Chapter 4

Cameroon Mangrove Forest Ecosystem: Ecological and Environmental Dimensions

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79021

Abstract

This study examined the ecological effects of local scale mangrove exploitation through surveys, empirical field experiments, modeling and questionnaires. The ecosystem "health" was assessed by parameterising a mass-balance model (ECOPATH with ECOSIM). The results suggest that forest exploitation affects mangrove forest structure and two-third of the canopy gaps were caused by human activities. Regeneration was affected, and more seedlings were recorded in canopy gaps compared to closed canopy areas. A total of 1358 crabs were collected to assess it population structure, 770 females (56.7%) and 588 males (43.3%), belonging to 13 species. The family Sesarmidae contains 5 species (38.5%), while Grapsidae 2 species (30.8%), Ocypodidae 1 species (15.4%) and to each of the families Portunidae and Gecarcinidae (7.7% each). *Uca tangeri* (Ocypodidae) and *Goniopsis pelii* (Grapsidae) were the two dominant species, constituting 44.1 and 21.9%, respectively, of the total sampled crabs. Propagules predation was a major source of mortality for mangrove. An average of 65.9% of the propagules was predated and most were found to be non-viable. The Ecopath analysis suggests that the Cameroon mangrove ecosystem is relatively healthy and moderately mature. This analysis allowed a reasonable model representation of the Cameroon mangrove system, as the model viability was determined by using the sensitive analysis function.

Keywords: crabs, West Africa, anthropogenic pressure, canopy gaps, propoagule recruitment, ecopath model

1. Introduction

Mangrove forests are one of the unique features of intertidal zones throughout tropical and subtropical regions of the world and cover an area of approximately 15 million hectares worldwide [1]. In recent years, these ecosystems have been extensively studied. The basic botany of mangrove has been described by Tomlinson [2]. An overview of mangrove ecology, distribution and biology has been described in [3–5].

Cameroon mangrove forests are found east and west of Mount Cameroon with smaller formations dispersed along the estuaries of the other rivers. The main stands of trees are the Rio-del-Rey and the Cameroon Estuary, respectively (**Figure 1**). The latter covers an estimated surface area of about 75,000 ha (approximately 50 km of coastline), while the former covers an estimated surface area of 175,000 ha (approximately 60 km of coastline from the River Sanaga to the Bimbia estuary).

The floristic composition of Cameroon mangrove is characteristic of the Atlantic mangroves of West Africa. It is dominated by *Rhizophora* and comprises mostly three species, *R. mangle*, *R. harrisonii* and *R. racemosa* [3]. The pioneer species *Rhizophora racemosa* constitute 90–95% of the mangrove area [6]. Other mangrove species include *Avicennia germinans*, which occurs on the higher elevation fibrous clay or sandier soils, *Laguncularia racemosa* and *Conocarpus erectus*, *Acrostichum aureum*, *Pandanus candelabrum* and the introduced *Nypa fruticans* [3, 6].

Human activities in coastal areas such as physical alteration of the habitat, over-exploitation of the resources and pollution cause significant pressure on the environment. These pressures have increased steadily as the human population increases. Coastal areas, including mangroves, are characterised by high productivity creating important nurseries for offshore fish,

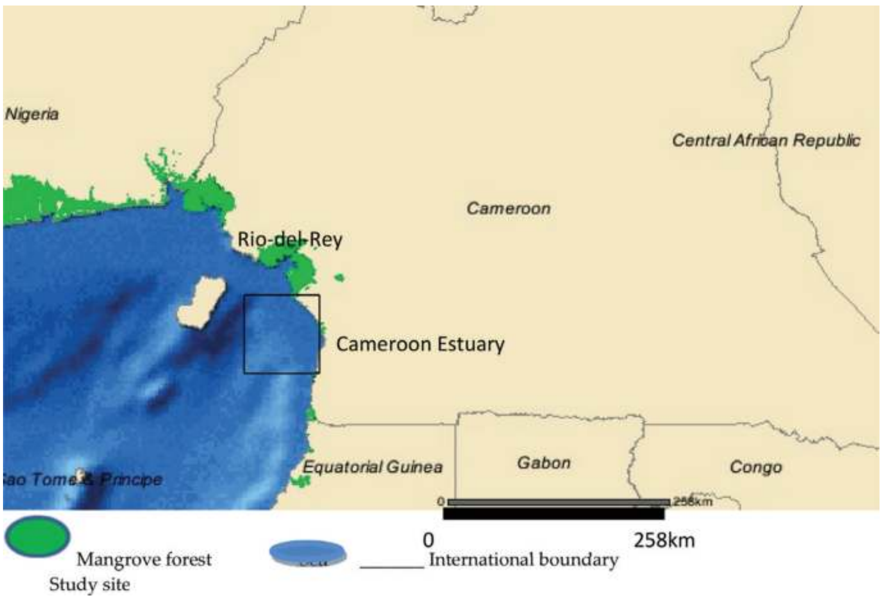

Figure 1. The Cameroon coastline showing mangrove forest locations (Adapted from UNEP –WCMC, 2005).

http://dx.doi.org/10.5772/intechopen.79021

but they are among the most exploited ecosystems [7]. Frequent, but low intensity, smallscale anthropogenic disturbance, such as firewood extraction, may strongly affect forest structure and species composition in tropical forests [8, 9].

Mangrove crabs are probably the most prominent and significant biotic components of mangrove ecosystems in terms of species richness and their ecological engineering role [10–12]. Their distribution is influenced by biotic and abiotic factors, such as water salinity, temperature, food availability and preference, sediment properties, vegetation type, interspecific competition and predation [13, 14]. The most common crabs in mangroves are either Fiddler crabs (Family Ocypodidae, genus *Uca*) or Sesarmid crabs (Family Grapsidae, subfamily Sesarmidae) [15].

The ecological role of crabs in terms of the functioning of the mangrove ecosystem is thought to be significant [16]. Energy assimilated by crabs plays a significant role in nutrient recycling [17], crabs aerate the soil by burrowing [18], increase nutrient content by burying organic matter, decrease toxic sulphide and ammonium concentrations within the sediment [19], reduce pore water salinity by flushing water through burrows [20] and create a microhabitat for other fauna [21]. Despite the vital role played by crabs in the mangrove ecosystem, data on crabs in some areas remain patchy in Cameroon.

Several species of mangrove macrofauna are known to consume plant materials, including crabs [22–24]. Among these, crabs are thought to be major consumers and to be a key source of leaf and seedling mortality in mangroves [25].

Ecosystem health is a concept that sets new goals for environmental management, and its definition and assessment methods are still being perfected [26]. According to Costanza [27], ecosystem health represents a desired endpoint of environmental management. The advances in this concept are evident from the fact that it is now recognised that a reflexive relationship exists between human systems and natural ecosystems in that the health of one is dependent on the health of the other [28]. According to Rapport et al. [29], healthy ecosystems must not only be ecologically sound, but must also be economically viable and able to sustain healthy human communities.

There are different approaches for assessing ecosystem health, and one is ecological modelling, used as a tool to describe complex system-level metrics related to health. Specifically, I use the mass balance model Ecopath [30]. This model represents trophic networks that connect species (functional groups) in a system, and the magnitude of flows of materials and higher-level indices within the different functional groups can be calculated from the complex network, which can in turn be related to ecosystem health.

1.1. Research framework and objectives

The research framework in which the present study fits involves a number of separate sections, each of which constitutes a piece of the entire study. The discussion links all of these sections, specifically, the objectives are to assess: (a) the mangrove use and structural effects of local-level cutting of Cameroon mangrove forests, (b) the distribution, diversity and abundance of mangrove crabs in Cameroon mangroves, (c) the ecological effect of mangrove crab herbivore feeding preferences in Cameroon mangrove forests, (d) to examine mangrove community function in terms of trophic linkages, in which a mass-balance model (ECOPATH with ECOSIM) is parameterised and explored.

2. Methodology

To assess mangrove, use and structural effects of local–level cutting of Cameroon mangrove forests data of forest characteristics were collected. I employed the quadrat/census plot method [12].

To assess the floristic composition and stand structure, data were collected on tree species composition, diameter at breast height (dbh), tree height, seedlings, canopy cover, gaps, gap size, stumps and snag (dead stems). In each plot, every tree was numbered, marked and measured (>1.0 m tall) and seedlings (<1.0 m) recorded [13]. The diameter at breast height (dbh) of each tree stem was measured at 1.3 m or above the highest prop root, following [12]. Tree height was measured using marked bamboo poles and clinometers. Evidence of human cutting was also recorded. Data for local uses were collected in villages in the study area, selection of the study site was on the basis of their accessibility, cooperation and background knowledge of village communities utilising mangrove forest. They are assumed representative of the larger mangrove community.

Data were collected by focus group discussion. Five group meetings were carried out per village, first with the chief and the village councillors, followed by three separate meetings with elderly fishermen and one meeting with the elderly women. Data collection was through in-depth interviews and systematic filling out of questionnaires and direct observation of everyday life during village visits. Answering of the questions was done through participatory rapid appraisal method (PRA). The participants were allowed to discuss among themselves and every person's opinion was relevant, until they reached a consensus. In some circumstances, they were given 20 stones to distribute them into categories, to reflect their views.

The questionnaire was mainly structured, with a few semi-structured questions. Elderly residents with a long residency history were chosen in order to explore perceptions of mangrove forest status. More males were interviewed because of the gender bias that exists in the division of labour in this region. Men alone are involved in fishing and harvesting wood, while women assist in wood transportation as well as fish smoking.

Increased participation and some degree of reliability of the interviewee to provide information was enhanced as follows:

1. Contact with the chief of each village before starting data collection;
2. High degree of socialisation with the interviewee during sampling;
3. The use of a field guard (interpreter).

The approach of administering the questionnaires was made flexible enough to accommodate questions and answers, with the aim of making the process more interactive, friendly and to obtain as much information as possible. Interviews were conducted in English, French and the local dialect, but the filling out the answers to the questions was done in English. The information gathered allowed an evaluation of the uses of the mangrove vegetation and ecosystem, an assessment of the mangrove area and the socio-economic profile of local communities.

Direct observation alone was carried out where a group refused to answer some questions or tried to give deliberately false answers based on my personal judgement and the opinion of the local interpreter.

To assess the distribution, diversity and abundance of mangrove crabs, data were collected at low tide when crabs are more active. Data on crab species present were recorded using 10 × 42 binoculars. Subsequently, crab species were collected by hand for 15–30 min. On approaching the crabs, it immediately retreated to their burrows or took refuge. To offset any bias in favour of collecting slow-moving species, more time and effort was allocated to catching the larger, faster-moving crabs. This may introduce another bias, but previous experience has shown that this gives a more representative overall assessment of species composition [31]. A 1-m^2 quadrat was placed randomly and excavated to a depth of 30 cm and all crabs collected. This excavation method is thought to offer a more reliable estimate of crab density [32]. The crabs were sedated in iced water for a few minutes, washed and stored in 70% alcohol, later identified, weighed (wet weight) and carapace width measured. All the specimens collected were stored carefully to ensure that no appendages were lost due to stress, and identified with the aid of field keys [33–35]. To assess the ecological considerations of mangrove crab herbivore feeding preferences, the level of damage to and preference for mangrove leaves and propagules was studied. Propagule predation was studied by tethered propagules independently with a 50-cm length of nylon twine, the other end of which was tied to a piece of wood on the forest floor. The propagules were spaced far enough apart so that the tethers could not get tangled. The length of each propagule was measured, and propagules individually tagged. The propagules were checked from a distance using binoculars over a 6-h period, after which they were checked once a day for 1 week. All observations were carried out during low tide when the crabs are very active.

Predation status was recorded following [22]: (1) when the epicotyl was eaten (2) when 50% of the hypocotyl was lost (3) when the propagule was pulled into the burrow of crab. Each propagule was classified as viable (capable of growth, i.e. ≤50% of propagule eaten), non-viable (incapable of growth, i.e. >50% of propagule eaten) and missing (when lost). Signs of snail predation were also recorded.

Leaf predation for all the three mangrove species in Cameroon (*Laguncularia*, *Avicennia* and *Rhizophora*). Fresh and senescent leaves were gathered, fresh leaves by harvesting from trees, whilst senescent leaves (yellow and easily abscised) were either picked from the forest floor or harvested from the tree. Ten replicate leaves (fresh and senescent) of each species were tethered with a nylon string 50 cm in length with the other end tied to approximately

5 m of string and tagged. The leaves were tied randomly and far apart to avoid tangling. The leaf surface was measured by tracing around the edge on graph paper. Leaves were checked after 24 h, damage recorded, and it was noted whether the leaves were found on the surface or in a crab burrow. Leaves that were in a burrow were removed by gently pulling on the attached string.

Additional data on leaf predation were gathered from crabs predating within the canopy. Crabs were seen residing on tree trunks, branches and the prop roots. They were observed climbing mangrove trees, usually early in the morning to feed on leaves and by midday they all moved back down, moving up the tree again early in the evening and down again by late evening. An average of 5 crabs was found on a single tree. Young trees (1.5–2 m tall, dbh 2.3–5 cm) of each species (*Laguncularia*, *Avicennia* and *Rhizophora*) were observed from a close distance for about 5 hours and crab feeding activities and presence of crab damage recorded. The percentage of the leaves with damage was used to calculate the damaged leaves per plant, and these values were averaged for each species within the sample area.

To evaluate ecosystem structure, its function and organisation, I applied the Ecopath with Ecosim model (www.ecopath.org) to the Cameroon mangrove estuarine system. Selected ecosystem indicators that could be used to monitor ecosystem status or health were analysed using a set of ecosystem goal functions, representative of Odum's attributes of ecosystem maturity [36]. The attributes represent three different aspects of ecosystem development: (1) complexity in community structure, (2) community energetics and, (3) overall community homeostasis.

The steps and governing principles of the general approach of Ecopath and Ecosim have been described in detail in [30, 37], and can be accessed at http://www.ecopath.org. The detail modelling approach (Ecopath with Ecosim) can be accessed at [35, 36, 38, 39].

For this study, the selection of functional groups to represent the Cameroon mangrove food web was a product of a collaborative process. A number of stakeholders and experts (including myself) participated in the discussion to produce functional groups based on the following criteria:

- The species must be representative and abundant
- The species must be relevant to the overall aims of the study
- There must be some relevant data for those species (although not necessarily for the Cameroon mangrove forest).

In the final iteration, based on these criteria, 26 functional groups were selected for this model (**Table 1**): 13 fishes, 3 kinds of birds (11 species), groupings of 3 crabs, mangroves, phytoplankton, zooplankton, detritus, benthos, shrimps and insects. All the species within a functional group have ecological similarities, defined by similarities in diet, production and consumption rates, life history, and habitat associations, but also sometimes on value-driven criteria, such as commercial status or importance for subsistence users. Because of the nature of the Cameroon mangrove forest, where mangrove wood products are used extensively as source of energy to smoke fish, it is important therefore to consider the mangrove forest as a

http://dx.doi.org/10.5772/intechopen.79021

primary producer and make the link with fishing pressure. The functional group benthos was included because of its contribution to the diets of other groups.

The input parameters for each group were: the biomass (B), the production/biomass ratio (P/B), the consumption/biomass ratio (Q/B) and ecotrophic efficiency (EE). Input parameters were estimated from the field or extracted from the literature, either from studies done within a similar mangrove ecosystem (in Central Atlantic region) or on the West Africa continental shelf. The diet matrix was constructed by designating the percentage of each prey that occurs in each predator's diet. Diets were derived mostly from the scientific literature, except for crab's groups

1.	Mangrove	*Rhizophora* spp., *Avicennia* spp., *Laguncularia racemosa*
2.	Phytoplankton	Diatoms, dinoflagellates and others
3.	Zooplankton	Neritic copepods, bivalve larvae, ostracods, mysids, nauplii, fish eggs and others
4.	Shrimps	*Peneaus* spp., *Parapenaeopsis atlantica*, *Penaeus notiali*
5.	Mangrove crabs	Sesarmid species
6.	Fiddler crabs	*Uca* species
7.	Other crabs	*Scylla serrata*, *Cardisoma carnifex* and others
8.	*Ilisha africana*	
9.	*Pseudotolithus* spp.	*P. senegalensis*, *P. typus* and *P. elongates*
10.	*Pentanemus quinquarius*	
11.	*Sardinella maderensis*	
12.	*Brachydeuterus auritus*	
13.	*Dreprane africana*	
14.	*Arius* spp.	*A. heudelotii* and *A. parkii*
15.	*Pomadasys jubelini*	
16.	*Galeoides decadactyl*	
17.	*Raja miraletus*	
18.	*Lutjanus* spp.	*L. goreensis* and *L. dentatus*
19.	*Mugil curema*	
20.	*Caranx* spp.	*C. senegallus*, *C. hippo* and *C. senegalensis*
21.	Shorebirds	Finfoot (*Podica senegalensis*), Avocet (*Recutrvirostra avosetta*), White-footed plover (*Charadrius marginatus*), Common Green shank (*Tringa nebularia*), Common sandpiper (*Actitis hypoleucos*).
22.	Birds of prey	Black kite (*Milvus migrans*), Fish eagle (*Haliaeetus vocifer*), Palm nut vulture (*Gypohierax angolensis*), Harrier hawk (*Polyboriodes typhus*)
23.	Insectivorous birds	Grey flycatcher (*Musicapa cassini*), Pied crow (*Corvus albus*)
24.	Benthos	
25.	Insects	
26.	Detritus	Organic matters and associated like bacteria

Table 1. Descriptions of some functional groups of the mangrove ecosystem in Cameroon.

	Prey	Predator																						
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Mangrove	—	—	0.6	0.5	0.9	—	—	—	—	—		—	—	—	—	—	—	—	—	—	—	0.9	0.1
2	Phytoplankton	0.8	0.1	0.1	—	—	0.3	—	—	0.4	0.2	0.3	0.2	—	—	—	—	0.8	—	—	—	—	—	0.5
3	Zooplankton	—	0.4	—	0.05	—	0.3	0.4	0.1	0.2	0.4	0.3	0.2	0.6	0.2	0.05	0.1	—	0.6	—	—	0.05	—	—
4	Shrimps	—	—	—	0.05	—	—	—	—	—	—	—	—	—	0.1	0.05	0.2	—	—	—	—	0.05	—	—
5	Mangrove crabs (Sesarmidae)	—	—	—	—	—	—	—	—	—	—	—	0.1	—	0.1	0.05	0.1	—	—	—	—	—	—	—
6	Fiddler crabs (*Uca*)	—	—	—	—	—	—	—	—	—	—	—	0.1	—	0.1	0.05	0.1	—	—	—	—	—	—	—
7	Other crabs	—	—	—	—	—	—	—	—	—	—	—	0.1	—	0.1	0.05	0.1	—	—	0.1	—	—	—	—
8	*Ilisha africana*	—	—	—	0.05	—	—	0.3	0.05	—	—	—	—	—	—	0.1	0.05	—	—	—	0.1	—	—	—
9	*Pseudotolithus* spp.	—	—	—	0.05	—	—		0.05	—	—	—	—	—	—	0.1	—	—	—	—	0.1	—	—	—
10	*Pentanemus quinquarius*	—	—	—	—	—	—			—	—	—	—	0.05	—	0.1	—	—	—	—	0.1	—	—	—
11	*Sardinella maderensis*	—	—	—	—	—	—	0.2	0.1	—	—	—	—	—	—	0.1	0.05	—	—	—	0.1	—	—	—
12	*Brachydeuterus auritus*	—	—	—	—	—	—	—		—	—	—	—	—	—	0.1	—	—	—	—	0.1	—	—	—
13	*Dreprane africana*	—	—	—	—	—	—	—	0.05	—	—	—	—	—	—	0.1	—	—	—	—	0.1	—	—	—
14	*Arius* spp.	—	—	—	—	—	—	—	0.05	—	—	—	—	0.05	—	0.1	—	—	—	—	0.1	—	—	—
15	*Pomadasys jubelini*	—	—	—	—	—	—	—	0.05	—	—	—	—	—	—	—	—	—	—	—	0.05	—	—	—
16	*Galeoides decadactylus*	—	—	—	—	—	—	—	0.05	—	—	—	—	—	—	—	—	—	—	—	0.05	—	—	—
17	*Raja Miraletus*	—	—	—	—	—	—	—	0.05	—	—	—	—	—	—	—	—	—	—	—	0.05	—	—	—
18	*Lutjanus* spp.	—	—	—	—	—	—	—	0.05	—	—	—	—	—	—	—	—	—	—	—	0.05	—	—	—
19	*Mugil curema*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.05	—	—	—
20	*Caranx* spp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
21	Shorebirds	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22	Birds of prey	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Prey		Predator																						
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
23	Insectivorous birds	—	—	—	—	—	—	—	—	—			—	—	—	—	—	—	—	—	—	—	—	—
24	Benthos	—	0.1	0.1	0.2	—	0.1	0.1	0.4	—	0.1	0.4	0.3	0.1	0.4	0.05	0.3	—	0.4	0.9	—	—	—	—
25	Insects	—	—	—	—	—	—	—	—	0.2	—	—	—	—	—	—	—	—	—	—	0.05	0.9	—	—
26	Detritus	0.2	0.4	0.2	0.1	0.1	0.3	—	—	0.2	0.3	—	—	0.2	—	—	—	0.2	—	—	—	—	0.1	0.4
		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 2. Diet composition.

http://dx.doi.org/10.5772/intechopen.79021

where stomach content analysis was carried out. The degree of confidence, that the parameters are appropriate for the Cameroon is expressed through the data pedigree coding option.

Diet information for crabs was obtained directly from stomach content analysis Literature data were used for all other functional groups (**Table 2**).

2.1. Balancing the model

After entering all the basic inputs into the Ecopath model, the first step is to check if the outputs are sensible, in other words, whether the biomasses of all groups can be supported by their consumption rates and the productivities of their prey. Detailed on how to balance the model can be accessed at [36, 37] in the Ecopath manual. Once the model was balanced, various ecosystem attributes were evaluated, these attributes include those given in [36, 40], allowing inferences to be drawn about the health of the ecosystem.

3. Results

3.1. Mangrove use and structural effects of local-level cutting

A total of 3167 individual trees, 423 stumps and 103 snags were recorded. *Rhizophora* (Red mangrove) was the dominant species (83.6%) followed by *Avicennia* (Black mangrove) at 9.1% and *Laguncularia* (White mangrove) at (7.1%).

3.2. Cameroon mangrove forest structure

Mangrove forests differed structurally, due to a combination of anthropogenic and natural factors. The mean tree density and seedling density, the mean diameter at breast height (dbh) and basal areas are presented in (**Table 3**).

3.3. Canopy gaps

A total of 257 gaps were recorded during the study. Human influence was responsible for most of the gaps created (**Table 4**). An average gap size of 3.1 m^2 was recorded. The average gap density of 27.4 was recorded overall. The relationship between seedlings and canopy was examined as an alternative way to estimate the effect of exploiting forest on mangrove

Characteristics	Average
Tree density (n/100 m^2)	16.0 (20.2)
Diameter at breast height (dbh) of stem (cm)	23.8 (19.7)
Stem basal area (m^2/ha)	60.1 (29.8)
Gap size (m^2)	0.32 (0.3)
Seedling density (n/100 m^2)	23.5(40.1)

Table 3. Summary of selected ecological characteristics with mean values and standard deviation (in parentheses).

	Average
Canopy gap density (n/100 m^2)	27.4
Canopy density (n/100 m^2)	72.3
Gap size (m^2)	3.1
Human cause (%)	66.3
Non-human cause (%)	33.6

Table 4. Canopy gaps.

regeneration. Significantly more seedlings were observed in canopy gaps compared to closed canopy areas (T = 3.5, P = 0.008). *Rhizophora* seedlings were more abundant in canopy gap than in closed canopy areas (T = 2.4, P = 0.04), whilst *Avicennia* and *Laguncularia* were not (**Table 5**).

3.3.1. Forest species composition

The size-frequency distributions of all mangrove species are represented in **Figure 2**. All three-species showed a higher concentration of stems in small size classes (<25 cm). Compared to *Rhizophora*, *Avicennia* is completely absent from size classes greater than 95 cm, and *Laguncularia* from classes more than >25 cm.

3.4. Local uses of mangrove wood

All mangrove species are used by the villagers for different purposes. The principal uses are sources for fuelwood and poles for construction (**Figure 3**) and the most preferred species are Rhizophora species (*Rhizophora racemosa*, *Rhizophora harrisonii*) and *Avicennia germinans*. They are preferred because of their slow burning properties, resilience and availability. One of the most interesting properties of mangrove wood is that it burns well when fresh, so the process of drying the wood is not necessary. This property contributes to make it a favourable choice of fuel wood. All the tree parts (branches, stem and roots) are used as fuelwood, mostly for fish smoking.

Poles for construction are used mostly for building houses, bridges, fences and fish smoking barns (**Table 6**). The preferred species for construction is *Avicennia germinans*; because of it resilience property and mostly tree stem of different sizes are used.

3.5. Distribution, diversity and abundance of mangrove crabs

A total of 1358 crabs were collected over the study period, 770 females (56.7%) and 588 males (43.3%) (**Table 7**) belonging to 13 species. Of the 13 species, 5 belonged to the family Sesarmidae (38.5%), 4 species to the family Grapsidae (30.8%), 2 species to the family Ocypodidae (15.4%) and 1 species to each of the families Portunidae and Gecarcinidae (7.7% each). *Uca tangeri* (Ocypodidae) and *Goniopsis pelii* (Grapsidae) were the two-dominant species, constituting 44.1 and 21.9% respectively of the total sampled crabs. *Uca tangeri* dominated the mudflat in zone four, whilst *Goniopsis pelii* dominated zone one (disturbed young forest).

Species	Canopy gap	Closed canopy	t-values	P-values
Rhizophora	863	375	2.4	0.04
Laguncularia	220	59	1.2	0.25
Avicennia	161	93	1.2	0.16
Total	1244	527	3.5	0.01

Table 5. Seedling abundance of different mangrove species in open and closed canopies.

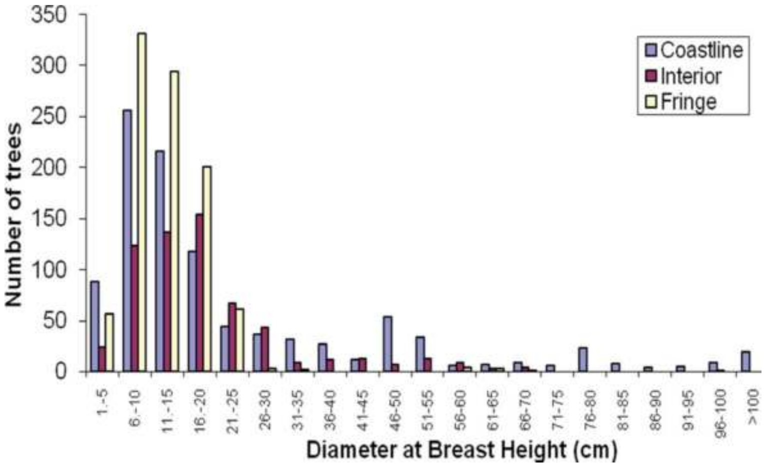

Figure 2. Size-frequency distribution of (dbh) of *Rhizophora*, *Avicennia* and *Laguncularia* species.

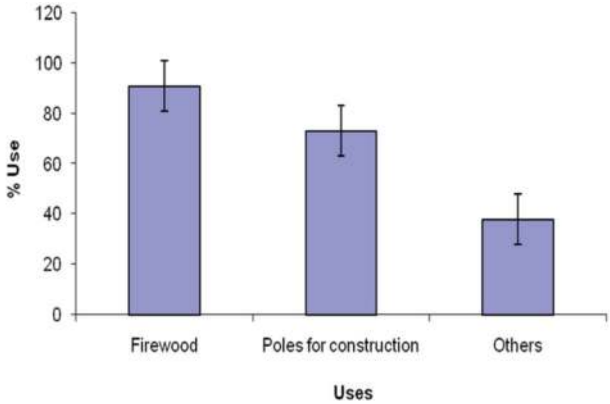

Figure 3. Different uses of mangrove wood as revealed by local users.

The size range for *Uca tangeri* was 0.1–5.5 cm, *Goniopsis pelii* 0.2–7.8 cm and *Sesarma* species 0.2–5.6 cm carapace width (CW) (**Figure 4a–c**). The size frequency distribution differed from normality, for *Goniopsis pelii* (KS = 2.902, P = 0001), *Uca tangeri* (KS = 2.56, P = 0.0001),

Tree	Local names	Uses
Avicennia	Black matanda	Furniture, fencing poles, firewood, construction poles, canoe anchors, poles for building bridges and fish smoking barns, paddles, fishing traps, roof supports, axe handles and resting beds
Rhizophora	Red matanda	Firewood, poles for building bridges and fish smoking barns, construction poles, fencing poles, resting bed, canoe anchors, fishing traps, and paddles
Laguncularia racemosa	White matanda	Firewood, poles for fences and furniture

Table 6. Local uses of mangrove trees in the sampled villages.

Family	Species	Female	Male	Total
Portunidae	*Portunus validus* (*Neptunus alidus*)	2	2	4
Sesarmidae	*Metagrapsus curvatus*	24	20	44
	Sesarma (*Perisesarma*) *huzardi*	28	17	45
	Sesarma (*Chiromantes*) *elegans*	21	9	30
	Sesarma (*Perisesarma*) *alberti*	17	8	25
	Sesarmine species	27	22	49
Gecarcinidae	*Cardisoma* species	39	28	67
Grapsidae	*Goniopsis pelii* (*G. cruentata*)	171	167	338
	Grapsus grapsus	49	60	109
	Pachygrapsus transversus	7	21	28
	Pachygrapsus spp.	8	4	12
Ocypodidae	*Ocypode africana*	50	20	70
	Uca tangeri	322	212	534
	Total	770	588	1358

Table 7. Number of crabs collected.

and *Sesarma* species (KS = 1.59, P = 0.013). All three of the most abundant species were better described by a bimodal rather than a unimodal distribution (**Figure 4a–c**). *Goniopsis pelii* shows a bimodal distribution with highest modal size ranging from 2 to 2.25 cm carapace width and a probable second mode at 6 cm, 2–2.3 cm carapace width for *Sesarma* species and *Uca tangeri* shows a bimodal distribution with highest modal sizes ranging from 1.5 to 1.75, 2 to 2.3, and 2 to 2.25 cm carapace width.

3.6. Relationship between carapace width and wet weight for *Uca tangeri* (Ocypodidae) and *Goniopsis pelii* (Grapsidae)

Uca tangeri (Ocypodidae) and *Goniopsis pelii* (Grapsidae) were the most abundant crabs associated with Cameroon mangroves. Estimating their biomass is essential in order to evaluate their importance to the system. Carapace width and wet weight were therefore determined for *Uca tangeri* and *Goniopsis pelii*. The relationships are as follows:

Goniopsis pelii WW biomass = 1.2588 (CW) $^{1.9095}$ (R^2 = 0.58) and *Uca tangeri* WW biomass = 1.1209(CW) $^{2.0917}$ (R^2 = 0.6619) (**Figure 5**).

3.7. Ecological effect of mangrove crab herbivore feeding preferences

Propagule predation by crabs occurred in all of the mangrove species ranging from 61.6 to 69.1% (**Table 8**). The effect of crab predation on propagules did not differ among mangrove species. The majority of propagules were found to be non-viable after predation and some were lost by being washed away by high tide (**Figure 6**). There was a significant difference between the number of non-viable and viable propagule (T = 2.13, df = 4, P = 0.002) with majority being non-viable. Some propagules were predated by gastropods, but the extent of this was minimal.

The percentage of leaves consumed by crabs varied among mangrove species (**Figure 6a**). *Rhizophora* species was the most consumed and *Avicennia* was the least, although this was not significant between species (ANOVA, F = 2.3, P = 0.24). Senescent leaves were preferred more than fresh leaves for all species (**Figure 7a**), and there was a significant difference in the percentage consumed of fresh and senescent leaves (T = 4.3, df = 2, P = 0.02). The majority of leaves

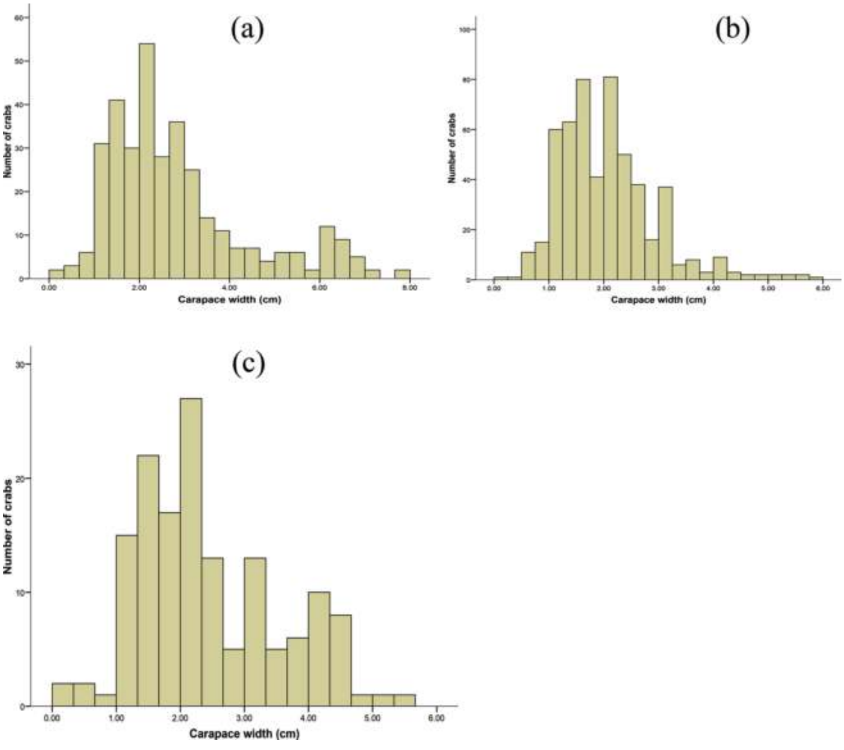

Figure 4. (a) Size (carapace width) frequency distribution of *Goniopsis pelii*, all zones combined. (b) Size (carapace width) frequency distribution of *Uca tangeri*, all zones combined. (c) Size (carapace width) frequency distribution of *Sesarma* species, all zones combined.

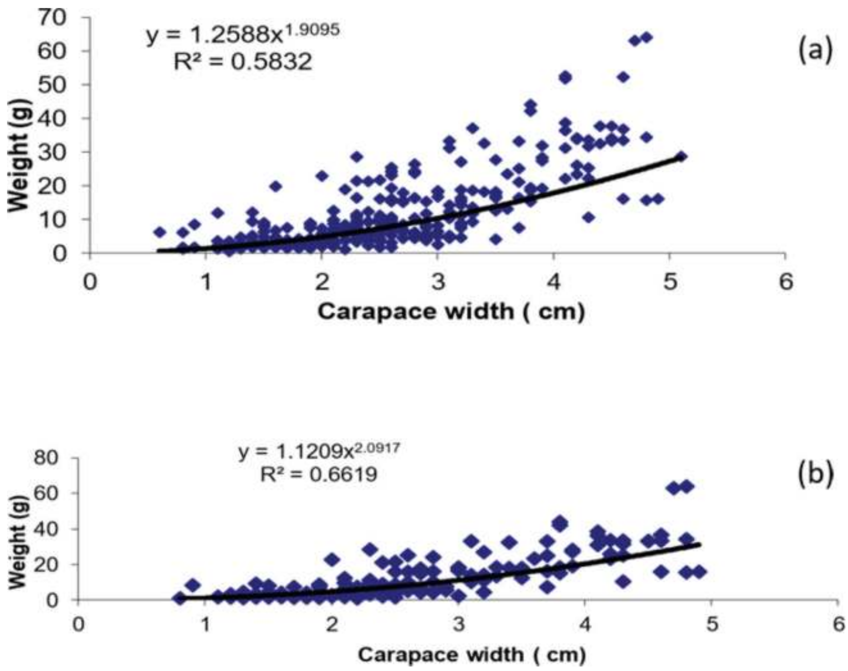

Figure 5. Relationship between carapace width and weight for (a) *Uca tangeri* (b) *Goniopsis pelii*.

Species	Average (%)
Rhizophora racemosa	69.8
Rhizophora mangle	66.3
Rhizophora harrisonii	61.6

Table 8. Summary of the percentage of propagules predated by crabs.

were taken into burrows (**Figure 7b** and **Table 9**), and they had been substantially grazed when recovered from those burrows. There was no leaf breakage during removal from the burrows.

3.8. Mangrove community function in terms of trophic linkages

The structure and network analysis parameter estimates for the model are shown in **Table 10**. These parameters include trophic estimates, biomass estimates, production/biomass estimates, consumption/biomass estimates, production/consumption ratios, gross efficiency estimates and omnivory index estimates. The Cameroon mangrove food web (as depicted here) consists of 3 trophic levels and 17 sublevels, which range from 1.0 to 3.74. The trophic level (TL) is an important index because it identifies an organism's food preferences. The highest values correspond to insectivorous birds, followed by the fish *Pentanemus quinquarius* and *Pseudotolithus* spp., whilst the lowest values correspond to the primary producer; mangrove, phytoplankton and detritus.

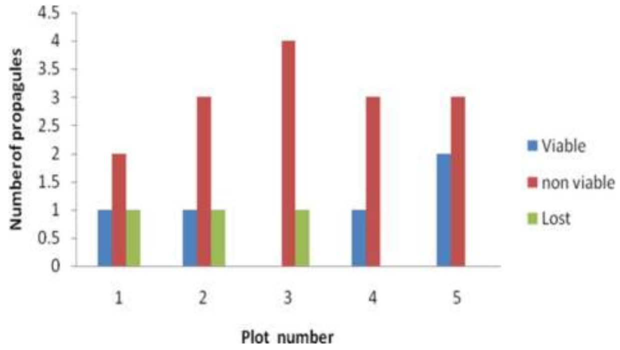

Figure 6. Number of propagules per plot killed by crabs, lost or still viable after predation.

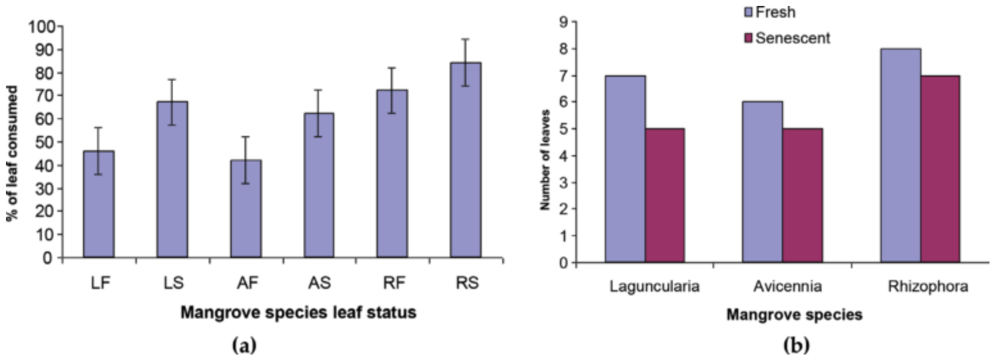

Figure 7. (a) Percentage of leaf material consumed by crabs for each mangrove species. LF = Laguncularia fresh, LS = Laguncularia senescent, AF = Avicennia fresh, AS = Avicennia senescent, RF = Rhizophora fresh, RS = Rhizophora senescent. (b) Number of leaves taken down crab burrows.

Species	**Leaf status**	**n**	**Number taken down burrows**
Laguncularia	Fresh	10	7
	Senescent	10	5
Avicennia	Fresh	10	6
	Senescent	10	5
Rhizophora	Fresh	10	8
	Senescent	10	7
Total		60	38

Table 9. Total number of leaves taken down crab burrows for each species and leaf status.

Summary statistics and basic flows and indices are shown in **Table 11**. The complexity in community structure is measured by the omnivory index (OI) [38]. The OI value for this study is 0.143 which is quite low when compared with Vega-Cendejas and Arreguín-Sánchez

	Habitat							
	TL	**Area (km^2)**	**Biomass (t/km^2)**	**P/B**	**Q/B**	**EE**	**P/Q**	**OI**
1 Mangrove	**1.00**	1.000	60.870	15.000	—	**0.564**	—	—
2 Phytoplankton	**1.00**	1.000	34.400	180.000	—	**0.712**	**0.313**	—
3 Zooplankton	**2.00**	1.000	27.130	15.000	160.000	**0.129**	**0.280**	—
4 Shrimps	**2.50**	1.000	0.417	5.380	19.200	0.950	**0.161**	**0.250**
5 Mangrove crabs (*Sesarmidae*)	**2.10**	1.000	2.400	2.250	14.000	**0.422**	**0.058**	**0.090**
6 Fiddler crabs (*Uca*)	**2.41**	1.000	1.300	5.500	95.000	**0.319**	**0.091**	**0.452**
7 Other crabs	**2.00**	1.000	2.500	2.000	22.000	**0.456**	**0.550**	—
8 *Ilisha africana*	**2.50**	1.000	1.993	3.006	55.000	0.950	**0.101**	**0.250**
9 *Pseudotolithus* spp.	**3.22**	1.000	1.780	0.648	6.400	0.950	**0.179**	**0.159**
10 *Pentanemus quinquarius*	**3.29**	1.000	0.294	1.775	9.900	0.950	**0.030**	**0.151**
11 *Sardinella maderensis*	**2.40**	1.000	1.015	1.260	42.200	0.950	**0.016**	**0.290**
12 *Brachydeuterus auritus*	**2.50**	1.000	1.615	1.026	63.000	**0.780**	**0.101**	**0.250**
13 *Dreprane africana*	**2.70**	1.000	1.396	0.820	8.100	**0.134**	**0.187**	**0.210**
14 *Arius* spp.	**2.65**	1.000	2.570	1.140	6.100	**0.440**	**0.187**	**0.303**
15 *Pomadasys jubelini*	**2.80**	1.000	0.289	0.731	7.700	**0.760**	**0.095**	**0.160**
16 *Galeoides decadactylus*	**2.99**	1.000	0.869	0.828	9.700	**0.223**	**0.085**	**0.284**
17 *Raja Miraletus*	**3.33**	1.000	1.645	0.560	6.900	**0.008**	**0.081**	**0.146**
18 *Lutjanus* spp.	**3.14**	1.000	2.017	0.770	4.300	**0.010**	**0.179**	**0.102**
19 *Mugil curema*	**2.00**	1.000	1.858	1.367	21.800	**0.350**	**0.063**	—
20 *Caranx* spp.	**2.80**	1.000	0.415	0.655	24.300	**0.083**	**0.027**	**0.160**
21 Shorebirds	**3.00**	1.000	0.021	0.160	65.000	**0.000**	**0.002**	—
22 Insectivorous birds	**3.74**	1.000	0.150	0.100	10.000	**0.000**	**0.010**	**0.167**
23 Birds of prey	**3.03**	1.000	0.022	12.000	60.000	**0.000**	**0.200**	**0.012**
24 Benthos	**2.00**	1.000	12.000	15.000	80.000	**0.571**	**0.188**	—
25 Insects	**2.00**	1.000	20.600	12.000	30.000	**0.054**	**0.400**	—
26 Detritus	**1.00**	1.000	10,000,000	—	—	**0.308**	—	**0.274**

TL: trophic level; **B**: biomass (t/km^2); **P/B**: annual production/biomass ratio; **Q/B**: annual consumption/biomass ratio; **EE**: ecotrophic efficiency; **P/Q** annual production/consumption ratio; **OI**: omnivory index

Table 10. Basic input and model estimated output **(bold)** of the Cameroon mangrove estuary.

Parameter	Value	Unit
Sum of all consumption	6723.632	t/km^2·year
Sum of all exports	3305.708	t/km^2·year
Sum of all respiratory flows	3810.424	t/km^2·year
Sum of all flows to detritus	4775.025	t/km^2·year
Total system throughput	18,615	t/km^2·year
Sum of all production	893	t/km^2·year
Total net primary production	7105.1	t/km^2·year
Total primary production/total respiration	1.865	t/km^2·year
Net system production	3294.4	t/km^2·year
Total primary production/total biomass	38.6	t/km^2·year
Total biomass/throughput	0.01	t/km^2·year
Total biomass (excluding detritus)	184.2	t/km^2·year
Connectance index	0.3	t/km^2·year
System omnivory index	0.143	t/km^2·year
Ascendancy (flow bits)	9929.2	
Relative ascendancy	0.25	
Overhead (flow bits)	19117.1	
Overhead (%)	48	
Capacity (flow bits)	39661.3	
Transfer efficiencies	6.3	
Finn's cycling index (FCI %)	2	
Finn's mean path length	1.717	
Flow to detritus		
Zooplankton	2050.348	t/km^2·year
Phytoplankton	1785.893	t/km^2·year
Mangrove	397.640	t/km^2·year
Insect	357.515	t/km^2·year

Table 11. Summary statistics and basic flows and indices.

[41] who estimated OI of 2 for the Yucantan Peninsula in Mexico. The low OI value may be due to some groups being highly specialised and environmental conditions might alter the availability of prey.

3.8.1. Community energetics

Attributes of ecosystem maturity and stability include connectivity index (CI), total system throughput (T), system total primary production/total respiration ratio (PP/R), primary production/biomass ratio (PP/B), and biomass over throughput (B/T). The connective index (CI) is the number of actual links to the number of possible links for a given food web [38].

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According to Christensen et al. [42], food web structure changes from linear to web like as the system mature. Hence, CI is correlated with maturity [42]. The Cameroon mangrove CI is 0.174 which is close to the value 0.191 reported by Villanueva et al. [43] for Ebere lagoon in Ivory Coast and lower than 0.3 reported by Vega-Cendejas and Arreguín-Sánchez [41] for Yucantan Peninsula in Mexico.

The total system throughput (T) is the size of the entire system in terms of flow [42, 44]. A high T value means the system is capable of growth, suggesting the system is full of energy and resilience. The Cameroon mangrove system T value is 18,615 t/km^2·year, relatively high compared to 3049 reported for Golfo de Nicoya (Costa Rica), 6240 reported for Ebere logoon (Ivory Coast) and 10,558 reported for Craeté mangrove estuary (Brazil) [45, 46].

Total system primary production and total respiration ratio (PP/R) shows the balance between production and consumption. When the PP/R ratio is close to 1, this indicates a mature ecosystem [40, 43]. When the PP/R ratio is greater than 1, production exceeds respiration and indicates the system is in an earlier development stages. When PP/R is less than 1, this indicates the system is accumulating a lot of organic matter. The Cameroon mangrove PP/R value is 1.865, low when compared with other values from tropical ecosystems.

The transfer efficiency for the Cameroon mangrove system is 6.4%, which is low compared to 9.8% reported for Yacatan Peninsula (Mexico) and 14.9% reported for Golfo de Nicoya (Costa Rica) [41, 45], meaning that the system is relative inefficient to recover after disturbance. The model estimate of primary production/biomass of 38.6 compared to 23.9 reported by Walters et al. [45] for Craeté mangrove estuary (Brazil), the system was reported to be relatively mature, hence this indicates that the Cameroon system is mature and may therefore be relatively stable.

Flow indicators related to "overall community homeostasis", which describes the size and the degree of organisation with which the material is being processed within the system, is within the range of most mangrove or estuary ecosystems. These are closely linked to ecosystem efficiency, maturity and development [44]. These indicators include ascendancy (9929.25) and relative ascendancy (0.250).

Energy use and matter recycling in the system are important processes in ecosystem functioning [40] and are measured as Finn's cycling index (FCI) and Finn's mean pathway. The model estimated value for FCI is 2 which are relatively low compared to 5.5 for Golfo de Nicoya (Costa Rica) and Finn's mean pathway of 1.717 estimated by the model is also relatively low compared to 3.4 and 4.4 reported for Craeté mangrove estuary (Brazil) and Yacatan Peninsula (Mexico). This indicates that the Cameroon system is immature.

4. Discussion

Few studies have examined the ecological impacts of small-scale exploitation of mangrove with the aim of assessing ecological and environmental dimensions. Small-scale cutting of mangrove in the Caribbean reduces the abundance of large trees, but greatly increase the density of smaller trees [47]. Cutting of mangroves in the Philippines resulted in stunted and shrubby tree growth [46], but other studies have shown otherwise. For instance, Nurkin [48] suggests that small-scale mangrove exploitation has an insignificant effect on mangrove forest structure. In the present study, the impact of small-scale mangrove wood exploitation created large forest gaps.

Not surprisingly, the canopy gaps created by trees cut were relatively small, the largest gap size measured for this study was 72.2 m^2, but the mean gap size was much smaller at 0.32 m^2, relatively small when compared to findings from other mangrove studies. For example, Ewel et al. [49] recorded a mean gap size of 158 m^2 for mangrove in Kosrae Micronesia, though the author deliberately ignored gap sizes less than 10 m^2. Smith et al. [19] observed gap sizes of mature mangrove forest in Australia of 40–120 m^2, but it is possible that he overlooked gaps of less than 10 m^2. By contrast, Walter [7] found a smaller mean gap size on 2.6 m^2 for Philippines mangroves and studies of other forest types have shown that such small canopy gaps have an important effect on the forest structure [50, 51].

Exploitation of mangrove wood product was not completely species selective in this study, but *Rhizophora* was the preferred species for fuelwood and for poles for construction. There is evidence that wood exploitation might have changed *Rhizophora* stem size distribution.

Mangroves are thought to recover quickly after disturbance [47], but the evidence is mixed. Thus, Ewel et al. [49] found no differences in gap regeneration as a result of selective logging in Kosrae. Clarke and Kerrigan [25] found that canopy gap had a strong influence on the abundance of mangrove seedlings, and the most sensitive species was *Rhizophora*, which shows a significant difference in gap regeneration. Smith [52] observed significant recruitment of *Rhizophora* species in gaps [53]. According to Feller and Mckee [50] gap size does not influence *Rhizophora* regeneration.

According to Smith [52] mangrove seedlings regenerate quickly in large numbers in the canopy opening. In the present study, the relatively low seedling density coupled with the small canopy size might suggest that the Cameroon mangrove canopy is relatively closed. This is supported by large canopy density and may imply that the Cameroon mangrove forest structure is relatively healthy.

This study suggests that mangrove resources play an important role in the economic and social life of most local communities within the mangrove area, resulting to significant level of dependency of the local communities on the mangrove resources. The framework of dependence include: pole for building houses, fuelwood for smoking fish, timber building of band, resting beds, bridges, anchor for canoe, pole for fish trap and fences. Among the fabric of uses, the most significant use was fuelwood for fish smoking. The use of mangrove wood as fuelwood mostly for charcoal and cooking has also been reported in Kenya, Vietnam and Malaysia as well [54]. The peculiarity in this study is that fuelwood is used predominantly used for smoking fish and this process is an important economic activity in the area.

In the present study, local mangrove wood exploitation is an important form of ecological disturbance and a potential threat to forest health. Although forest alteration is not dramatic, impacts on species composition and regeneration are apparent. Whilst dramatic changes in mangrove forest species composition and ecosystem health have been seen in many places, due to anthropogenic influences, hence, small-scale exploitation like that seen here, might contribute significantly to long-term environmental problems if not properly managed.

http://dx.doi.org/10.5772/intechopen.79021

The mangrove forest habitat is unique and rich in crab species. Thirty-nine crab species have been recorded in West and Central Africa mangroves [55]. In this study 13 species were identified belonging to two dominant groups, grapsid and fiddler crabs. All the species in the present study are found in mangroves elsewhere in the Central African region and common genera such as *Uca* and *Sesarma* tend to occur in mangrove habitats worldwide. The distinctness of the Central African mangrove fauna lies in the relative importance of particular families. For example, four to six species of *Uca* are found in all other mangrove regions, but only one species, the widespread *Uca tangeri*, has been reported in Central African mangroves [56].

Environmental factors such as vegetation, substratum, salinity and tidal exposure have been reported to influence the distribution of mangrove crabs [14, 57], with vegetation playing an important role. Environmental conditions were not formally measured in the present study, but the distribution of crab species did differ in the study area. The size frequency distribution of the major species in this study seems bimodal, skewed to the right. Similar distributions have been reported from Mozambique [58] and South American mangrove areas [27]. This distribution suggests that the crab populations recorded here have good recruitment.

According to Mantelatto et al. [59], sexual dimorphism is a result of females being smaller having reduced somatic growth compared to males, because they devote more energy to gonad development. Also larger male crabs are more successful in copulating with females, and win more intra-specific fights [60].

Grapsid and sesarmid crabs are clearly predators of mangrove propagules. *Sesarma* and *Metapograpsus* spp. have been reported predating *Rhizophoraceae* and *Avicennia* propagules [22, 62]. In the present study, 66.7% of the propagules were predated leaving 50% non-viable. This high predation pressure could affect natural restoration of mangrove forest in Cameroon.

Seedling establishment (i.e. type of planting strategy, horizontal or vertical) may also influence predation rate. In the present study, horizontally planted propagules were predated more heavily. This might be because the crabs face difficulties handling vertical propagule due to their size and weight. Although seedling establishment type and tides might influence recruitment, selectivity of crabs might also alter natural restoration of mangrove seedlings in a species-specific way [10]. In the present study, propagule predation did not differ significantly between crab species, but the dominant species foraging on plant material was *Goniopsis pelii*.

In the present study, the average percentage of the leaves consumed was high (71.3%), and similarly high leaf consumption rates have been reported in Australia [23, 61]. The "swept" appearance of the forest floor observed during this study might be as a result of a combination of tidal inundation and high crab activity in the region, and any addition of leaves for crabs (as done here) will be consumed rapidly. Removal of leaves by tide action may be the reason for the large number of leaves dragged into burrows (as well as avoiding predation).

The ecopath model analysis allowed a reasonable model representation of a Cameroon mangrove system. Model viability was determined by using the sensitive analysis function i.e. pedigree index [42]. The sensitivity analysis suggests that parameterisation of groups within the model is most sensitive to decreases in biomass estimates and that the impact of changes in the parameters of one group on another is influenced by the trophic dependency of the impacting group on the impacted group. The impacts of an increase in biomass in one group on other groups within the systems can be shown using a mixed trophic impact plot. This can be used to get an overall indication of the sensitivities and responses to reduced biomass in one group on another and dependent upon them.

The viability value of 0.52 estimated by the model is an indication that the model was tightly fitted, as the simulation values have remarkably little difference from the original input. The balanced model parameter estimates indicate a mixture of a mature and immature system. The mature indices include: total system throughput (T) that is the sum of all flows (consumption, respiration, export and flow into detritus) is 18,615 t/km^2·year, appears to be high when compared to other values from tropical coastal system. The system primary production/respiration (PP/R) ratio estimated by the model is 1.87 indicating that the system is relatively developed [38].The high ascendancy value of 9929.2 and relative ascendancy of 0.250 indicate that the system is mature. However, the relative ascendancy of 0.250 reported by Vega-Cendejas and Arreguín-Sánchez [41] for Yucatan Peninsula (Mexico) was considered high by the author. The total system biomass value is 184.193 t/km^2·year which appears high fits well within the range of other tropical systems [38].

The model results show that more than 98.6% of the flows to detritus is from TL 1 and 2, these levels playing a significant role in supporting the energy utilised by higher TL groups, and indicate a detritus-based food web and bottom-top control system, which is typical of a mature system.

System energy and matter recycling is an important process in ecosystem functioning [40], and the model low estimate of Finn's cycling index (FCI) and Finn's mean pathway of 1.983 and 1.717, respectively, is indicative of an immature system.

5. Conclusion

In the present study, has shown that local mangrove wood exploitation is an important form of ecological disturbance and a potential threat to forest health. Although forest alteration is not dramatic, impacts on species composition and regeneration are apparent. Whilst dramatic changes in mangrove forest species composition and ecosystem health have been seen in many places, due to anthropogenic influences, hence, small-scale exploitation like that seen here, might contribute significantly to long-term environmental problems if not properly managed. Furthermore, it revealed that Cameroon grapsid and sesarmid crabs consumed large amounts of mangrove plant material, both leaves and propagules, and this may have significant ecological consequences for ecosystem structure and function.

The above system parameters provide a mixed picture of the maturity stage of the Cameroon mangrove ecosystem. Some indicate the system is immature and others that it is mature. It could be concluded that the overall health of the system is sustainable.

Nevertheless, to establish a truly holistic, ecosystem-based approach to the management of the Cameroon mangrove forest, social and economic indicators need to be included and local users, the beneficiaries of the services delivered by the forest, need be included at all stages in the management process and this process need more research.

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