural habitats, such as mangroves (Din *et al.*, 2017). Mangroves have traditionally been the foundation of local livelihoods and provide essential ecosystem functions, goods, and services (Getzner and Islam, 2020; Afonso *et al.*, 2021). They play a critical role in the economy and ecology of coastal communities (Rizal *et al.*, 2018; Kathiresan, 2021), fighting against coastal erosion and protecting surrounding populations from damage caused by cyclones, tsunamis, and hurricanes (Asari *et al.*, 2021). Mangrove ecosystems are crucial for maintaining biodiversity and fighting global warming by absorbing atmospheric CO_2 (Ndema-Nsombo *et al.*, 2016; Johnson *et al.*, 2020; Kathiresan, 2021).

However, their area is steadily declining due to anthropogenic activities and environmental changes (Asbridge *et al.*, 2015; Friess *et al.*, 2019; Ávila-Flores *et al.*, 2020). The destruction of mangroves is often caused by their use for aquaculture, agriculture, rice cultivation, uncontrolled urbanisation, excessive logging, and oil activities (Friess *et al.*, 2019; Spalding and Leal, 2021; Asante *et al.*, 2023).

In Cameroon, the expansion of the port of Douala, firewood and timber exploitation, charcoal production, sand collection, rapid demographic growth leading to the construction of huts, anarchic urbanization of adjacent areas, creation of villages and fishing camps, and absence of appropriate legislation have further depleted mangroves (Nfotabong-Atheull *et al.*, 2013; Din *et al.*, 2017; Emanè *et al.*, 2021; Lontsi *et al.*, 2023). Local people traditionally cut down mangrove trees close to dwellings for firewood. However, the felling of mangrove trees becomes harmful when it becomes a lucrative timber exploitation activity for populations who rely on it as their main source of income (Din *et al.*, 2008).

Human activities constantly disturb mangrove ecosystems, leading to dysfunction. In some cases, the initial vegetation degradation leads to the proliferation of *Acrosthicum aureum*, *Nypa fruticans*, and associated species such as *Hibiscus tiliaceus* or *Phoenix reclinata* when the environment is favourable.

The mangroves of the Sanaga River primarily house fishing camps, and the various fishing-related activities impact the ecosystem's evolution. The accumulation and interaction of impacts from exploitation systems with divergent rationalities may exacerbate risks. This is especially concerning given the combination of various anthropogenic activities and climate change, which have a significant impact on the ecosystem (Alongi, 2015; Wilson, 2017; Bryan-Brown *et al.*, 2020). The purpose of this work is to evaluate the impact of logging on the evolution of mangrove vegetation in the Sanaga river estuary, in order to prepare a management plan for the Douala-Edea National Park.

Material and methods

Study area

This study was conducted in the mangroves of the Douala-Edea National Park, which is located between 3°14' and 3°50' north latitude and 9°34' to 10°03' east longitude. The study focused on six fishing camps (Bolondo, Mbiako, Youmè I, Youmè II, Yoyo I and Yoyo II) in the Mouanko District (Fig. 1).

Fig. 1. Location of study area adapted from (Ajonina and Chuyong, 2011)

The area experiences abundant rainfall, with annual precipitation ranging from 3000 to 4000 mm. The months of December and January are relatively dry, with less than 50 mm of rainfall. Monthly temperatures in the area range from 24°C to 29°C year-round (Ajonina and Chuyong, 2011). Mangroves grow in loose, muddy, and sandy-loamy substrate. The locality is watered by two main rivers (Sanaga and Kwakwa) and an arm of the Atlantic Ocean. The tide follows a semidiurnal pattern, with high tides reaching a height of about 2 meters.

Fishing is the dominant and most practiced activity in the area. Agricultural activities and house construction have a limited impact. Logging practices vary by location, and the collected wood is primarily used for cooking and smoking fish.

Data collection

Field data was collected during different campaigns at low tide. At each site, a one-meter wide transect was opened perpendicular to the main tidal channels. Plots of 25m × 25m with a 20m interlude were established on both sides of each transect, and an inventory of all plant species within these plots was conducted. Trees with a circumference greater than 15cm were measured for height and circumference, while the number of stumps and their circumference were recorded. Circumference measurements were taken for the genus Rhizophora at 30 cm above stilt roots (Kauffman and Donato, 2012) and for other species at 1.30 m from the ground. A 150 cm tape measure or a decametre was used if the circumference of the tree was greater than 150 cm. Tree heights were measured using a Suunto brand clinometer (Essomè-Koum *et al.*, 2017).

Data analysis

Identification of plants

The number and biological type of each species were noted. All species identified in the sampled plots have been classified into two categories: characteristic species and associated species (Tomlinson, 1986).

Structural parameters

The diameters of trees and stumps were calculated from field data using classical formulas $D=C/\pi$. Analysis of the vegetation was based on the following biological growth indices (Cintron and Novelli, 1984): number of individuals (Ni), abundance (A), density (D), and basal area (BA).

Diversity

The study sites' diversity was expressed through three indices: the Margalef specific richness index (Mg), the Shannon-Weaver specific diversity index (H'), and the Pielou index (J) (Ludwig and Reynolds, 1988). These ecological community indices were calculated using PAST software version 2011.3.05.

Impact assessment

To characterise the impact of logging, four situations were considered. It is important to note that these factors were considered in order to characterise the impact of logging and not to make any subjective evaluations.

Firstly, the ratio (R) of the number of stumps to trees was used to determine the intensity of logging.

Secondly, the density of *Acrostichum aureum* (DA) clumps was used to assess the dominance of *A. aureum* in different sites.

Thirdly, the density of *Nypa fruticans* stems (DN) was used to determine the level of invasion of the environment by this species.

The aim of this study was to determine the impact of logging activities on the environment, specifically on the development of species other than true mangrove species. To achieve this, the number (N) of associated species was recorded.

Depending on the local situation, each variable was scored from 0 to 5, with scores based on the percentage:

≤ 10 = 0 was considered Negligible

10 - 20= 1 was considered Very low

20 - 30= 2 was considered Low

30 - 40 = 3 was considered Moderate

40 -50= 4 was considered High

> 50 = 5 was considered Very high

For the fourth variable, which is the number of associated species, the scores are given as follows

0 = No associated species

1 = Very low (Presence of one associated species)

2 = Low (Presence of two associated species)

3 = Moderate (Presence of three associated species)
4 = High (Four associated species present)
5 = Very high (Presence of more than four associated species)

The Anthropogenic Disturbance Index (ADI) for each site was determined by calculating the sum of scores for several variables, including the presence of more than four associated species, according to Blanco-Libreros and Estrada-Urrea's (2015) method. The values of each variable were then calculated and summarised:

$$ADI = R + DA + DN + N$$

The Anthropogenic Disturbance Index (ADI) ranges from 0 to 20, indicating the level of degradation of the mangrove. The assessment includes three levels: low, moderate, and high, based on the ADI value at each site.

A value of $0 < ADI \leq 6$ indicates low degradation,
$6 < ADI \leq 12$ indicates moderate degradation
$ADI > 12$ indicates high degradation.

Statistical analysis

A grouping analysis was performed to determine the degree of similarity (Bray-Curtis) between sites based on their floristic composition using PAST software version 2011.3.05. Cluster analysis ranks the total composition of the community in the six mangrove sites. The dendrogram shows connections between classes and the level of similarity. The Wilcoxon test made it possible to compare the structural parameters between the different sites.

Results

Floristic composition and distribution

Nine genera, comprising a total of eleven (11) species, have been identified and classified into seven (07) families (Table 1). Of these, one species was herbaceous (*Acrostichum aureum*), two (02) were palms (*Nypa fruticans*, *Phoenix reclinata*), five (05) were trees (*Avicennia germinans*, *Laguncularia racemosa*, *Rhizophora harrisonii*, *Rhizophora mangle*, *Rhizophora racemosa*), and the remaining three (03) were shrubs (*Dalbergia ecastaphyllum*, *Drepanocarpus lunatus*, *Hibiscus tiliaceus*). The Rhizophoraceae family was the most represented with 03 species of *Rhizophora*, followed by the Arecaceae and Fabaceae families, each with two species. Finally, four families consisted of a single species (Acanthaceae, Combretaceae, Malvaceae, Pteridaceae). *Rhizophora harrisonii* and *R. racemosa* were present in all surveyed localities. Additionally, *Laguncularia racemosa*, *Phoenix reclinata*, and *Rhizophora mangle* were only present in Yoyo II, Mbiako, and Bolondo respectively. Out of the eleven recorded species, Mbiako had the highest number with 09, followed by Yoyo II with 08 species, Bolondo with 06 species, Youme II with 05 species, and the lowest number of 04 species was observed in Youme I and Yoyo I.

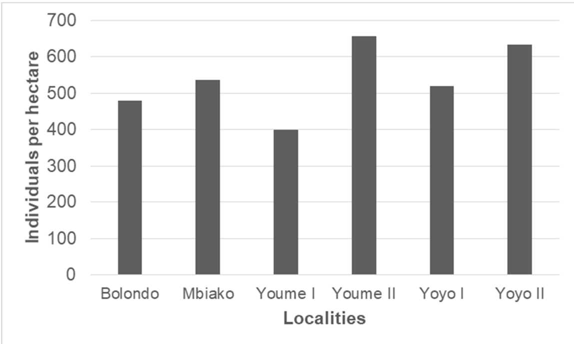

Fig. 2. Tree's abundance in different localities

Structural parameters of trees

The abundance at the sites showed significant variation ($t = 2.2014$; $p = 0.0312$). Youme II had the highest mean abundance (656 ± 90.5 ind. ha^{-1}), followed by Yoyo II (632 ± 33.9 ind. ha^{-1}), Mbiako (536 ± 56.6 Ind. ha^{-1}), Yoyo I (520 ± 56.6 ind. ha^{-1}), Bolondo (480 ±. 22.6 ind. ha^{-1}), and finally Youme I (400 ± 67.9 ind. ha^{-1}) with the lowest abundance (Fig. 2).

Table 2 shows the variation of structural parameters across different sites. The minimum height was lowest in Youme II (2.5 m) and highest (27 m) in three localities (Bolondo, Youme II, Yoyo I). The mean height was highest in Yoyo I (17.4 ± 0.8 m), followed by Bolondo (14.2 ± 2.7 m), Yoyo II (7.3 ± 1.4 m), Mbiako (6.7 ± 1 m), Youme I (6.8 ± 0.6 m), and Youme II (4.7 ± 0.4 m).

Table 1. Distribution of species in the different sites. N = Number of individuals; D = density (%)

Species	Family	Life form	Localities											
			Bolondo		Mbiako		Youme I		Youme II		Yoyo I		Yoyo II	
			N	D	N	D	N	D	N	D	N	D	N	D
Acrostichum aureum Linn.	Pteridaceae	Herb	6	8.2	27	22.3	35	41.2	35	11.8	0	0	32	24.1
Avicennia germinans (Linn.) Stearn	Acanthaceae	Tree	21	28.8	10	8.3	9	10.6	2	0.7	7	5.8	1	0.7
Dalbergia ecastaphyllum Taub.	Fabaceae	Shrub	0	0	9	7.4	0	0	0	0	0	0	11	8.3
Drepanocarpus lunatus G. F. Meyer	Fabaceae	Shrub	0	0	3	2.5	0	0	0	0	0	0	6	4.5
Hibiscus tiliaceus Linn.	Malvaceae	Shrub	0	0	6	5.0	0	0	0	0	0	0	5	3.8
Laguncularia racemosa Gaertn.	Combretaceae	Tree	0	0	0	0	0	0	0	0	0	0	4	3.0
Nypa fruticans (Thurnb.) Wurmb	Arecaceae	Palm	7	9.6	7	5.8	0	0	180	60.6	57	46.7	0	0
Phoenix reclinata Jacq.	Arecaceae	Palm	0	0	2	1.7	0	0	0	0	0	0	0	0
Rhizophora harrisonii Leechman	Rhizophoraceae	Tree	10	13.7	22	18.2	16	18.8	34	11.4	21	17.2	26	19.5
Rhizophora mangle Linn.	Rhizophoraceae	Tree	6	8.2	0	0	0	0	0	0	0	0	0	0
Rhizophora racemosa Meyer	Rhizophoraceae	Tree	23	31.5	35	28.9	25	29.4	46	15.5	37	30.3	48	36.1
Total			73	100	121	100	85	100	297	100	122	100	133	100

Table 2. Structure parameters measurements in the studied localities

Parameters		Localities					
		Bolondo	Mbiako	Youme I	Youme II	Yoyo I	Yoyo II
Height (m)	Min	3	2,8	2,8	2,5	4	3,2
	Max	27	22	23	27	27	25
	Mean	14,2 ± 2,7	6,7 ± 1	6,8 ± 0,6	4,7 ± 0,4	17,4 ± 0,6	7,4 ± 1,4
Diameter (cm)	Min	5,2	5	4,8	4,8	5,5	4,8
	Max	92,4	58,9	63,7	64,6	48,4	47,8
	Mean	18,8 ± 3,4	12,2 ± 2	11,4 ±04	7,7 ± 1,4	22,3 ±4,2	11,4 ± 2,2
Mean basal area (m^2ha^{-1})		14,9 ± 6,1	6,5 ± 2,7	4,1 ± 0,7	3,2 ± 1,3	21,1 ± 10	6,6 ± 2,8

Table 3. Diversity indices of the different sites. NS = Number of species; NI = Number of individuals; Mg = Species richness index of Margalef; H' = Shannon-Weaver index; λ = Simpson index; J = Pielou index.

Localities	NS	NI	Diversity indices			
			Mg	H'	λ	*J*
Bolondo	6	73	1.17	1.63	0.22	0.91
Mbiako	9	121	1.67	1.88	0.19	0.85
Youme I	4	85	0.68	1.28	0.30	0.92
Youme II	5	297	0.70	1,13	0.42	0.70
Yoyo I	4	122	0.62	1.19	0.34	0.85
Yoyo II	8	133	1.42	1.64	0.24	0.79

The diameter of the trees ranged from 4.8 cm to 92.4 cm. The tree diameters ranged from 92.4 cm in Bolondo to 4.8 cm in Youme I, Youme II and Yoyo II. The mean diameter was smallest in Youme II (7.7 ± 1.1 cm) and largest in Yoyo I (22.3 ± 4.2 cm). In Yoyo II, Youme I, Mbiako, and Bolondo, the mean diameters were 11.3 ± 2.2 cm, 11.4 ± 0.1 cm, 12.2 ± 2 cm, and 18.8 ± 3.4 cm, respectively. The mean basal area for trees in different sites was measured. Youme II had the smallest mean basal area of 3.2 ± 1.3 m^2ha^{-1}, while Yoyo I had the largest covered area of 21.1 ± 10 m^2ha^{-1}. Bolondo had a mean basal area of 14.9 ± 6.1 m^2ha^{-1}, followed by Yoyo II (6.6 ± 2.8 m^2ha^{-1}), Mbiako (6.5 ± 2.7 m^2ha^{-1}), and Youme I (4.1 ± 0.7 m^2ha^{-1}).

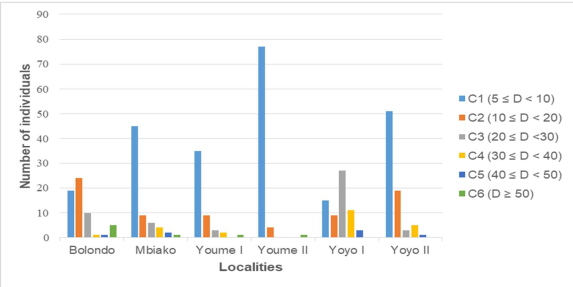

Fig. 3. Distribution of diameter classes in the site

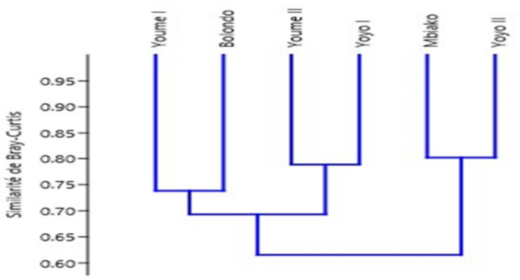

Fig. 4. Dendrogram showing the similarity between study sites

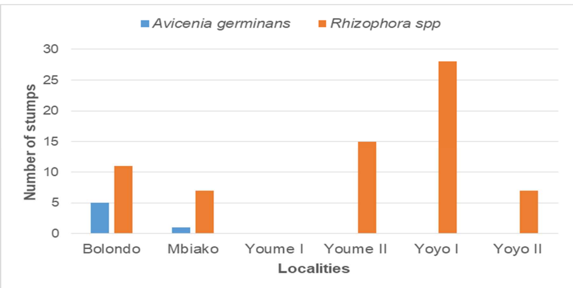

Fig. 5. Number of stumps per species and per site

The distribution of diameter classes across the various sites was irregular, as shown in Fig. 3. Not all diameter classes were represented, with only Bolondo and Mbiako having all diameter classes. Bolondo and Yoyo I exhibited a bell-shaped structure. In Bolondo and Yoyo I, Class 2 (10 ≤ D <20 cm) and Class 3 (20 ≤ D < 30 cm) had the highest number of individuals, with 24 and 27 individuals respectively. The Mbiako, Youme I, Youme II, and Yoyo II sites had an L-shaped distribution and were dominated by individuals of class 1. At Youme II, three diameter classes were identified.

Mangrove diversity assessment

The studied mangrove stands have a relatively low species richness overall. The Shannon-Weaver index (H') had values below 2, ranging from 1.13 to 1.88. The Margalef species richness index (Mg) ranged from 0.62 to 1.67, while the Simpson dominance index ranged from 0.19 to 0.42, with the highest value found in Youme II. The Pielou index (J) was generally high, ranging from 0.7 in Youme II to 0.92 in Youme I (Table 3).

The cluster analysis in Fig. 4 shows a clear separation of the study sites into groups with similar species composition and number of individuals. The dendrogram identifies two main groups: group 1 includes Bolondo, Youme I, Youme II, and Yoyo I with a similarity of over 65%, while group 2 includes Mbiako and Yoyo II with a similarity of 80%. At a higher level of separation, the analysis showed that the floristic composition and number of individuals were very similar between Bolondo and Youme I, as well as between Youme II and Yoyo I in group 1.

Impact of logging activities

The number of stumps varied across the different sites. The highest number of stumps was found in Yoyo I (28 stumps), followed by Bolondo (16 stumps), Youme II (15 stumps), Mbiako (8 stumps), and Yoyo II (7 stumps). However, there were no stumps in Youme I. The species of the genus *Rhizophara* had the most stumps. *Rhizophora* stumps were present in all sites where stumps were found, except for the sites of Bolondo and Mbiako, which also had stumps of *Avicennia germinans* (Fig. 5).

The stumps obtained were classified into six diameter classes. Interestingly, the fifth class (40 ≤ D < 50 cm) had no individuals. The highest number of individuals were found in class 2 (10 ≤ D < 20 cm) in Mbiako, Youme II, Yoyo I and Yoyo II. Bolondo was the only site where the sixth diameter class (D > 50 cm) was present, and this site was dominated by stumps of the first diameter class (D < 10 cm) (Fig. 6).

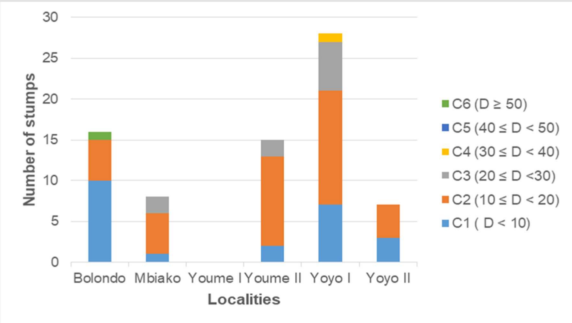

Fig. 6. Stump diameter distribution per site

When assessing degradation among different categorical variables, stumps were found to be more prevalent at Yoyo I. The Youme I site was dominated by clumps of *A. aureum*, while *Nypa fruticans* was more prevalent at Youme II and Yoyo I. In terms of associated species, Mbiako had the highest number of species. The evaluation of mangrove degradation, based on variable scores affected by logging, revealed that among the six sampled sites, the Anthropogenic Disturbance Index (ADI) was higher at Yoyo I (8) and lower at Youme I (4), depending on the extent of damage. This index enabled the identification of three (03) slightly degraded sites (Bolondo, Youme I and Yoyo II) and three (03) moderately degraded sites (Mbiako, Youme II and Yoyo I) (Table 4).

Table 4. Assessment of the level of degradation of the various sites. R = Ratio of stump number to tree (%); DA = Density of *A. aureum* (%); DN= Density of *N. fruticans* (%); N' = Number of associated species; ADI = Anthropogenic Disturbance Index

Parameters		Localities					
		Bolondo	Mbiako	Youme I	Youme II	Yoyo I	Yoyo II
Ratio of stump to tree (%)		26,7	11,9	0	18,3	43,1	8,9
Density of *A. aureum* (%)		8,2	22,3	41,2	11,8	0	24,1
Density of *N. fruticans* (%)		9,6	5,8	0	60,6	46,7	0
Number of associated species		0	4	0	0	0	3
Variables	R	2	1	0	1	4	0
	DA	0	2	4	1	0	2
	DN	0	0	0	5	4	0
	N	0	4	0	0	0	3
	ADI	5	7	4	7	8	5
Degradation level		Low	Moderate	Low	Moderate	Moderate	Low

Discussion

The inventory conducted in the plots enabled the identification of seven characteristic species and four associated species, as reported by numerous authors for the mangroves of Cameroon (Nfotabong-Atheull *et al.*, 2013; Essomè-Koum *et al.*, 2017; Emanè *et al.*, 2021). The characteristic species were *Acrostichum aureum*, *Avicennia germinans*, *Laguncularia racemosa*, *Nypa fruticans*, *Rhizophora harrisonii*, *Rhizophora mangle*, and *Rhizophora racemosa*. The associated species recorded were not specified. The plant species found in the studied areas *Dalbergia ecastaphyllum*, *Drepanocarpus lunatus*, *Hibiscus tiliaceus* and *Phoenix reclinata*.

At Youme II and Yoyo I, *Nypa fruticans* was the dominant species, which prevented the establishment and growth of other species. In sites with more *Acrostichum aureum* clumps, such as Mbiako and Yoyo II, several accompanying species were present. It is important to note that the dominance of *N. fruticans* in some areas may have contributed to the lack of diversity in plant species. However, the presence of *Acrostichum aureum* is associated with environmental degradation and may promote the growth of non-mangrove species.

Abundance generally expresses the average competition in the stand (Favrichon *et al.*, 1998). It is an important variable used to assess the maturity of the vegetation. In this study, abundance ranged from 400 ± 67.9 to 656 ± 90.5 ind. ha^{-1}. With the exception of Bolondo and Yoyo I, where the vegetation appeared to be mature, the other sites studied had vegetation consisting mainly of young individuals, although the level of degradation is low or moderate. The differences in abundance observed in the mangrove areas of the Sanaga estuary are a result of human activities. The exploitation of mangrove resources, especially wood, hinders the growth of large trees.

Abundances obtained in the Sanaga estuary fell within the range frequently found in Cameroon mangroves, including the Rio del Rey estuary (Essomè-Koum *et al.*, 2017) and some mangroves of the Cameroon estuary (Emanè *et al.*, 2021), where abundances ranged from 225 to 1536 ind. ha^{-1}. However, Darmarini *et al.* (2022) reported that the total abundance of mangrove trees on the Lubuk Damar coast of Indonesia ranged from 10 to 225 ind. ha^{-1}.

The basal areas in this study ranged from 3.2 ± 1.3 to 21.1 ± 10 m^2ha^{-1} and varied between sites. The variability of these basal areas could be attributed to the structure of the vegetation. Not all species exhibit the same growth pattern. Low basal areas correspond to young or juvenile stands, while high basal areas suggest a mature stand (Ondo, 2006; Essomè-Koum *et al.*, 2017; Emanè *et al.*, 2021). The sites Youme I, Youme II, Yoyo II, and Mbiako, which are composed of young individuals, have smaller basal areas compared to the Bolondo and Yoyo I sites, which consist of more mature vegetation. According to Ndema-Nsombo *et al.* (2015), the mangroves in the Rio del Rey estuary have low basal area values ranging from 0.38 m^2ha^{-1} to 1.48 m^2ha^{-1}. However, the basal areas in this study are similar to those obtained by Sreelekshm *et al.* (2018), who recorded the highest basal area of 20.19 m^2ha^{-1} in the mangroves of the southwestern Indian coast.

The distribution of diameter classes was non-uniform across all sites, with some classes missing. Notably, larger classes did not always have fewer individuals than smaller classes, as seen in Yoyo I where the third diameter class ($20 \leq D < 30$ cm) had more individuals than the first two classes. With the exception of Bolondo and Yoyo I, the sites studied had trees of small diameter and low height. Only Mbiako exhibited an L-shaped normal distribution. The distribution of diameter classes in the mangroves of the Sanaga River reflects a forest that has been disturbed. It is believed that this disturbance is linked to the various activities carried out by the local population.

Species diversity is a crucial parameter for determining the ecological characteristics of mangroves, forest stands, and the level of succession or stability of a community. Mangrove forests with high diversity tend to exhibit greater community stability than those with low diversity (Setiawann, 2019). The diversity of mangroves in the Sanaga estuary remains relatively low. Margalef's species richness indices range from 0.62 to 1.67, and Shannon-Weaver's diversity index ranges from 1.13 to 1.88, confirming the low diversity of African Atlantic mangroves, as pointed out by Din and Baltzer (2008). This could be linked to a definition that does not allow for an objective analysis of the evolution of the flora in all regions.

Logging activities were effective in all sites based on stump numbers, with accentuated effectiveness in Yoyo I. Timber exploitation involved all diameter classes. Wood was used for various purposes, including timber, fish smoking, poles, fences for dugout canoes, and gardening, as reported by several authors (Solly *et al.*, 2018; Findi and Wantim, 2022). The distribution of trees is likely a consequence of logging, although the ADI has two levels of degradation (low and moderate). Regular logging does not allow for the development of large trees, as is the case at the Mbiako, Youme II, and Yoyo II sites, where most trees are small and have small diameters.

With the exception of Bolondo, the other sites studied are dominated by *Acrostichum aureum* or *Nypa fruticans*. The Mbiako and Yoyo II sites, where *A. aureum* is partially dominant, are composed of associated species whose development seems to be linked to the presence of this fern following the degradation of the environment. Logging activities in mangroves can increase floristic diversity by promoting the establishment and development of associated species, but this can come at the expense of true mangrove species.

Conclusion

The Sanaga estuary mangroves exhibit low diversity, with only eleven species and seven characteristic ones. *Rhizophora racemosa* is the most dominant species. Excessive logging has impacted the diversity of these mangroves, as the wood was used for smoking fish and construction. The sites that have been exploited generally have a disturbed environment, with small trees and clumps of *Acrostichum aureum*, as well as many associated species. Logging has caused degradation of the environment, which has led to the development of *A. aureum* and a senescence phase of the mangrove, characterized by the relative abundance of associated species.

Acknowledgments

Thanks to Mr. Elimbi Benjamin and Mr. Majong Richard Ade for helping in mangroves field sampling.

References

Afonso F, Felix PM, Chainho P, Heumüller JA, De Lima RF, Ribeiro F, Brito AC. 2021. Assessing ecosystem services in mangroves: insights from Sao Tomé Island (Central Africa). Frontiers in Environmental Science **9**, 1-16

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 p. 27.

Alongi DM. 2015. The impact of climate change on mangrove forest. Current Climate Change Reports **1**, 30-39.

Asante F, Hugé J, Asare NK, Dahdouh-Guebas F. 2023. Does mangrove vegetation structure reflect human utilization of ecosystem goods and services? iScience **26**, 106858.

Asari N, Suratman MN, Ayob NM, Abdul Hamid NH. 2021. Mangrove as a Natural Barrier to Environmental Risks and Coastal Protection. In: Rastogi RP, Phulwaria M, Gupta DK, Eds. Mangroves: Ecology, Biodiversity and Management. Springer, 305-322

Asbridge E, Lucas R, Accad A, Dowling R. 2015. Mangrove response to environmental changes predicted under varying climates: case studies from Australia. Current Forestry Reports **1**, 178-194.

Ávila-Flores G, Juárez-Mancilla J, Hinojosa-Arango G, Cruz-Chávez P, López-Vivas JM, Arizpe-Covarrubias O. 2020. A Practical Index to Estimate Mangrove Conservation Status: The Forests from La Paz Bay, Mexico as a Case Study. Sustainability **12**, 858**.**

Blanco-Libreros JF, Estrada-Urrea EA. 2015. Mangroves on the Edge: Anthrome-Dependent Fragmentation Influences Ecological Condition (Turbo, Colombia, Southern Caribbean). Diversity **7**, 206-228.

Bryan-Brown DN, Connolly RM, Richards DR, Adame F, Friess DA, Brown CJ. 2020. Global trends in mangrove forest fragmentation. Scientific Reports **10**, 7117.

Cintron G, Novelli YS. 1984. Methods for studying mangrove structure. In: Snedaker SC, Snedake JG, Eds. The Mangrove ecosystem: research methods UNESCO, Paris, France, 91-113.

Darmarini AS, Wardiatno Y, Prartono T, Soewardi K, Samosir AM, Zainuri M. 2022. Mangrove community structure in Lubuk Damar Coast, Seruway, Aceh Tamiang. Journal of Natural Resources and Environmental Management **12(1)**, 72-81.

Din N, Baltzer F. 2008. Richesse Floristique et évolution des mangroves de l'estuaire du Cameroun. Africa Geoscience Review **2**, 119-130.

Din N, Ngo-Massou VM, Essomè-Koum GL, Ndema-Nsombo E, Kottè-Mapoko EF, 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, Eds. Wetlands: Alteration and Remediation Coastal. Coastal Research Library, vol. 21, Springer, 81-131.

Din N, Saenger P, Priso RJ, Dibong DS, Blasco F. 2008. Logging activities in mangrove forest: A case study of Douala Cameroon. African Journal of Environmental Science and Technology **2(2)**, 022-030.

Emanè JM, Essomè-Koum G.L, Ngotta-Biyon JB, 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)**.

Essomè-Koum GL, Ngo-Massou VM, Kottè-Mapoko EF, Bilong P, Din N. 2017. Diversity Shifts in the Mangrove Vegetation of the Rio del Rey Estuary (Cameroon). International Journal of Research Studies in Biosciences **5(4)**, 6-14.

Favrichon V, Gourlet-Fleury S, Bar-Hen A, Dessard H. 1998. Parcelles permanentes de recherche en forêt dense tropicale humide, Eléments pour une méthodologie d'analyse des données. CIRAD-Forêt, Campus International de Baillarguet, Montpellier, France p. 67.

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(3)**, 222-235.

Friess DA, Rogers K, Lovelock CE, Krauss KW, Hamilton SE, Lee SY, Lucas R, Primavera J, Rajkaran A, Shi S. 2019. The state of the world's mangrove forests: past, present, and future. Annual Review of Environment and Resources **44,** 1-27

Getzner M, Islam MS. 2020. Ecosystem Services of Mangrove Forests: Results of a Meta-Analysis of Economic Values. International Journal of Environmental Research and Public Health **17**, 5830.

Johnson J, Raw J, Adams JB. 2020. First report on carbon storage in a warm-temperate mangrove forest in South Africa. Estuarine, Coastal and Shelf Science **235**, 106566.

Kathiresan K. 2021. Mangroves: types and importance. In: Rastogi RP, Phulwaria M, Gupta DK, Eds. Mangroves: Ecology, Biodiversity and Management. Springer, 1-32.

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 p. 40.

Lontsi FRZ, Tchawa P, Mbaha JP. 2023 Mapping and Botanical Study of Pressures Causing Mangrove Dynamics of Tiko (Southwest Cameroon). Open Access Library Journal **10**, e9723.

Ludwig AJ, Reynolds JF. 1988. Statistical Ecology: A Primer on Methods and Computing. John Wiley & Sons, New York p. 337.

Ndema-Nsombo E, Ako'o BF, Etamè J, Din N, Ajonina G, Bilong P. 2016. Effects of vegetation's degradation on carbon stock, morphological, physical and chemical characteristics of soils within the mangrove forest of the Rio del Rey Estuary: Case study- Bamusso (South-West Cameroon). African Journal. of Environmental Science and technology **10**, 58-66.

Ndema-Nsombo E, Sone-Essoh W, Ajonina G, Etamè J, Din N, Diyouke-Mibog E. 2015. Dynamique de croissance et taux de mortalité de *Rhizophora* spp. dans les mangroves de l'estuaire du Rio del Rey: Site de Bamusso (Sud-Ouest Cameroun). Journal of Applied Biosciences **85**, 7824-7837.

Nfotabong-Atheull A, Din N, Dahdouh-Guebas F. 2013. Qualitative and quantitative characterization of mangrove vegetation structure and dynamics in a peri-urban setting of Douala (Cameroon): An approach using air-borne imagery. Estuaries and Coasts **36**, 1181-1192.

Ondo AE. 2006. Dynamique des paysages végétaux du littoral centre-ouest du Gabon autour de Port-Gentil: Approche spatiale et analyse des données de terrain. Thèse de doctorat. Université. Paul-Valery Montpellier 3, France p. 302.

Rizal A, Sahidin A, Herawati H. 2018. Economic value estimation of mangrove ecosystems in Indonesia. Biodiversity International Journal **2(1)**, 98-100.

Setiawan H. 2019. Vegetation Characteristic and Micro Environment of Mangrove Rehabilitation Forest at Coastal Areas of East Sinjai, South Sulawesi. IOP Conference Series: Earth and Environmental Science **236**, 012054.

Solly B, Dièye EHB, Sané T. Diaw AT. 2018. Dynamique de la mangrove de Thiobon dans l'estuaire de la Casamance (Sénégal) entre 1972 et 2017. European Scientific Journal **14(33)**, 118-133.

Spalding MD, Leal M. 2021. The State of the World's Mangroves 2021. Global Mangrove Alliance.

Sreelekshmi S, Preethy CM, Varghese R, Joseph P, Asha CV, Nandan SB, Radhakrishnan CK. 2018. Diversity, stand structure and zonation pattern of mangroves in southwest coast of India. Journal of Asia-Pacific Biodiversity **11**, 573-582.

Tomlinson PB. 1986. The botany of mangroves. Cambridge University Press p. 413.

Wilson R. 2017. Impacts of Climate Change on Mangrove Ecosystems in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS). Caribbean Marine Climate Change Report Card: Science Review, 60-82.