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Mangrove Forest Characterization in Southeast Côte d'Ivoire

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Abstract

Mangrove ecosystems are faced with far more existential threats of erosion than their terrestrial counterparts. Consequences of their degradation vary from decline in edible aquatic stocks, coastal erosion and aquatic weeds invasion. Mangrove forest dynamics was assessed from multi-temporal analyses of remotely sensed satellite images (mosaics of 1989/90 and 2014/15) within 233,900 hectares. Ground-truthing was accompanied by field measurements in selected forest stands to characterize structure, estimate biomass and carbon pools. With conservation as overriding goal, a socio-economic survey was conducted to underpin the factors influencing mangrove forests over-exploitation and qualitatively assess the sensitivity of the locals to resources decline. The region recorded fifty percent loss of mangrove area during the 25-year period. Low leaf area index (1.02 - 2.52 $m^2 \cdot m^{-2}$) confirms canopy openness. Above-ground root biomass (kg per root) ranged between 110.67 and 382.64. The roots demonstrate capacity to fix up to 176 Mg C ha^{-1} with average carbon content of 46 percent. Highest carbon pools were in the Eloka-To forest stands, in near natural conditions. Despite harsh environmental conditions, potential for natural regeneration was evidenced by seedlings density (individuals per m^2) up to 76. Pilot survey revealed high dependence on mangrove resources for direct income (70 percent) and daily energy needs (60 percent). Despite the heightened awareness of the impending dangers posed by mangrove deforestation and willingness to conserve, riverine communities are incapacitated by lack of viable economic alternatives. External interventions are therefore imperative to achieve conservation goals with long-term implications for climate change adaptation and mitigation.

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Keywords

Carbon Pool, Climate Change, Conservation, Degradation, Mangrove Forest Resources

1. Introduction

Mangroves are trees and shrubs limited to tropical and subtropical coastlines between 25˚N and 38˚S [1] [2], adapted to harsh (high salinity and anoxic) conditions of growth [2] [3]. They are key ecosystems within wetlands that make immense contributions to the wellbeing of societies by their ability to attenuate coastal waves, and provide households with clean water, food, recreation, and income sources [4] [5]. These sea-land boundary ecosystems support biodiversity conservation, climate change mitigation and adaptation measures. They form the core of primary productivity and constitute a large proportion of blue carbon sinks [6] [7]. They also play active roles in balancing global carbon budgets [8]. Their carbon storage potential is higher than that of phytoplankton [9] and fifty times more than that of terrestrial rainforests [10]. In pristine conditions, mangrove forests serve as soft coastal defense structures, reinforcing the resilience and adaptation of riverine rural communities to climate change. For instance, in Vietnam, 12,000 hectares of planted mangrove forest lands provided protection against a typhoon that devastated neighboring areas [11]. In spite of the heightened awareness of their economic and ecologic benefits [12], globally increasing human pressures have resulted in loss of over fifty percent of mangrove area coverage, estimated at 165,000 hectares [13] [14]. Indiscriminate exploitation continues unabated at a rate of 0.1 percent per annum [5], three to five times the values for terrestrial rainforests [5]. Different mangrove forest regions of the world have different forest structures and species composition. The primary uses are adapted to available mangrove species as well as the socio-economic structures and demands of the populations. On a regional basis, Asia suffered the largest net losses with a disappearance of over 1.9 million hectares between 1980 and 2005 [5]. The main threats arise from salt production and agriculture (rice, shrimp and pastoral farming). North and Central America recorded losses in forest area of approximately 690,000 hectares, while Africa recorded a loss of approximately 510,000 hectares during the 1980-2005 period. In North and Central America, the main threats are from real estate, eco-tourism development and aquaculture, while in Africa, urban encroachment, commercial exploitation and environmental pollution are the main culprits [15].

In Côte d'Ivoire, a francophone country in West Africa, mangroves cover 0.3 percent of national landmass of 322,463 km^2, 26.9 percent of which lies within RAMSAR sites, protected by the country's Ministry of Water and Forestry [15]. They account for 0.02 percent of global mangrove forests and belong to the species-poor Atlantic East Pacific (AEP) group of mangroves [16], represented by *Rhizophora racemosa* G.F.W. Meyer (Rhizophoraceae), *Laguncularia racemosa*, *Avicennia germinans* (Avicenniaceae), *Conocarpus erectus* (Combretaceae), *Drepanocarpus lunatus* G.F.W. Meyer (Papilionaceae) and *Acrostichum aureum* (Adiantaceae) [15] [17]. There are two broad categories: a western group extending from Liberia (western border) to Fresco, dominated by black mangroves, *Avicennia germinans* and an eastern group extending from Fresco to Axim (Ghana border), dominated by *Rhizophora racemosa*. These forests have undergone severe decline and recorded the highest annual rate of decline (−4.4%) amongst the African mangroves [15]. The socio-economic and ecological impacts of their degradation are widespread, reaching beyond the local communities to the entire country. Rural household protein intakes and incomes have greatly reduced as a result. There exist strong linkages between fisheries productivity and mangroves as studies have shown that every hectare of cleared forest results in the loss of between 100 - 600 kg of fisheries in nearby coastal waters [18]-[20]. Although details of mangrove patterns of distribution and uses can be found in the works of [15] [17] [21], information regarding their structure, productivity and carbon pools are limited.

This study is a first attempt to bridge data gap and provide information on *Rhizophora* forest structure, above-ground root biomass and carbon storage potential. It also serves to document indigenous traditional knowledge and main uses of the mangrove plants from survey population and recommend ways to get the host population to actively participate in its conservation. This could aid to formulate, plan and execute restoration and conservation programs in communities with high dependence on a common pool resources.

2. Materials and Methods

2.1. Land Use Cover Change Detection

Land use cover change was assessed using remote sensing (ENVI 4.8, ITT Corporation) and GIS (ArcGIS 10.2, ESRI Inc.) techniques. The study window (longitudes 3˚15" and 3˚40"W and latitudes 6˚15" and 6˚40"N) encompasses an area of 236,842 hectares. Post-classification comparison was between mosaics of Lands at 5 Thematic Mapper (TM) images of January 1989 (path/row 195/56) & January 1990 (196/56) and Lands at 8 Operational Land Imager, OLI images of November 2014 (path/row 195/56) and January 2015 (196/56), on a 30 × 30 m spatial resolution. Therefore, land areas less than 3,000 hectares were not represented. Image preprocessing steps include layer stacking, cloud masking (cloud covers 7% of study area) and sub-setting. Image processing techniques made use of a combination of spectral signal analyses (principal component analysis (PCA), normalized difference vegetation index (NDVI) calculated as [Near Infrared (Band 4) − Red (Band 3)/Near Infrared (Band 4) + Red (Band 3)] and wetness index, WI = 0.1509ETM1 + 0.1973ETM2 + 0.3279ETM3 + 0.3406ETM4 − 0.7112ETM5 − 0.4572ETM7 (Tassel-cap transformation; [22]). For both satellite images, supervised classification of land use/cover categories (mangroves, other forest types, settlements/bare soils, water bodies and agricultural lands) was based on maximum likelihood algorithm. Ground data was collected from eighty randomly selected locations within the study area. Result validation was with matrix of confusion and Kappa coefficient. Subsequently, a matrix of transition [23] was generated by the intersection of the two maps.

2.2. Field Measurements—Survey Sites

This study focused on the eastern group of mangroves, growing in the upland tidal areas of the Ébrié lagoon, the largest in West Africa. Further to ground-truthing activities, field measurements were carried out in four selected mangrove forest stands (**Figure 1**), subjected to different hydrological regimes: Eloka-To (longitude 3˚44'08"W and latitude 5˚18'04"N) and Agban (longitude 3˚18'38"W and latitude 5˚18'04"N) forest stands are located along the eastern fringes of the lagoon, while Audoin-Bégréto (longitude 4˚08'01"W and latitude 5˚17'16"N) and Mois (longitude 4˚14'42"W and latitude 5˚17'22"N) forest stands are located along the central areas of the lagoon. Mean annual (1970-2014) precipitation is 1704 mm and mean annual temperature for the same period is 26.8˚C. Relative air humidity is constant at an average of 83 percent [24].

Eloka-To (hereinafter refer to as site A) has a minimally impaired forest with large continuous stands and continuous freshwater inputs, estimated annually at 5.0×10^9 cubic metre from the Comoé and La Mé Rivers. It is the most hydrodynamic area of the lagoon with up to 15 times annual renewal rates [25]. Tidal amplitudes in these parts can reach up to 2 meters. *Rhizophora* prop roots branch out from stems in near horizontal position to the ground. Adjacent to the mangroves are ephemeral, free-floating mats of water hyacinth *Eichhornia crassipes* (Pontederiaceae), water lilies, *Pistiastratiotes* (Araceae), and sea grass meadows. These are however restricted to mangrove stands at the eastern borders of the lagoon.

Agban (hereinafter refer to as site B) has highly degraded forest stands, located 27 kilometres southwest of Eloka-To. Here freshwater supply is intermittent and tides can reach up to 0.6 metres after rainfall events.

Audoin-Bégréto (hereinafter refer to as site C) mangroves are subjected to seasonal salinity stress. Aquatic weeds are absent from these environment characterized by long island bars of oysters, *Crassostrea agar* contributing to the oxygenation of its soils.

Mois (hereinafter refer to as site D) hosts minimally impaired stands, subjected to seasonal salinity stress. It is located about 55 km southwest of Anna. Aquatic weeds are also conspicuously absent from this environment characterized by empty oyster shells, *Crassostrea agar* clinging to mangrove roots. The shorelines consist of coarse-grained sands unlike in the other forest stands with silty clay soils.

2.3. Environmental Variables

Physicochemical properties of the lagoon water were measured to characterize water sources and identify salinity impacts on the lagoon. Environmental variables (temperature, pH, dissolved oxygen and turbidity) were measured on the Ébrié lagoon using handheld sensors before (January) and after (October) rainfall events of 2014 to characterize the environment. In addition, water stable isotope (oxygen-18 and deuterium) analyses were carried on lagoon water samples using laser spectrometry (LS2120-i, Picarro Inc., Santa Clara, USA) at the Helmholtz Zentrum, München, Germany. δ values were normalized relative to Vienna-Standard Mean Ocean

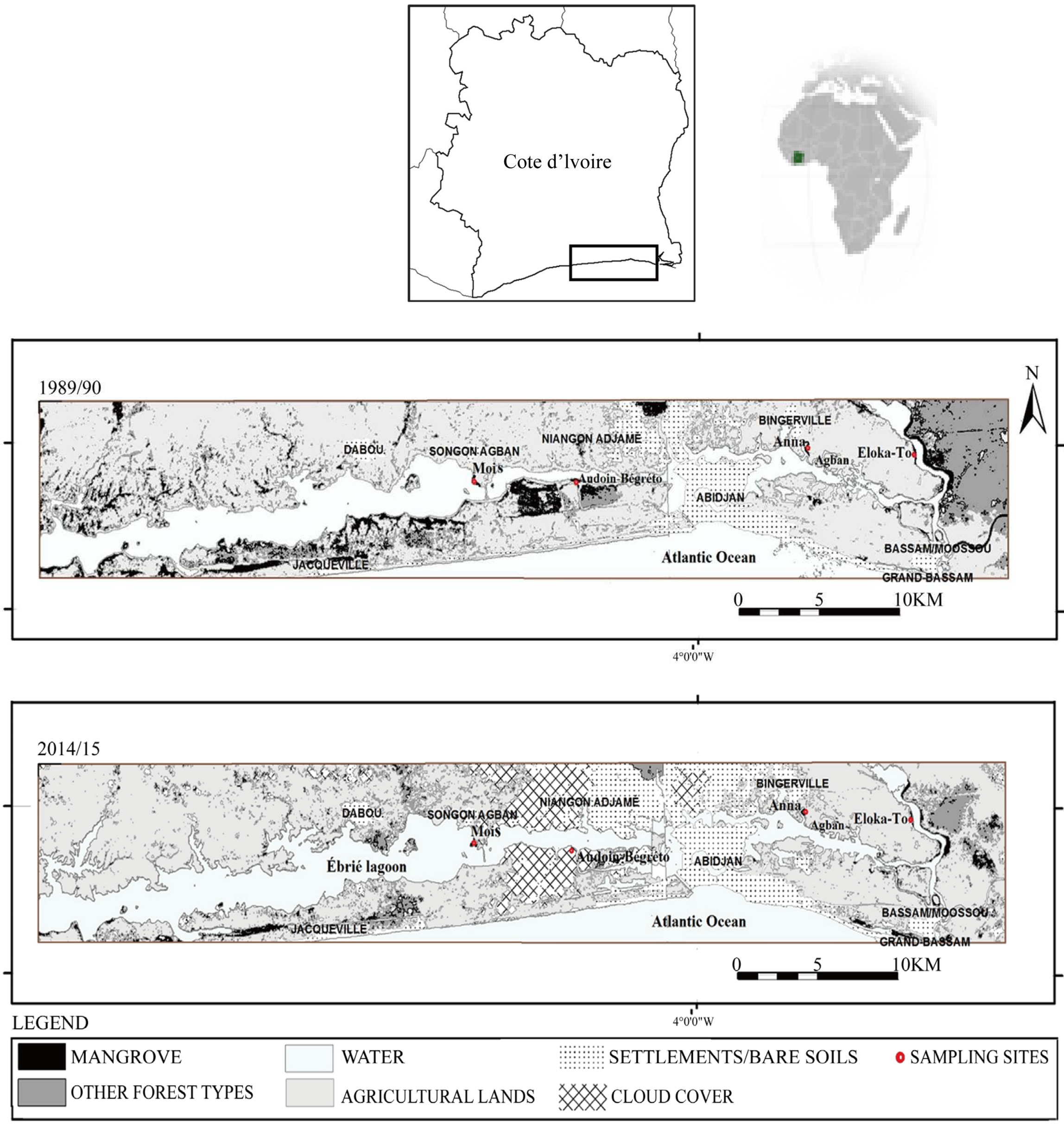

Figure 1. 1989/90 (top) and 2014/15 (bottom) temporal patterns of land cover change as observed with remotely sensed images showing sampling sites. Seven percent cloud cover was masked from both images.

Water (V-SMOW):

$$\delta = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000‰$$

where δ ($\delta^{18}O$ or $\delta^{2}H$) is the normalized difference of the isotope ratios R ($^{18}O/^{16}O$ or $^{2}H/^{1}H$) of the sample and the standard. Triplicate analyses indicate a precision of ±0.3‰ for $\delta^{18}O$ and ±1.6‰ for $\delta^{2}H$.

2.4. *Rhizophora* Forest Characterization

Forest survey followed the procedures of [26]. Counts and measurements were random within ten, 1 m^2 plots marked by PVC pipes, perpendicular to the shorelines. Maximum canopy height (m) was estimated using a clinometer. Canopy cover was by ocular estimation. Leaf area index, LAI (leaf area/ground area, $m^2 \cdot m^{-2}$) was estimated from measurements of light absorption by the forest canopy [27]:

$$\text{LAI} = \frac{\log_e\left(I/I_o\right)}{-k} \times \cos\theta$$

where I/I_o is ratio of photon flux density beneath the canopy and at ground level under direct sunlight. *K*, a light extinction coefficient was set as 0.5. For each sampled site, loge (I/I_o) was calculated for pairs of simultaneous readings and averaged. Corrections were made for the angle of the sun from the vertical (cos*θ*). LAI was in turn used to estimate net canopy photosynthesis (PN) using the formula:

$$\text{Net carbon fixed, } P_N \text{ (Mg C ha}^{-1}\text{ year}^{-1}\text{), } P_N = \text{A} \times \text{d} \times \text{LAI}$$

where d is the day length (average of 12.4 hours) and A is the average rate of photosynthesis per unit leaf area (0.216 g C m^{-2} leaf area hr^{-1}; [28].

2.5. Above-Ground Root Biomass and Carbon Stock Estimation

Prop root diameter at 30 cm above ground was measured with a vernier caliper. Wood density was determined from fresh: dry weight ratio (oven drying at 70˚C for 72 hours) of disk samples. Carbon content of prop roots were determined by combusting 600 µg vacuum-dried wood chips from 3 centimeter thick sample disks in a EURO EA elemental Analyser at 1700˚C. The resulting carbon dioxide, CO_2 was cryogenically separated using a manual extraction line and isotope ratios were determined on Isotope Ratio Mass Spectrometer, IRMS (Finnigan MAT 253; Thermo Electron). δ^{13}C (^{13}C/^{12}C ratio) values were expressed as per mil relative to Vienna-Pee Dee Belemnite. Triplicate analyses indicate a precision of ±0.17‰. Above-ground roots biomass was estimated from species-specific allometric equation of [27]:

$$\text{Above-ground root biomass}\left(\text{kg per root}\right) = 0.196\rho^{0.899}\left(D_{0.30}\right)^{2.22}$$

where ρ is root density ($\text{t}\cdot\text{m}^{-3}$) and $D_{0.3}$ is diameter at 30 cm for the Rhizophoraceae family. Results were multiplied by carbon content to determine carbon stocks.

2.6. Natural Regeneration Capacity

Rhizophora regenerative capacity was determined from seedlings (established propagules less than 1.3 m height) density. Supplementary information on density of periwinkles *Pachymelania aurita* were also used as metrics of ecosystem health. Collection was by hand picking within 0.25 m^2 plots.

2.7. Pilot Socio-Economic Survey

Social vulnerability of the riverine communities of Eloka-To, Anna and Mois to decline in mangrove forest resources was assessed by way of interview of 240 randomly selected and willing members of the survey population based on questionnaires that focuses on the uses, perception and conservation of mangrove forest resources. Eloka-To, Anna and Mois has 1021, 967 and 300 inhabitants respectively [29]. The choice of the number of respondents (sample size of 240) was based on the recommendations of [30], for conducting a pilot social survey. This number represents about 10% of the target population.

3. Results and Discussions

3.1. Land Use Cover Change

Land use classification accuracy for both satellite images ranged between 61.9% and 97.6% with overall accuracy of 88.1% and 90.3% for 1989/90 and 2014/15 respectively. Confusion was between mangroves and other forest vegetation (**Table 1**). Kappa coefficient was excellent, greater than 0.8 for both maps, signifying few unclassified pixels. Generally, forested areas showed strong reduction in areal extent (**Table 2**). Mangrove forest cover decreased from 7863 hectares in 1989/90 to 3867 hectares in 2014/15 representing a net decrease of 3996 hectares or 50.8 (**Figure 1**). It is evidenced that only 18% of primary forest still exists from the matrix of transition (**Table 3**). Urbanization accounts for about 70% of the total loss in forest area. About 31.8% of forest land has been converted to settlements/bare soils, while a much higher percentage (43.8%) has been converted to

Table 1. Matrix of confusion (error matrix) for the different land use maps. Above, 1989/90 and below, 2014/15.

		Mangrove	Other forests	Water body	Agricultural lands	Settlement/bare soils	Sum
Categories	**Mangrove**	61.88	0	5	0.27	0.27	**67.42**
	Other forests	26.17	95.86	0	8.9	0	**130.93**
	Water body	0	0	95	0	0	**95**
	Agricultural lands	11.95	4.14	0	95.4	2.09	**113.58**
	Settlement/bare soils	0	0	0	1.3	97.64	**98.94**
	Sum	**100**	**100**	**100**	**105.87**	**100**	**505.87**
						Overall accuracy	**88.12%**
						Kappa coefficient	**0.87**

		Mangrove	Other forests	Water body	Agricultural lands	Settlement/bare soils	Sum
Categories	**Mangrove**	72.01	0	2	1.27	0	**75.28**
	Other forests	19	95.86	0	8.2	0	**123.06**
	Water body	0.94	0	98	0	0	**98.94**
	Agricultural lands	8.05	4.14	0	90.53	4.7	**107.42**
	Settlement/bare soils	0	0	0	0	95.3	**95.3**
	Sum	**100**	**100**	**100**	**100**	**100**	**500**
						Overall accuracy	**90.30%**
						Kappa coefficient	**0.88**

Table 2. Percentage change in land occupation for the different land use cover categories between 1989/90 and 2014/15.

Land use categories	1989/90	2014/15	Rate of change (%)
Mangroves	3.21	1.73	−49.15
Other forest types	10.25	3.30	−69.68
Settlements/bare soils	7.66	13.37	+64.42
Water	25.17	31.56	+18.07
Agricultural lands	53.71	50.03	−12.29

Table 3. Matrix of transition. Shading intensity represents stability. Grey-colored areas are stable areas, while light-colored areas are percentage conversion to other land use cover types.

	Settlements/bare soils	Forest	Mangrove	Agricultural land	Water
Settlements/bare soils	77.31	31.83	5.35	37.42	3.50
Forest	4.25	18.46	2.37	10.32	0.19
Mangrove	0.73	3.87	87.24	0.96	0.29
Agricultural land	13.77	43.81	2.32	50.71	0.03
Water	3.93	1.93	2.70	0.51	96.03

agricultural lands. This is to be expected as the Abidjan population increased from 2,102,000 inhabitants in 1990 [31] to 4,707,404 inhabitants in 2014 [29]. Land under permanent agriculture in the study area was about 50% during the investigation period. Concerning the water bodies, the position of the shoreline showed a 5% landward displacement during the investigation period. Mangroves thrive best with alternating rise and fall of sea level. Their biological response to permanent inundation of saline water resulting from sea level rise is landward migration [32]. However, land use modifications imposes migratory barriers, inhibiting propagation.

3.2. Habitat Characterization

The physicochemical parameters of the lagoon water indicated differences in water chemistry during the dry and wet season as well as between the different locations (**Table 4**). The lagoon was slightly alkaline (pH 7 - 7.6) except in site A, where the mangroves were exposed to weak acidic waters (pH 6.5 - 6.5) and after rainfall events in site B (pH 6.8). Temperatures were constant with lowest and highest values recorded in sites A and B respectively. Low salinity and water stable isotopes indicate the strong influence of freshwater at site A independent of the season, while other sites experienced seasonal salinity stresses. Site C has the highest fraction of saline water. All sites were oxic in the dry and wet season. At site B, dissolved oxygen levels were higher in the wet compared to the dry season; site C showed the opposite seasonal influences in dissolved oxygen levels. Highest turbidity was recorded in the highly degraded forest of site B after rainfall events.

3.3. *Rhizophora* Forest Characterization

Maximum canopy height ranged between 3.6 and 14.7 m (**Table 5**). Canopy cover ranged between 25% - 75%, 5% - 55%, 5% - 45% and 25% - 75% for sites A, B, C and D respectively. Canopy exposure as evidenced in

Table 4. Seasonal variations of the physicochemical parameters of mangrove standing waters, Ébrié lagoon.

Location	pH		Temperature (˚C)		Conductivity (µS/cm)		Dissolved oxygen (% saturation)		Turbidity (NTU)		Oxygen-18 (‰ V-SMOW)		Deuterium (‰ V-SMOW)	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
A	6.5	6.6	29.6	27.5	660	66.7	55	57	24.9	29.1	−0.9	−2.4	2.7	−8.9
B	7	6.8	31.1	27.7	11500	133	38	63.4	18.8	51.4	−0.7	−3.6	0.2	−20.9
C	7.6	7.2	30.2	27.9	22200	3800	84.6	66.1	6.7	9.8	0.3	−0.9	7.2	−2.4
D	7.4	7.2	30.7	30.3	10750	1650	84.4	86	25.6	10.2	0.1	−1.2	7.7	−4

Table 5. Mean and range (in parenthesis) of estimates of vegetation parameters for the different mangrove forest stands.

	Site A	Site B	Site C	Site D
Individuals, N	261	226	200	230
Maximum canopy height, H (m)	7.5 (4.2 - 12.9)	8.3 (3.6 - 17.9)	5.8 (4.0 - 7.1)	7.5 (4.6 - 14.7)
Root diameter @ 30 cm, $D_{0.3}$ (mm)	26.0 (9.1 - 47.3)	15.8 (2.9 - 50.1)	25.1 (12.8 - 41.5)	25.7 (2.7 - 49.3)
Root basal area (m^2)	0.13 (0.05 - 0.24)	0.08 (0.01 - 0.25)	0.14 (0.11 - 0.24)	0.13 (0.02 - 0.25)
Root density (ind·m^{-2})	22	22	26	18
Wood bulk density (t·m^{-3})	1.06	0.86	0.95	0.83
Above-ground root biomass (t·ha^{-1})	382.64	110.67	381.39	246.69
Carbon content (%)	46.2 ± 0.25	46.16 ± 0.24	44.84 ± 0.38	44.6 ± 0.13
Carbon stored (Mg C ha^{-1})	176.02	50.91	171.62	113.48
Leaf area index, LAI (m^2·m^{-2})	1.9	1.03	1.25	2.52
NPP (t C ha^{-1}·year^{-1})	43.78	8.63	12.15	24.58

some plots of sites B and C leads to direct sunlight penetration, which in turn promotes high transpiration rates with consequences of decline in plant water use efficiency, net photosynthesis, stunted growth and die-off in extreme cases [9]. Light gaps are however advantageous to seedlings, as they are shade intolerant [33]. *Rhizophora* roots showed aggregate distribution with average root density of 22 individuals per m^2 for surveyed sites. Log-normal plots [34] of diametric sizes of roots follows unimodal, negatively skewed distributions (**Figure 2**), reflect striking dissimilarities in root diameter, suggesting degraded forests. In a log-normal plot, undisturbed communities usually start high on the abscissa and flatten out towards higher classes. Conversely, disturbed communities start lower on the abscissa as observed in the different mangrove stands albeit with varying degrees of disturbances. The LAI values observed in these mangrove stands are similar to those of tropical savanna (mean ± S.D: 1.88 ± 1.81, [35]). The amount of radiation transmitted from the top of the canopy to the forest ground are averages of 38, 59, 54 and 29 percent for sites A, B, C and D respectively. Lower amounts of radiation were transmitted to the forest floors in stands with relatively higher LAI values.

3.4. Carbon Storage Potentials

The lowest carbon influx rates were recorded in site B. Assuming the average annual net primary productivity of 22.28 t C ha^{-1} (**Table 5**), prop roots within the investigated area are capable of fixing a crude estimate of 0.86 Gt CO_2 annually. Carbon contents of roots constitute an average of 44.9% of the oven-dry mass (**Table 5**). $\delta^{13}C_{mangrove}$ were isotopically lighter compared to standards and ranged between −26.09 and −29.08, suggesting a Calvin mechanism (C3) of photosynthesis. These values are comparable to those of the *Rhizophora* mangroves of Malaysia [36], Sri Lanka [37] and Tanzania [38]. Carbon pools, on per hectare basis were highest in site A, the freshwater stands, while lowest values were in the degraded forests of site B. Stored carbon values fell into the range (160 - 200 $Mg \cdot ha^{-1}$) estimated by [39], except those of sites B and D that were lower.

3.5. Regenerative Capacity

A common feature of these *Rhizophora* forests is the absence in their under-storey of other vegetation types. Their seedlings constitute the ground-storey. The studied forests showed potential for natural unaided regeneration with average seedlings density of 10 (**Figure 3**). Site D demonstrates the highest rates of survival of propagules

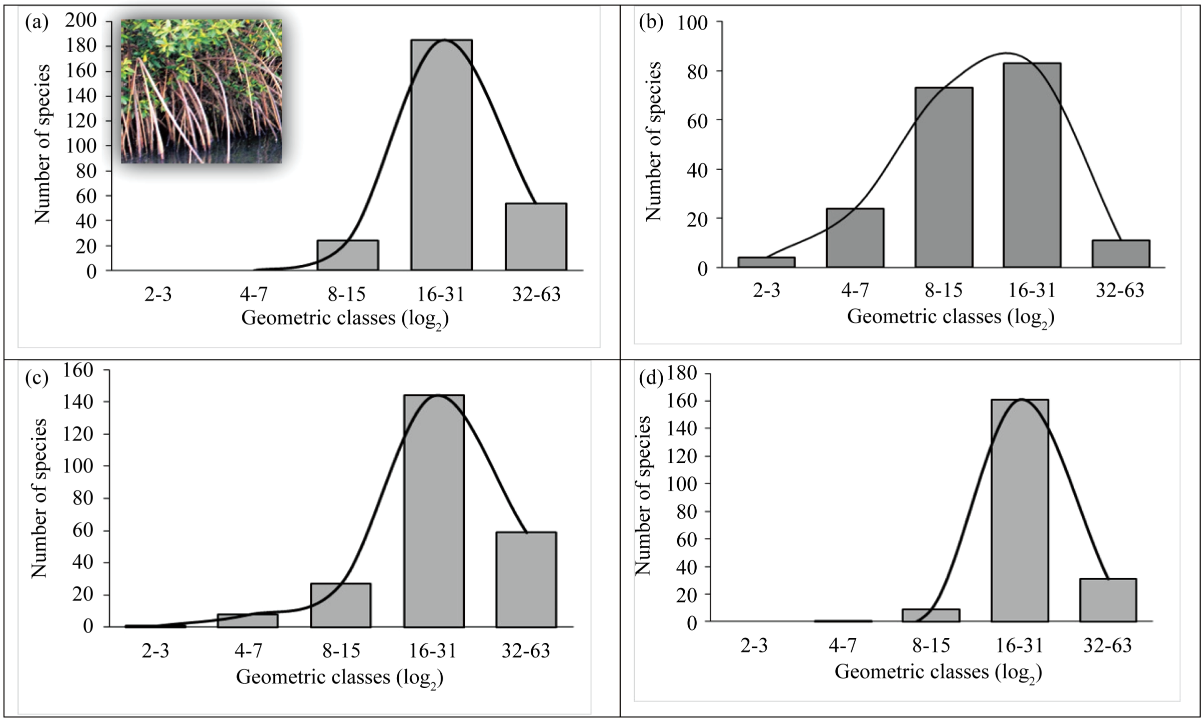

Figure 2. Lognormal plots of mangrove prop root density in 1 × 1 m plots at the different localities.

with seedlings density up to 73 roots per m^2. This might be probably due to the firm sandy layers that facilitates the successful establishment of propagules. Conversely, site A recorded the lowest seedlings density. Dense canopy cover coupled with water-logged soils that prevent solar radiation and dissolved oxygen from reaching the forest floors are likely causes of low survival rates of propagules.

3.6. Supplementary Ecological Data

Litter fall (materials on forest floor, 5 mm below ground layer) density was on average 3.2, 1.5, 2.0, and 4.7 kg·m^{-2} for sites A, B, C and D respectively. These were mostly from dried leaves, stems and fresh and dried propagules. Highest litter fall density (6.1 kg·m^{-2}) was recorded at site D, while the lowest (1.5) was recorded at site C. Conclusions cannot however be drawn from this ecological data as more information are needed on sedimentation rates, burial rates and nutrient cycling.

The distribution of a gastropod mollusc, *Pachymelania aurita* increases with decreasing water salinity (**Figure 4**). Mangrove crabs were common features in all forest stands.

3.7. Pilot Socio-Economic Survey

The diverging views and knowledge of mangrove forest resources stem from ethnic diversity. Eloka-To is a homogenous population of indigenous Ébriés, Anna is a community with indigenous population of Ébriés mixed with nationals of neighboring countries like the Republic of Benin and Togo. Mois is an encampment largely

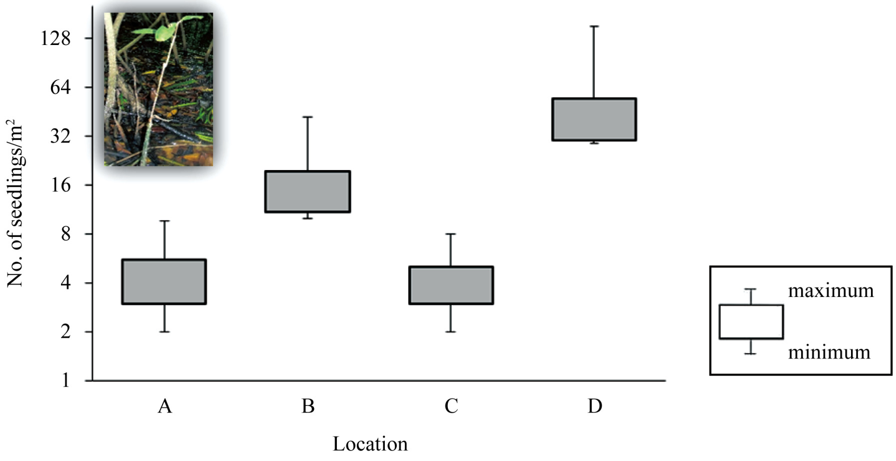

Figure 3. Box plots of seedlings density on 1 × 1 m plots in the different localities. Values are means ± range.

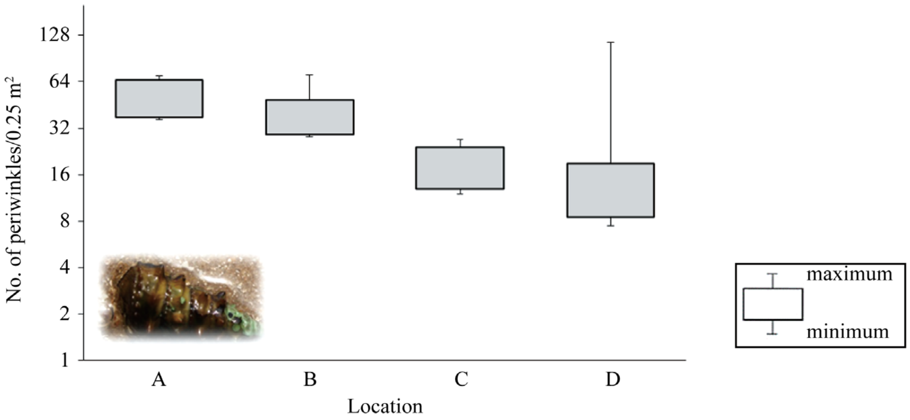

Figure 4. Box plots of population density (individuals per 1/4 m^2) of benthic grazer, *Pachymelania aurita*. Values are means ± range.

populated by nationals from neighboring Republic of Benin. More than 70% of the survey population can identify mangroves species. In the local Ébrié dialect *Rhizophora racemosa* is referred to as "n'tagbagna" meaning legged tree. They are also commonly called "palétuviers rouge". *Raphiahookeri* and *Dreparnocarpuslunatus* are locally referred to as, "palmiers" and "griffes des leopards" respectively. Other mangrove species including the mangrove fern, *Acrostichum aureum* are regarded as weeds. All respondents, except those from Mois opined that there has been a decrease in areal extent of the mangrove forest and that the trend will continue. Vulnerability is assessed based on a triad of exposure, sensitivity and adaptive capacity [40]. In this regard, Anna with a slope of 1.5% is geographically most vulnerable to coastal barrier degradation and therefore the most prone to coastal hazards, followed by Mois encampment (slope: 3.7%) and Eloka-To (6%). Sensitivity of the locals to mangrove forests resource decline was assessed by their dependence on the resource. Polls reveal high dependence on mangrove timber and non-timber forest products (crabs, fishes, shrimps and birds). The key areas of use are as direct income sources (70%) and domestic energy needs (60%). **Figure 5** highlights anthropogenic activities in some of the mangrove forest stands. There is unhindered access to forest resources in all communities except in Eloka-To, where community management committee organizes and supervises logging activities. In spite of these laudable initiatives, there are still several reported cases of illegal and indiscriminate logging.

Adaptive Capacity

According to [41], more than half of the rural population in Côte d'Ivoire lives below the poverty line (less than US $1 per day). Faced with steady decline of mangrove resources, survey results show that the capacity of the population to adapt to alternative economic activities is low due to lack of alternative revenue sources. In


(a) (b) (c) (d)

Figure 5. Anthropogenic activities in selected mangrove forests: (a) Logged timbers on the Ébrié lagoon in Eloka-To; (b) Mangrove forest land reclaimed for construction in Anna; (c) Mangrove forest lands re-claimed for community extension in Audoin-Bégréto; (d) Mangrove forest lands reclaimed for agriculture in Mois (bottom right). Photos by Osemwegie I.

Eloka-To, 95% are fishermen with 65% involved in subsistence farming and 5% into commerce. In Anna, over 75% are fishermen, even though quite a number of them have given up this occupation due to dwindling aquatic stocks, 40% are subsistence farmers and 45% traders. In Mois, 69% of the respondents are fishermen, 30% of which are directly involved in the sales of their produces.

Prior to investigation, it was hypothesized that locals will willingly refrain access and make contributions to conservation as they are the primary beneficiary. However, results show otherwise. Restoration plans and corrective measures aimed at conservation will depend largely on grassroots involvement [42] [43]. In order for conservation efforts to be effective, it is imperative to address the peculiar socio-economic needs of the host communities. The provision of social amenities and services (**Figure 6**) will be crucial motivating factors in ensuring local participation in mangrove forest restoration programs.

Livelihood diversification will help reduce human pressures on these ecosystems. Micro projects such as aquaculture and establishment of skills acquisition centers should be encouraged with a view to diversifying sources of income for the riverine population.

Unsustainable agribusiness and other human activities pose considerable threat to mangrove conservation. Nature plays only secondary roles. For instance, in Anna, mangroves are threatened by urban encroachment and sand mining/dredging activities that results in drained soils. Mangroves stands in Eloka-To are threatened by commercial exploitation and low survival rates of juveniles owing to increased tidal amplitudes, the result of the silting up of the mouth of the Comoé River. That of Mois is threatened by strong wave actions that hinder the successful establishment of propagules and forest land reclamation for agricultural purposes. The high demand for *Rhizophora* timber as fuel wood lies in its unique hard wood structure, high calorific value and ease of acquisition. The prices are comparable to those of other forest woods. At current exchange rate of US $1 dollars to 598.5 West African CFA franc, a bundle of ten pieces of chopped wood is sold for between 200 CFA franc (US $0.33) and 500 CFA franc (US $0.84) and a twenty kilogram bag of wood charcoal is sold for 3000 CFA franc (US $5). Bakeries and eateries in nearby urban areas spend between 60,000 CFA Franc (US $100.26) and 400,000 CFA Franc (US $668.34) monthly on fuel woods. There is an organized supply chain structure from producers to end users. In order to discourage demand, pigouvian taxes needs to be levied on end users. Existing national anti-logging legislations should be enforced and offenders sanctioned to serve as deterrent. Incentives; monetary and materials should be provided towards the empowerment of existing local environmental protection committees to patrol and protect the forests. Reforestation projects—manual establishment of propagules, temporal restraint of access to forest and the exploitation of other fuel sources such as agricultural wastes and timber woods like *Albiziazygia* (leguminosae) and *Acacia magnum* (Fabaceae) with fast growth, and good regeneration capacity (Centre National de Recherche Agronomique, CNRA, 2013) should be encouraged.

4. Conclusion

It is clear from the foregoing that the integrity of the *Rhizophora* mangrove forests in the studied regions have

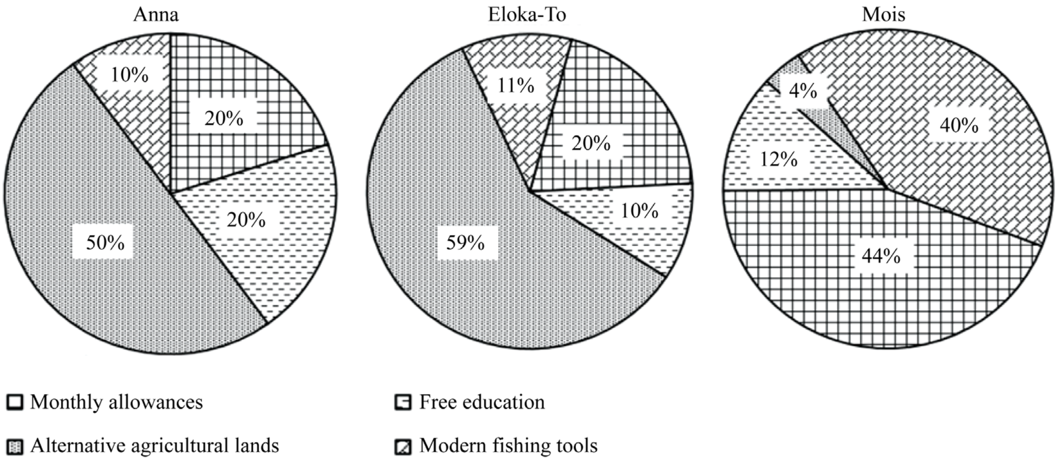

Figure 6. Forms of indemnity respondents are willing to accept from the government in order to restrain temporary use of mangrove forest resources.

been compromised. Their geographic form and occurrence are such that interference with their functionality has generated ripple effects on inherent aquatic biodiversity and adjoining terrestrial ecosystem. The theory of the tragedy of the commons is more exemplified in these mangrove forests today than ever before. The dangers of mangrove forest degradation are not restricted to carbon dioxide emissions, but can generate socio-economic displacements due to loss of biodiversity and ecosystem services. Although, deforestation is a global threat, solutions and reforestation programs must take into consideration socio-economic peculiarities of different host communities in order to be sustainable and successful.

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