Assessment of carbon pools and multiple benefits of mangroves in Central Africa for REDD+

Gordon Ajonina[1], James Kairo[2], Gabriel Grimsditch[3], Thomas Sembres[3], George Chuyong[4], Diyouke Eugene Mibog[1] and Claire FitzGerald[5]

[1]CWCS Coastal Forests and Mangrove Programme, BP 54 Mouanko, Cameroon

[2]Kenya Marine and Fisheries Research Institute, PO Box 81651, Mombasa, Kenya

[3]UNEP, PO Box 30552-00100, Nairobi, Kenya

[4]University of Buea, BP 63 Buea, Cameroon

[5]UNEP World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge, CB3 0DL, UK

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EXECUTIVE SUMMARY

Mangroves of West and Central Africa extend over 20,144 km^2 representing 59% of the African mangroves or 11% of the total mangroves area in the World (UNEP, 2007). These forestsare particularly important for subsistence economies; providing harvestable wood and non-wood products; as well as ecosystem services such as shoreline protection, fish habitat, and climate change mitigation through carbon sequestration. However; over-exploitation, conversion pressure, and pollution effects havedegraded or reduced mangroves in the region by about 20-30% over the last 2 decades. Climate change threatens the remainingmangroves in the region through increased sedimentation. Losses and transformation of mangroves in Central Africa is affecting local livelihood through shortage of firewood and building poles, reduction in fisheries, and increased erosion. To reverse the conditions, Governments of the region have variously supported programmes for improved mangrove management. Nevertheless, these programs have remained small and un-coordinated, and have not reversed current trends of rapid mangrove loss in the region, apart from a few localised exceptions.

REDD+ is an emerging international financial mechanism enabling tropical countries to get rewarded for their efforts in reducing CO_2 emissions from deforestation and forest degradation. Previously, no study existed in the Central Africa region quantifying mangrove carbon stocks, sequestration rates, and possible emissions in response to their degradation. To this end,UNEP provided support to the implementation of a small scale mangroves and REDD+ project in - Cameroon, Gabon, Democratic Republic of Congo (DRC) and Republic of Congo (RoC); collectively occupying 90% of mangroves in Central Africa.

Remote sensed data and GIS was used to analyse mangrove cover change between the periods 2000 and 2010. Volume equation developed for the area, shoot: root ratios, and Biomass Expansion Factors (BEF) were used to estimate stand biomass. Four major carbon pools were considered in this study, including; above ground carbon, below ground root carbon, deadwood, and the soil organic carbon. In mangrove environment, litter is insignificant carbon pool as part of it is eaten or buried underground by crabs hence accounted as sediment carbon. Total ecosystem carbon stock for the region was derived from adding individual country Carbon pools. Other ecosystem services especially fisheries, shoreline protection, mangrove wood products and tourism were assessed through standard contingent valuation techniques.

Mangrove cover change (2000 – 2010)

The overall rate of mangrove loss in Central Africa was estimated at 1.8%, an average of approximately 685 ha of mangroves per year between 2000 and 2010. Republic of Congo experienced 3.5% loss of mangroves between 2000 and 2010. This was followed by Gabon (1.9%), Cameroon (1.8%) and DRC (0.6%). While causes of mangrove degradation may vary from one country to another, the major causes seem to be over-exploitation of mangrove wood and non-wood products, conversion of mangrove areas for urban development and infrastructure, degradation due to pollution from pesticides and fertilizers (eutrophication) and from hydrocarbon and gas exploitation, as well as clearance of mangroves for palm plantations particularly in Cameroon. In addition, climate change related factors such as increased sedimentation have affected the fringing mangroves in Cameroon, Gabon, DRC, and Congo. These factors have collectively led to loss of mangrove cover, shortage of harvestable mangrove products, reduction in fisheries, shoreline change, loss of livelihood, and increase in poverty (UNEP, 2007).

Structure of mangroves in Central Africa

There are8 mangrove species in Central Africa. The dominant species is *Rhizophoraracemosa*which occupies more than 70% of the forest formation. The average stand density ranged from a low of 450 tree/ha in heavily exploited forest of Republic of Congo, to a high of 3255.6 tree/ha in pristine stands of Cameroon. Standing volume ranged from a low of 213.0 m^3/ha in RoC to a high of 427.5 m^3/ha in Cameroon; corresponding to above ground biomass values of 251.3 and 504.5 Mg/ha respectively.

Together with the deadwoods, the total vegetation biomass in the study area ranged from a low of 393.5 Mg/ha in Congo to a high of 825.0 Mg/ha in Cameroon.

Growth and carbon stock of mangroves in Central Africa

Mean diameter increment (MAI) for primary and secondary stems under different management regime was 0.15 cm/yr. This translates to above and below ground annual biomass increment of 12.72 Mg/ha/yr and 3.14 Mg/ha/yr respectively. Our results onbiomass increment are consistent with published productivity data in Thailand (Komiyama*et al.*, 1987), Malaysia (Ong*et al.*, 1993), and Kenya (Kairo*et al.*, 2008). As expected, heavily degraded forests had the lowest biomass increment; whereas the moderately exploited and undisturbed forests had better rates of growth.

Total ecosystem carbon in non-degraded system was estimated at 1520.22 ± 163.93 Mg/ha with 982.49 Mg/ha (or 65%) in below ground component (soils and roots) and 537.73 Mg/ha (35.0%) in the above ground components. Carbon density differed significantly ($p<0.05$) with forest conditions. The least ecosystem carbon of 807.8 ± 235.5 Mg/ha was recorded in moderately degraded forests, translating to CO_2-equivalent of 2961.8 Mg/ha. High carbon densities in highly degraded as well as moderately degraded forests of Congo and DRC were influenced by peri-urban setting that suffers pollution effects.

Carbon sequestration

Pristine mangrove forests sequester annually 16.52 MgC/ha against 6.89MgC/ha for degraded systems but average carbon sequestration per tree in degraded systems (6.44 kg/tee) were higher than the pristine system (5.07kg/tree) probably due to large available growing space.

Valuation of other ecosystem services

Fisheries

Average output of fresh fish from mangrove area is estimated for the four countries at US$ 12,825/ha/yr (or 6.4 million francs CFA). Our estimates were in the lower values reported in literature, possibly due to low data on mangrove fisheries in the region. In Mexico, for instance, Aburto-Oropeza et al (2008) estimated the value of mangrove fisheries from the fringing mangroves of the Gulf of California as USD37, 500/ha/yr.Large volumes of fish caught in mangroves can be justified because mangroves serve as nursery and feeding grounds for many fish species - and therefore many fish caught outside the mangrove areas are dependent on the mangroves for some part of their life cycle.

Shoreline protection

Using replacement method, the protective function of mangroves in Central Africa was estimated at US$0.2million (or 3.6 million FCFA) and US$9.1million (or 76.0 million FCA) respectively for rural and urban areas. The cost may not imply total protection of these infrastructures by mangroves perhaps 25-50% protection margin may be attributed to mangroves making these estimates comparable to values obtained from the cost of constructing a sea wall within the mangrove area that range between 3.6 – 9.0 million FCFA (7, 143 – 18, 000 USD).

Mangrove wood products

Average annual household consumption value for mangrove wood products including fuelwood, and construction poles is estimated at 55.56 m3/yr (49.53 tonnes/yr) for the four countries. The highest being from Cameroon where there is massive mangrove harvesting for fish smoking. These estimate are comparable with values obtained from other mangroves areas in the region (Ajonina and Usongo, 2001; Feka and Ajonina, 2011, Forest Trends – MARES, 2011).

Tourism

Though there was a scarcity of data, available information show that mangroves are also important tourisms sites receiving at least 84 visitors per year, in Congo up to 840 visitors were recorded in the Mazra Club Touristique mangrove site.

Conclusion and recommendations

Conclusion

- Mangrove forests in Central African countries of Cameroon, Gabon, Congo, Equatorial Guinea, Sao Tome and Principe, DRC and Angola are estimated to cover 437 340 ha; 90% of which occurs in Cameroon, Gabon, Congo and DRC.
- Mangrove forests play an important role in the protection of coastal areas (shoreline and seashore protection, stabilization of coastal and shoreline substrate) against natural disasters such as floods. Besides, mangroves serve as habitat for fish and other wildlife, and regulate effects of climate change thus ensuring food and ecological security for more than 30% of the population of countries along coasts;
- Data presented in this report indicate mangrove deforestation and degradation rate to exceed 1.8% annually.
- Major mangrove threats in Central Africa can be ranked as over-exploitation of resources, conversion pressure and pollution effects resulting from industrial, agro-industrial and oil exploration activities.
- Like other productive forests, mangroves in Central Africa are Carbon rich ecosystem with carbon stocks in natural undisturbed mangrove forests estimated to be more than 2-3 times that of adjacent tropical rainforest. More than 80% of carbon stocks in natural undisturbed forests are stored in the soil layers

Recommendations

- Mainstreaming Mangrove related REDD+ and PES initiatives in future management options.
- Continuous monitoring using mangrove permanent plot systems.
- Integrating mangrove protection in coastal and marine protected area network.
- Policy and legal protection of mangrove forests are needed.
- More allometric study of African mangrove forests
- Enhance environmental awareness on mangroves at all levels
- Strengthening of existing networks and partnerships
- Other specific actions that can reduce the overharvesting of mangroves include especially
    - improved mangrove wood energy efficiency for fish smoking and cooking stoves ;
    - Alternative energy use such as carbon briquettes, icing plants, to reduce fuel wood use;
    - Improved enforcement of existing protected areas (currently deforestation rates in protected areas is similar to outside protected areas, showing very little enforcement); and
    - Inclusion of mangroves in national forest definition and REDD+ readiness plans
    - Develop cutting plans for mangroves in areas designated for harvesting

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TABLE OF CONVERSION FACTORS

Centimetre (cm)	=	0.394 inches
Cubic meters (m^3)	=	35.31 cubic feet
Hectare (ha)	=	10,000 m2
Kilometre (km)	=	0.6214 miles, 1000 m
Tonne, ton (t)	=	1,000 kg
1Mega gramme	=	1 Tonne
One Gigatonne	=	1000 Teragrams

ABBREVIATIONS

AGB	Above Ground Biomass
BA:	Basal Area
BEF	Biomass Expansion/conversion Factor
BGB	Below Ground Biomass
CWCS:	Cameroon Wildlife Conservation Society
Dbh:	Diameter at breast height
DRC	Democratic Republic of Congo
FAO	Food and Agriculture Organisation
g:	tree basal area
h:	tree height
ha:	hectare
IUCN	International Union for Conservation of Nature
KMFRI	Kenya Marine and Fisheries Research Institute
NGO:	Non-Governmental Organisation
PI:	Periodic increment
Pom:	Point of measurement
PSP:	Permanent Sample Plot
QMD	Quadratic mean diameter
REDD+	Reducing Emission from Deforestation and Forest Degradation and Enhanced Forest Stocks in Developing Countries
UNEP	United Nations Environment Programme
WRM	World Rainforest Movement
WWF:	World Wide Fund for Nature

GLOSSARY

Carbon credit: a generic term representing the right to emit 1.0 ton of carbon dioxide or the mass of another green house gas

Compliance market: Carbon markets created and regulated by mandatory national, regional or international carbon reduction regimes under Kyoto Protocol.

Crown closure (also crown cover) - Ground area occupied by tree canopy. In the present survey dense forests have more than 40% cover, while open forests have crown cover of less than 40% but more than 10.

Deforestation: The clearing of forests, conversion of forest land to non-forest uses.

Forest degradation: Biotic or abiotic processes that result in the loss of productive potential of natural resources in areas that remain classified as forests. Degraded forest may take a long time to recover thus requiring human intervention.

Propagule: A dispersal unit in mangroves. In some mangrove literature a propagule is also referred to as a seed.

Reforestation: Is the reestablishment of forest cover, either naturally (by natural seeding, coppice, or root suckers) or artificially (by direct seeding or planting)

Sapling: Used here to denote a young mangrove tree, normally less than 2 m height with a stem diameter of less than 10 cm.

Sustainable forest management: Utilization of forest resources without compromising their use by present and future generations.

Tree biomass: The biomass of vegetation classified as trees including foliage, trunk, roots and branches.

Voluntary Carbon Market: Are offset markets that function outside the compliance markets and enable companies and individuals to purchase carbon offsets on a voluntary basis

1. INTRODUCTION

Mangrove forests along the coast ofWest and Central Africa extend over 20,144km^2;representing 59% of the Africanmangroves or 11% of the total mangroves areain the world (UNEP, 2007).According to a UNEP (2007) report, 20-30% of mangroves in West and Central Africa have been degraded or lost over the last 2 decades. Major threats in the region include increasing coastal populations, civil unrest, uncontrolled urbanization, exploitationof mangroves for firewood, housing and fishing, deforestation, pollution from hydrocarbon exploitation and oil and gas exploration.The consequences of current rates of mangrove deforestation and degradation in Central Africa are enormous as these seriously threaten the livelihood security of coastalpeople and reduce the resiliency of mangroves to mitigate climate change effects.

Recent findings indicate that mangroves sequester several times more carbon per unit area than any productive terrestrial forest (Donato*et al.*, 2011). Although mangroves cover only around 0.7% (around 140,000 km^2) of global tropical forests (Giri*et al.*, 2011), degradation of mangrove ecosystems potentially contributes 0.02 – 0.12 Pg carbon emissions per year, equivalent to 10% of total emissions from deforestation globally (Donato*et al.*, 2011).However, loss and transformation of mangrove areas in the tropics is affecting local livelihood through shortage of firewood and building poles, reduction in fisheries, and increased erosion. In addition, mangroves provide a range of other socio-economic benefits including regulating services (protection of coastlines from storm surges, erosion and floods; land stabilization by trapping sediments; and water quality maintenance), provisioning services (subsistence and commercial fisheries; honey; fuelwood; building materials; and traditional medicines), cultural services (tourism, recreation and spiritual appreciation) and supporting services (cycling of nutrients and habitats for species). For many communities living in their vicinity, mangroves provide a vital source of income and resources from natural products and as fishing grounds. It is no wonder that the Total Economic Value of mangroves has been estimated at US$9,900 ha^{-1} per year by Constanza*et al.*,(1997) or US$ 27,264–35,921ha^{-1} per year bySathirathai and Barbier(2001).

Maintaining a balance between the needs of the coastal communities and the ecological securityof the remaining mangrove ecosystems has been causing renewed national and international interests for Central Africa mangrove swamps. Governments of the region have variously supported programmes on the rehabilitation, conservation, and sustainable utilization of mangrove resources. Nevertheless, these programs have remained small and un-coordinated, and have not reversed current trends of mangrove loss in the region, apart from a few localised exceptions. Further, mangroves in protected areas in Central Africa are generally not less affected by deforestation and degradation than those outside protected areas. More comprehensive responses addressing the root causes of the problems at national and local levels are required. To date, most discussions and preparations for national strategies to reduce deforestation and forest degradation in Central Africa have focused on terrestrial forests, in particular in the context of REDD+ ("Reducing Emissions from Deforestation and forest Degradation, conservation of forest carbon stocks, the sustainable management of forests and the enhancement of forest carbon stocks"). REDD+ is an emerging international financial mechanism enabling tropical countries to get rewarded for their efforts in reducing CO_2 emissions from deforestation and forest degradation, and a number of Central African countries have embarked into ambitious national reforms and investments to improve forest landscapes management in order to benefit from REDD+.

The potential inclusion of mangrove forests in the national REDD+ processes in Central Africa is a key focus of this report. Although mangrove forests constitute only a small fraction of total forest cover in Central Africa, reported carbon stocks, sequestration capacities and potential emissions from conversion of regional mangrove ecosystems are on average much higher per unit area than those of terrestrial forests. In addition, these mangroves are declining at a fast rate, which implies that successful initiatives for mangrove conservation and restoration could achieve significant mitigation benefits. The causes of deforestation and degradation of mangroves are also similar to these affecting terrestrial forests. In fact, the types of cross-sectoral political reforms, investments and monitoring systems being developed for terrestrial forests through REDD+ would be relevant in many ways to mangrove forests which face similar pressures and can provide similar benefits in terms of climate change mitigation& adaptation, and other ecosystem services.

Countries engaged in REDD+ are aiming to harness multiple benefits from sound forest management. Carbon payments alone are unlikely to be sufficient to make forest protection an attractive solution in the long term. Effective REDD+ mechanisms should yield returns beyond carbon payments and climate change mitigation, for instance, by improving water and soil quality, which often underpins future economic growth in the energy and agriculture sectors. As we have seen earlier in this introduction, the multiple benefits that mangrove ecosystems provide are remarkable for livelihoods, food security and climate change adaptation.

A key challenge for successfully implementing any REDD+ Project is the reliable estimation of biomass carbon stocks in forests. A reliable estimation of forest biomass has to take account of spatial variability, forest allometry, wood density, and management regime. Many studies have been published on above ground carbon stocks in tropical forests around the world, but limited studies exist on below-ground root biomass and soil carbon. The level of knowledge is evenlower for mangroves, where localised allometric equations for different mangrove species are limited. In the present study we used volume equations, shoot: root ratios, and Biomass Conversion/Expansion Factors (BCEF) to estimate stand biomass from inventory data. The value of vegetation carbon stocks was then combined with the soil, and litter carbon in order to estimate the total carbon pool of the Central Africa mangroves.

Because of these challenges, the connection between REDD+ and mangroves in Central Africa has not been considered seriously to date. Knowledge gaps and carbon accounting methodological issues resulting from the complexity of mangrove ecosystems impede effective inclusion into REDD+ strategies. No studies until now exist in the Central Africa region quantifying mangrove carbon stocks, sequestration rates, and possible emissions in response to their degradation. In order to further improve our global understanding of the climate change mitigation potential of mangroves, UNEP provided support to a small scale project entitled ‘Mangroves and REDD+ in Central Africa’ - Cameroon, Gabon, Democratic Republic of Congo (DRC) and Republic of Congo (RoC).Thespecific activities of the project were as follows:

a) Assess mangrove forest cover and change over the recent period (2000-2010), through validation of satellite data of mangrove cover and deforestation rates, with an identification of deforestation hot spots;
b) Analyze the recent causes and future threats related to deforestation and degradation of mangroves for each country;
c) Measure carbon stocks in mangrove biomass and soils, and estimate carbon sequestration rates;
d) Value the range of multiple benefits provided by mangroves beyond carbon.

This report presents the results of the field assessment in the four selected countries in Central Africa, including: Cameroon, Gabon, Congo and DRC;accounting for90% of mangroves in Central Africa. The report also benefitted from the summary ideas and results contained in the assessment of Mangroves of Western and Central Africa (UNEP, 2007), as well as data and long-term experiences of the establishment and monitoring of mangrove Permanent Sample Plots (PSPs) in Cameroon.Current estimates of regional mangrove cover, above and below-ground carbon stocks, carbon sequestration rates, and values of multiple benefits, are provided. This information can serve as a basis to establish initial baselines in future mangrove projects and REDD+ programmes in the region.

Box 1: The decline of mangroves: a global problem

Recent global estimates indicate that there are about 137,760 km^2 of mangrove in the world; distributed in 118tropical and sub-tropical countries (Giri*et al*., 2010). The decline of these spatially limited ecosystems due to both human and natural pressuresis increasing (Aksornkoae*et al*., 1993; MacKinnon 1997, Valiela*et al*., 2001; FAO 2007, Gilman *et al*. 2008), thus rapidly altering the composition, structure and function of these ecosystems and their capacity to provide ecosystem services essential for the livelihoods of people in most tropical countries (Kairo*et al*.,2002, Bosire*et al*., 2008, Mumby*et al*., 2004, Dahdouh-Guebas*et al*., 2005, Duke *et al*. 2007). Deforestation rates of between 1-2% per year have been reported thus precipitating a global loss of 30-50% of mangrove cover over the last half century majorly due to overharvesting and land conversion (Alongi 2002, Duke *et al*., 2007, Giri*et al*., 2010, Polidoro*et al*., 2010).

2. STUDY APPROACH AND METHODOLOGY

2.1. The Project Area

Biophysical characteristics

Mangrove forests in Central Africa stretch continuously along the Central African coast from Cameroon contiguous to larger expanse of the mangrove of Niger Delta in Nigeria through Gabon, Congo, DRC to Angola covering over 4,512 km^2, representing 14.7% of African coverage (UNEP, 2007). A variety of habitat types (coastal lagoons, rocky shores, sandy beaches, mudflats etc.) characterize the Central African coastline with a vast array of rivers flowing from the hinterlands into the Atlantic Ocean. The confluences of these rivers with marine waters form suitable conditions for the development of outstanding giant mangrove vegetation in the region that also harbors the world's second largest tropical rainforest. The climate in Central Africa is mainly equatorial characterized by abundant rains (3000 – 4000 mm in Cameroon, 2500-3000 mm in Gabon and Congo and 772mm in DRC)and generally high temperatures with monthly average of 24-29 ^{o}C, with a dry season spanning November to March in Cameroon and June to October in DRC. A typical climate diagram in Central Africa (Cameroon) is given in Figure 1. September is normally the month with the highest rainfall, while December has the least.

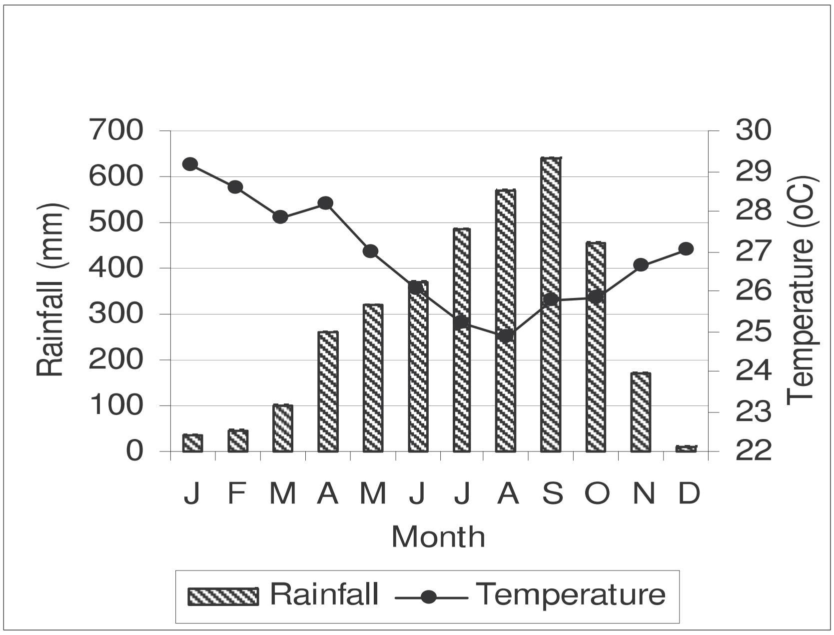

Figure 1: Typical climate diagram in Central Africa. This particular diagram is for Doula-Edea Reserve, Cameroon.

Composition and distribution of mangroves in Central Africa

Mangrove formation in Western and Central Africa is characterized by low species composition common with new world mangroves (Tomlinson, 1986). In Central Africa, there are 8 mangrove species of economic importance (UNEP, 2007). Largest blocks of mangroves in the region are found in deltas and large rivers estuaries in Cameroon and Gabon (UNEP, 2007). The dominant species is *Rhizophoraracemosa*(Rhizophoraceae)whichaccounts for more than 90% of the forest formation. The species fringes most shorelines and river banks; attaining up to 50m in height with tree diameter of over 100cm around the Sanaga and Wouri estuaries marking one of the tallest mangroves in the world (Blasco*et al*, 1996 p.168).Other important mangrove species in the region are *R. mangle*, *R. harissonii*, *Avicenniagerminans* (Avicenniaceae), *Lagunculariaracemosa* and *Conocarpus erectus*(both Combretaceae) (Table 1). Undergrowth in upper zones can include the pantropical*Acrostichumaureum* (Pteridaceae) where the canopy is disturbed. *Nypafruticans*(Arecaceae)is an exotic species introduced in Nigeria from Asia in 1910 and has spread to Cameroon.

Table 1: Distribution of mangrove species throughout Central Africa

Species	Country					
	Cameroon	Equatorial Guinea	Gabon	Congo (RoC)	Congo (DRC)	Angola
Acrostichumaureum	x		X	X	x	
Avicenniagerminans	x	x	X	X	x	x
Conorcarpus erectus	x		X	X	x	
Lagunculariaracemosa	x		X	X	x	
Nypafruticans	x					
Rhizophoraharrisonii	x		X	X		
Rhizophora mangle	x		X		x	x
Rhizophoraracemosa	x	x	X	X	x	x
Total	8	2	7	6	6	3

Common mangrove associates in Central Africa include(Annonaceae), *Cocosnucufera* (Areaceae), *Guiborutidemensei* (Caesalpiniaceae), *Achorneacordifolia* (Euphorbiaceous), *Dalbergiaecastaphylum* and *Drepenocarpuslunatus* (both Fabaceae), *Pandanus candelabrum* (Pandanaceae), *Hibiscus tilaeceus* (Malvaceae), *Bambusavulgaus* (Poaceae) and*Paspalumvaginatum*, among others (Poaceae) (Ajonina, 2008).

Socioeconomic characteristics

Fishing is a major economic activity along the West-Central African coastline (Department forInternational Development of the United Kingdom and FAO, 2005) especially in Central Africa with a mangrove population of about 4 million (Table 2). About 60% of fish harvested in these rural areas is of artisanal origin. Open drying, salting, icing, refrigerating, and smoking are the common methods used to preserve fish in the region (Feka and Ajonina, 2011 citing others). Scarcity of electricity in the rural areas, together with easily available fuel-wood has made fish smoking the most preferred method in the region (Satia and Hansen, 1984; FAO, 1994; Lenselink and Cacaud, 2005). Mangrove wood is widely preferred for fish smoking within coastal areas of this region because of its availability, high calorific value, ability to burn under wet conditions, and the quality it imparts to the smoked fish (Oladosu*et al*., 1996). Fish smoking and fish processing activities are largely responsible for more than 40% degradation and loss of mangroves in the region (UNEP, 2007). The mangrove wood, *Rhizophorasp*., is preferred from other species for its high calorific value, good burning characteristics under wet conditions, which reduce unnecessary wood processing cost and time (especially drying) before use.Traditional low energy serving open-type smoking rafts implanted in kitchens are used across the region. Mangrove wood harvesting intensities vary across countries and intensityis determined by season and gender. Harvesting patterns are further determined by the level of policy implementations and the local stewardship.

Table 2. Population within mangrove areas in Central Africa

Country	Population (thousands)[a]	Population within mangrove areas (thousands)	As % of total
Cameroon	16 322	3 000	18.4
Gabon	1 384	300	21.7
Congo	3 999	500	12.5
DRC	57 549	112	0.2
Total	79 254	3 912	4.9

[a]Data from UNEP 2007

2.2. Scope of the methodology and site selection

The project was set to validate satellite data of mangrove cover and deforestation rates and to quantify mangrove goods and services in Central Africa. Four pilot areas in Central Africa were selected for the study, including:-Cameroon, Gabon, DRC and RoC (Figure 2, Table 3,). Two of the pilot countries i.e. DRC and the Republic of Congo are part of the UN-REDD programme, whereas Cameroon and Gabon have the highest mangrove cover in Central Africa. The following general criteria were used in selecting study sites:

- the forest structure and composition appear to be typical of other sites in the region
- water ways and canals are reasonably navigable even during low tides to allow for access and transportation of equipment and materials
- differentforest conditions are represented,
- The area is not so readily accessible that sample plots may be illegally felled

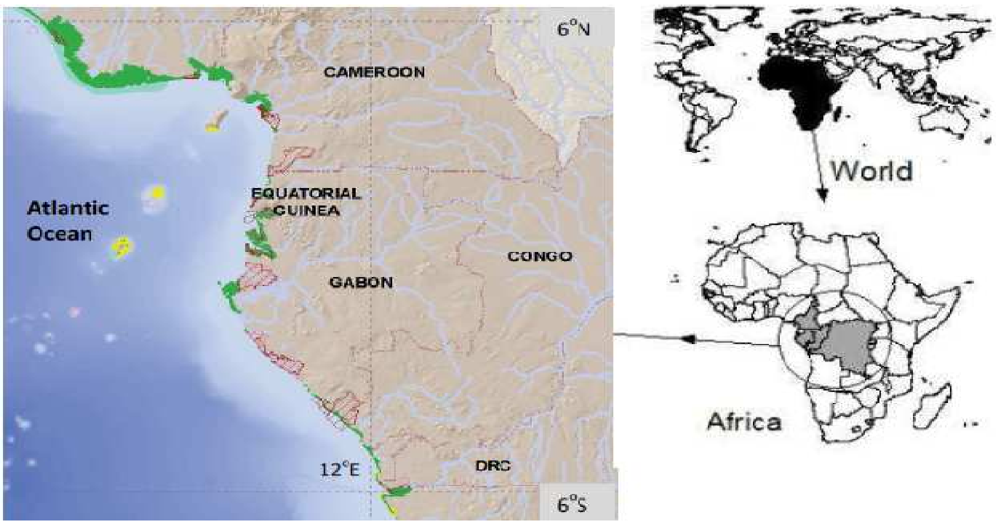

Figure 2: Map showing the location of selected mangrove countries

Table 3: Selected sites within the central African mangroves for ecosystem services assessment

Country	Number of mangrove sites	Study site	Site description	Forest condition
Cameroon	5	South West Region, Bamasso mangroves	Sites contiguous to the mangroves of Delta region in Nigeria have relative undisturbed mangroves	Undisturbed mangroves
		Littoral region, Moukouke	Sites within the mangroves of Cameroon estuary having relatively undisturbed mangroves	Undisturbed mangroves
		Littoral Region, Yoyo mangroves	Sites within the mangroves of Cameroon estuary with heavy exploitation of mangroves	Heavy exploitation of mangroves
		Littoral Region, Youme mangroves	Sites within the mangroves of Cameroon estuary with moderate exploitation of mangroves	Moderate exploitation of mangroves
		South region, Campo mangroves	Transboundarymangroves at the Ntem estuary	Undisturbed mangroves
Gabon	4	Province de l'Estuaire, Commune de Libreville	mangroves near Akanda National Park having relatively undisturbed mangroves	Undisturbed mangroves
		Province de l'Estuaire, Commune de Libreville	Peri-urban mangroves,	Heavy exploitation of mangroves
		Province de l'Estuaire, Commune de Coco-Beach	Transboundary mangrove near Equatorial Guinea,	Moderate exploitation of mangroves
		Province de l'Estuaire, Commune de Coco-Beach	Emone-Mekak mainly undisturbed estuarine mangrove	Undisturbed mangroves
Congo	3	Département de Pointe Noire	Peri-urban mangroves of Louaya	Heavy exploitation of mangroves
		Département de Pointe Noire	Moderately disturbed mangroves located within the touristic centre of Songolo town	Moderate exploitation of mangroves
		Département du Kouilou	Transboundary mangroves in Gabon-Angola border	Undisturbed mangrove
DRC	3	Province du Bas-Congo, district de Boma the only mangrove zone in DRC entirely in Muanda Mangrove Park and transborder with mangroves of Soyo in Angola	Marana Line with heavily disturbed mangroves	Heavy exploitation of mangroves
			Km 5 with moderately exploited mangroves	Moderate exploitation of mangroves
			Île Rosa Tompo with relatively undisturbed mangrove	Undisturbed mangrove

2.3. Remote sensing methodology

30m resolution Landsat satellite imagery for the base years 2000 and 2010 were classified using iterations of unsupervised and supervised image classification procedures. Initial satellite data acquisition and processing was facilitated by and conducted at the North American node of UNEP's Global Resource Information Database (GRID), designated as GRID-SiouxFalls, located at the EROS Data Centre of the United States Geological Survey in Sioux Falls, South Dakota, USA. Further data processing and spatial analyses were undertaken at UNEP-WCMC, Cambridge, UK.

For the mangrove classification, the Landsat archive was searched and cloud free imagery for the area of interest (where available) downloaded. In this region it is extremely difficult to source 100% cloud free images, therefore, scenes were chosen from the same season for the years either side of 2000 and 2010 – this allows for gap filling of areas with cloud presence from images where the spectral signature of the land cover, i.e. mangroves, are the same/very similar. 30m resolution cloud free composite images were then prepared for mangrove classification.

Using the global UNEP/USGS mangrove data (Giri*et al.*, 2000) and the World Atlas of Mangroves 2010 (Spalding *et al.*, 2010) as mangrove presence indicators, the composite images were subset to an extent of known mangrove occurrence. A hybrid unsupervised and supervised classification procedure was then undertaken, classifying the region into 4 classes: Probable Mangrove, Possible Mangrove, Other Land, and Water. The data then underwent validation by an expert from Cameroon, using both visual inspection and local knowledge of mangrove distribution in the region, to discern between the classes, validating was correct and editing was incorrect.

2.4. Quantification of carbon pools

Carbon density was estimated with data from existing and newly established rectangular 0.1 ha (100m x 10m) Permanent Sample Plots (PSP). ExistingPSPs in Cameroon provided an excellent opportunity to model stand dynamics and carbon sequestration potential of the mangroves in the region.Based on mangrove area coverage in each country 5 PSPs in Cameroon, 4 in Gabon, 3 in Congo and 3 in DRCwere selected for the study (Table 1).Measurement protocol consisted of species identification, mapping, tagging, and measurements of all trees inside the plot using modified forestry techniques for mangroves (Pool *et al.,* 1977; Cintron and Novelli, 1984; Kauffman and Donato, 2012).Transect and plots boundaries were carefully marked and GPS points taken. Detailed procedures for establishment of PSP are given in Ajonina (2008). The following carbon pools were considered in the present study:

1. vegetation carbon pools (both above and below ground)
2. litter,
3. coarse deadwood
4. soil

Measurement of vegetation carbon

An important carbon stock in mangroves is the aboveground component.Trees dominate the aboveground carbon pools and serves as indicator of ecological conditions of the forest.In each PSP, three plots of 20m x 10m were established along transect at 10 m intervals (Figure 3a).Inside the plots, all trees with diameter of the stem at breast height (dbh_{130}) ≥ 1.0 cm were identified and marked. Data on species, dbh, live/dead and height were recorded for all individuals. In*Rhizophora*,dbh was taken 30cm above highest stilt root.

Above ground roots and saplings (dbh ≤ 1cm)were sampled inside five 1m^2 plots placed systematically at 1m intervals along the 10m x 10m plot (Figure 3b).Middle diameter and height of the roots, seedlings and saplings were also measured.Newly recruited saplings were enumerated; while missing tags were replaced by reference to initial plot maps.

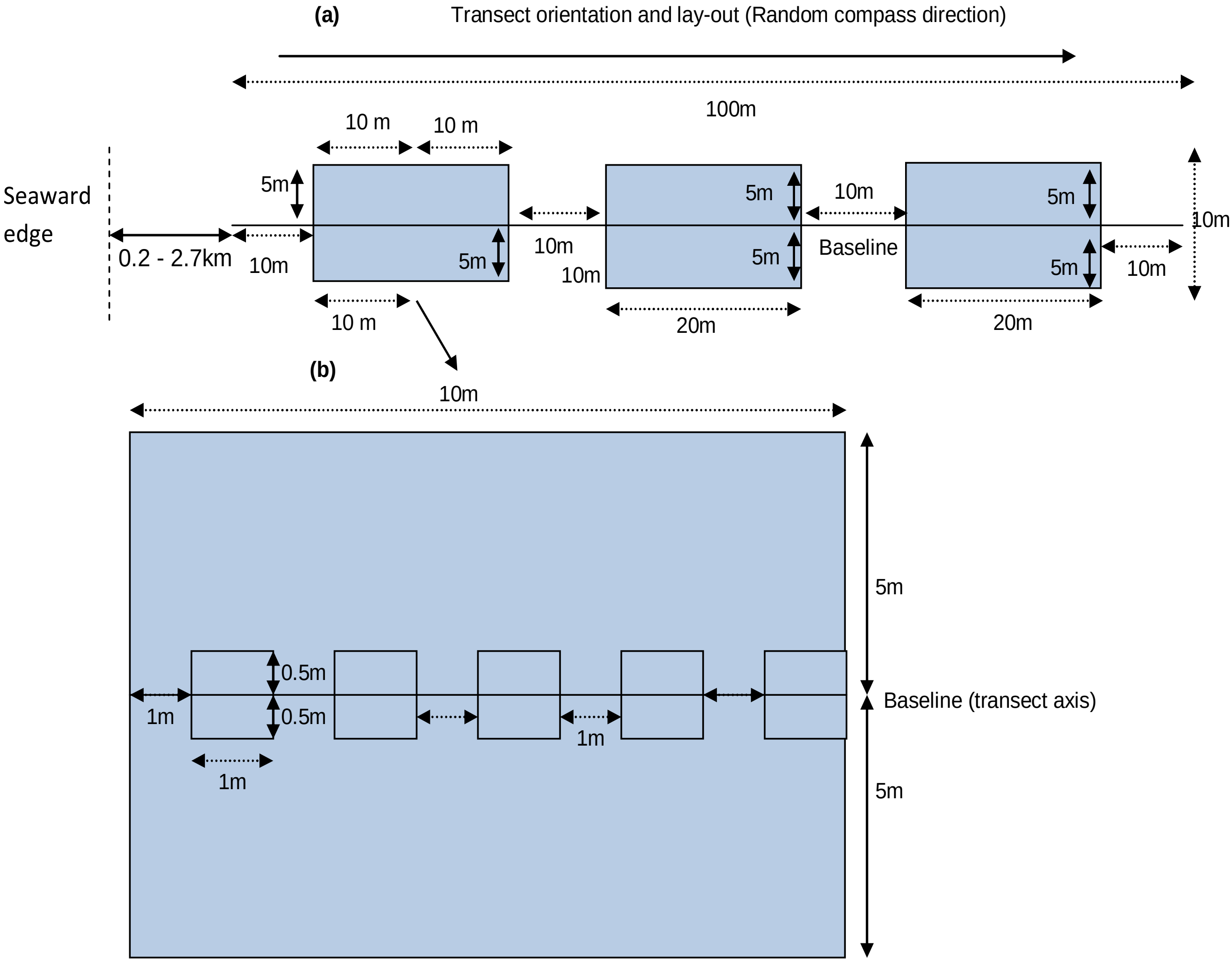

Figure 3: (a) Schematic lay-outs of mangrove forest stands permanent sample plots (b) roots and sapling inventories (After Ajonina, 2008)

Plate 1: Measured, marked and tagged trees in Gabon

Dead and downed wood

Dead wood was estimated using the transect method whose application is given in Kauffman and Donato(2012). The line intersect technique involves counting intersections of woody pieces along a vertical sampling transect. The diameter of dead-wood (usually more than 0.5cm in diameter) lying within 2 m of the ground surface were measured at their points of intersection with the main transect axis. Each deadwood measured was given a decomposition ranking: rotten, intermediate, or sound.

Soil samples

Mangrove soils have been found to be a major reservoir of organic carbon (Donato*et al.*, 2011). Soil carbon is mostly concentrated in the upper 1.0m of the soil profile. This layer is also the most vulnerable to land-use change, thus contributing most to emissions when mangroves are degraded. Soil cores were extracted from each of the 20m x 10 m plots (above) using a corer of 5.0 cm diameter and systematically divided into different depth intervals (0–15 cm, 15–30 cm, 30–50 cm, and 50–100 cm); following the protocol by Kauffman and Donato, (2011). A sample of 5cm length was extracted from the central portion of each depth interval to obtain a standard volume for all sub–samples.A total of 180 soil samples were collected and placed in pre-labelled plastic bags - Cameroon (60 soil samples), Gabon (48), Congo (36), and Democratic Republic of Congo (36). In the laboratory, samples were weighed and oven-dried to constant mass at 70^{o}C for 48 hours to obtained wet:dry ratio (Kauffman and Donato 2012). Bulk density was calculated as follows:

$$\text{Soil bulk density } (\text{gm}^{-3}) = \frac{\text{Oven−dry sample mass (g)}}{\text{Sample volume } (\text{m}^3)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where, Volume = cross-sectional area of the corer x the height of the sample sub-section

Of the dried soil samples, 5-10g subsamples were weighed out into crucibles and set in a muffle furnace for combustion at 550^{o}C for 8 hours through the process of Loss- On-Ignition (LOI), and cooled in desiccators before reweighing. The weight of each ashed sample was recorded and used to calculate Organic Concentration (OC). Total soil carbon was calculated as:

$$\textit{Soil C } (Mg/ha^{1}) = \textit{bulk density } (g/cm^{3}) * \textit{soil depth interval (cm)} * \%\ C \ldots\ldots\ldots\ldots 2$$

The total soil carbon pool was then determined by summing the carbon mass of each of the sampled soil depth.

It must be recognized that although loss-on-ignition can generally be regarded as an accurate measure of the organic matter content of sediment, the amount of fine fraction in the sediments is a limiting factor for an absolute organic determination and directly influences the correction factor. In order to provide accurate organic carbon content determinations for sediment, loss-on-ignition data must be corroborated by standard total carbon analysis (Veres, 2002).

Plate2: Collecting soil samples from permanent sample plots with soil auger

2.5. Valuation of other ecosystem services

As discussed in Chapter 1 of this document, mangroves provide many goods and services beside Carbon sequestration. Other ecosystem services valued as part of the project were: Fisheries, Shoreline protection, Mangrove wood products and Tourism.

2.5.1. Fisheries

Fisheries data was missing in most of the pilot areas; so a contingent method was used in the form of questionnaires with localfishing communities regarding catch landings, composition and weight within a given area of the mangrove site. Local guides and interpreters were largely employed for this exercise.

Plate 3: Fish landing spot in Leme mangrove site Gabon

2.5.2. Shoreline protection

Data was non-existent in the sites on records of incidence and expenditure on disasters. Consequently, a damagecost avoided method was used to calculate the costs of all infrastructure and amenities including houses, roads, buildings, telecommunications, water and electricity within 500m band in the mangrove sites as areas likely to be affected by any impact due to mangrove destruction. Infrastructure was classified into permanent and semi-permanent housing, roads, institutional (all equipment, assets materials belonging to a given institution), electricity (transmission poles, equipment, etc.), water (portable), tele-communication (transmission poles, station and equipment). A replacement method was also employed to calculate the cost per unit area of replacing mangroves with seawalls.

2.5.3. Mangrove wood products (e.g. firewood and building)

A contingent method, combined with structuredquestionnaire and observation techniques was used to value mangrove wood products. The amount of wood used by a household[1] in the area wasestimated as well as estimates of turnover rates by members of the household for cooking and fish smoking activities. The data was then used to estimate annual mangrove wood requirements per household.

[1]A household was defined in this case as people irrespective of families, sleeping under one roof or living in same house.

Plate 4: Fish smoking in Cameroon

2.5.4. Tourism

The touristic value of mangrove sites was evaluated wherever visitor data were available from local governments and businesses.

2.6. Data analysis and allometric computations

Allometric computations

General field data was organized into various filing systems for ease ofanalysis and presentation. Both structural and bio-physicaldata were entered into prepared data sheets. Later the data was transferredinto separate Excel Work Sheets containing name of the country, zone and other details of the site. Sample data sheets for different data types are given in the Annex 1.Standing volume was determined using locally derived allometric relations from sample data with dbh as the independent variable:

$v = 0.0000733*D^{2.7921}(R^2 = 0.986, n = 677)$ ....(3)

where:

v = volume

D = diameter of the stem for the range: 1cm $\leq$ D $\geq$ 102.8cm)

Biomass conversion/expansion factor (BC/EF), which is the ratio of total above-ground biomass to stand volume, and shoot/root ratio (SRR) developed by Ajonina (2008), Ajonina *et al.*, (2012a, b) were used for the estimation of total tree biomass and carbon densities. The BC/EF used in the study was1.18 (Ajonina, 2008) which is comparable to that reported for humid tropical forests by Brown (2002).

Tree, stand dynamics, and carbon sequestration estimations

For tracking changes in carbon stocks of forests, experience has shown that tagging trees with a unique number is the preferred approach—this way the fate of all trees can be tracked as they accumulate carbon, new ones enter the minimum diameter size (ingrowth) or trees die (Clark *et al.*, 2001).Using

Permanent Sample Plots (PSP) in Cameroon, we estimated periodic annual increment (PAI) of the forest as a function of mortality and recruitment of seedlings at the beginning and end of each growing period. Development of detailed carbon sequestration estimates will, however, require long term studies on regeneration, stand dynamics and also the distribution pattern of the seedlings under mother trees.

Deadwood

Deadwood volume was estimated using the protocol by Kauffman and Donato(2012):

$$\text{Volume } (m^3/ha) = \Pi^2 * \frac{\sum_{i=1}^{n} d_i^2}{8L} \qquad (4)$$

Where $d_i = d_1, d_2 \ldots d_n$ are diameters of intersecting pieces of deadwood (cm) L = the length of the intersecting line (transect axis of the plot) generally L = 20m being the length of each plot or 100m being the length of thetransects.Deadwood volumes were converted to carbon density estimates by using the different size specific gravities provided by Kauffman and Donato(2012).

Carbon dioxide (greenhouse gas) emission potential

Ecosystem carbon pools in mangroves are reviewed in the introductory section of this document. As noted, a large proportion of mangrove carbon is in the above ground biomass and soil-C (Donato*et al*., 2011). The most vulnerable carbon pools following mangrove deforestation and degradation are the above ground carbon as well as soil-C from the top 30cm. Estimating emissions from land-use change was conducted using uncertainty-propagation approach detailed in Donato *et al.*, (2011). For the mangrove of Central Africa, a conservative low-end estimate of conversion impact, with 50% above ground biomass loss, 25% loss of soil C from the top 30 cm, and no loss from deeper layers. Use of low-end conversion impact in the current study is justified by low-level reclamation of mangroves for aquaculture and agriculture in Central Africa. In Belize Lovelock *et al.*,(2011) reported large short-term CO_2 efflux from the sediment surface of cleared mangroves ofapproximately 29 tC/ha. In Honduras, a mangrove forest impacted by Hurricane was estimated to release 15tC/ha (Cahoon*et al.*, 2003).

Data from other ecosystem services

Fisheries, shoreline protection and wood productions from mangrove sites were expressed on per ha basis of mangrove sites used in the collection of such data. For example, the cost of infrastructure within the 500m band of mangroves was expressed on hectare basis of total costs divided by the area of band covering the infrastructure.

3. RESULTS AND DISCUSSION

The results presented below summarize the findings from the surveys conducted in the four target countries: Cameroon, Gabon, Republic of Congo, and DRC. Here wepresent information relevant to setting critical baselines for REDD+ projects by determining historical deforestation rates, providing a threat analysis for mangrove ecosystems, calculating values of ecosystem services and presenting carbon stocks, sequestration as well aspotential emissions. Having accurate estimates of these metrics can help governments and project developers in making the case for the inclusion of mangroves in national REDD+ plans and can allow for improved monitoring, reporting and verifications necessary to prove the additionality values of REDD+ activities in the region.

3.1. Mangrove area change (2000 – 2010) and threat analysis

Mangrove area change (2000 – 2010)

The following data are presented with some important caveats that must be taken into account when interpreting the results (Table 4-6, Figure 4). Firstly, the relatively low 30m spatial resolution Landsat imagery from which the mangrove classifications were derived does not allow for identification of very localized small-scale (<30m) patch deforestation important in many mangrove areas. This relatively low 30m spatial resolution also does not allow us to qualify the quality of the ecosystem in terms of density and height of trees. A forest may have been degraded to a degree but not deforested and this may not be evident from the satellite images analysed here. Furthermore, the Congo River Basin has extremely high levels of cloud cover, thus making access of cloud-free images for the region difficult. To generate cloud free coverage's for the area of interest images from years preceding and following the study years were acquired, usually 3 in total, and merged together in a process which selected the best quality pixels from all 3 images, again decreasing the accuracy of analysis. Finally, although the satellite images and derived mangrove classifications were validated by an expert in the field, a far greater amount of validation is recommended to increase confidence in the results and improve the accuracy of our analysis.Validation by experts in each country rather than one for the whole region would be highly beneficial.

However, even given these caveats, some interesting trends do emerge from the analysis. Deforestation rates are high, with 1.8% loss per year in Cameroon, 3.5% loss per year in the Republic of Congo, 0.6% loss per year in the Democratic Republic of Congo and 1.9% loss per year in Gabon. The overall rate of loss per year for the region is 1.8%. However, along with these fast rates of loss the analysis also found areas of regrowth and resilience, meaning that the overall net loss was relatively insignificant. Cameroon exhibited 0.05% net loss per year, Republic of Congo 0.25%, DRC 0.16%, Gabon 0.27% and the overall region 0.16%. However, as stated above this net loss does not take into account degradation and thinning of systems (rather than complete deforestation), and it does not take into account small-scale patch deforestation of less than $30m^2$, typical of a lot of artisanal use of mangroves. Therefore we can see that even at a relatively course resolution there is important deforestation occurring, and furthermore hotspots of extreme deforestation can be defined.

Table 4: Changes in Mangrove cover for Central Africa countries - Cameroon, Republic of Congo, DRC and Gabon

Country	Area 2000 (km^2)	Area 2010 (km^2)	Loss (km^2)	% loss	Gain (km^2)	Net change 2000-2010 (%)
Cameroon	2060.35	2050.75	375.67	18.23	366.07	-0.47
Gabon	2030.44	1975.66	378.58	18.65	323.80	-2.70
Congo	5.79	5.65	2.05	35.41	1.90	-2.50
DRC	242.38	238.44	14.77	6.09	10.83	-1.60
Total	4338.96	4270.50	771.07	17.77	702.60	-1.58

Table 5 – Rates of loss in protected areas

Country	Mangrove area under protection in 2000	Loss (km^2)	Gain (km^2)	% loss	Net change 2000-2010 (%)
Cameroon	168.61	37.82	34.92	22.4	-1.72
Gabon	779.25	91.11	79.85	11.7	-1.44
Congo	4.59	1.59	1.39	34.6	-0.04
DRC	151.36	3.73	3.77	2.5	+0.03
Total	1103.81	134.25	119.93	12.2	-1.30

The hotspots of deforestation identified from the classified satellite imagery are interesting for this study, as they present the most pressing opportunities for ecological restoration. As we can observe from Table 4, all countries exhibited high rate of loss of mangroves both inside and outside protected areas except for DRC whichexhibiteda net gain in protected area mangroves. In Cameroon, high areas of deforestation were recorded in the peri-urban areas around Douala and Bonaberi, with almost complete loss of mangrove stands in many areas and deforestation rates above 90%. Mangroves in protected areas showed similar patterns of losses and gains to those in non-protected areas.Establishment of protected areas do not seem to reduce the rate of deforestation in the region. In DRC, hotspots of deforestation are found at the edge of mangrove forests. A similar picture is shown in the Republic of Congo with hotspots of deforestation at the edge of mangrove forests and also in some areas of the national park Conkouati-Douli,whichcontains 78% of the country's mangroves but offers them little protection and exhibits40-50% deforestation in some areas. In Gabon, deforestation hotspots are found inthe peri-urban areas around Libreville, Port Gentil and SetteCama, with over 90% deforestation in some places. 36% of Gabonese mangroves fall within 12 protected areas, but high deforestation rates are also apparent here in some areas. High regrowth is also evident in all countries, but the data does not show us the quality and density of the forest and whether the condition of existing patches continues to degrade and become less dense.

Overall, the low net loss rates mask the fact that there are areas of very high deforestation, especially around peri-urban areas, and also that protected areas do not seem to be effective in preventing deforestation as they exhibit similar patterns to the rest of the country. They also mask localized deforestation and forest degradation, and thus are most useful for identifying the particularly alarming areas of deforestation for urgent intervention and management.

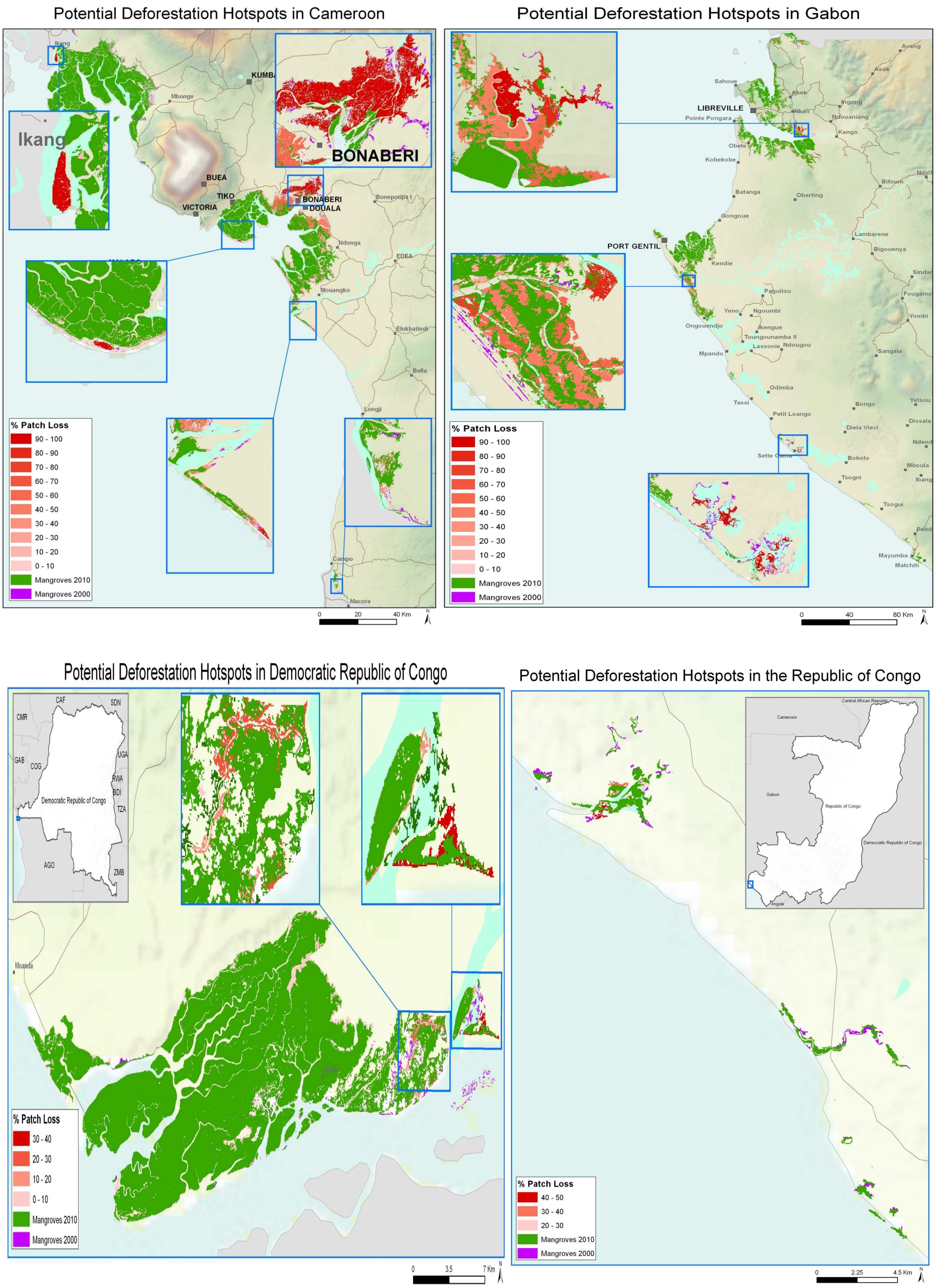

Figure 4: Maps showing loss in mangroves between 2000 and 2010 in Cameroon, DRC, Republic of Congo and Gabon. Graded red colours show percentage loss within each contiguous patch. Purple shows loss in areas too small to be classified as a patch (i.e. fragments < 0.5km²); while green shows remaining mangrove in 2010.

Threat analysis

Deforestation rates described above reveals that the Central African region lost approximately 771 $km^2$of mangroves between 2000 and 2010. While causes of mangrove degradation may vary from one country to another, the major causes seem to be over-exploitation of mangrove wood and non-wood products, conversion of mangrove areas for urban development and infrastructure, degradation due to pollution from pesticides and fertilizers (eutrophication) and from hydrocarbon and gas exploitation, as well as clearance of mangroves for palm plantations particularly in Cameroon (Table 6). The table below indicates the severity of each threat in each country. The most important cause of mangrove cover reduction in most countries is urbanization and coastal infrastructure development, except for in DRC where pollution is the major threat. Over-exploitation of mangrove products is also a major cause of loss in most countries.Of the threats and pressures described here, the most amenable to management and threat reduction through REDD+ activities and projects are agriculture and over-exploitation of wood and non-wood forest products. National REDD+ strategies could explore actions to reduce these threats to mangroves in an economically and environmentally sustainable manner.

Table 6. An overview of major threats of mangroves in Central Africa

	Countries			
Threats	Cameroon	Gabon	Congo	DRC
Urbanization, coastal infrastructure development	xxx	xxx	xxx	x
Agriculture (e.g. palm plantations)	xx	x	-	-
Over-exploitation of wood and non-wood forest products	xxx	xx	x	x
Pollution (includingeutrophication, oil &gas pollution)	xx	x	xxx	xx
Invasive species (e.g. *Nypafruticans*)	x	-	-	-

(x=low xx =medium xxx = high)

The underlying root causes of the loss and modification of mangroves in Central Africa are associated with population pressure, poor governance, economic pressure in rural and urban, and poverty status of local communities. In addition, climate change related factors such as increased sedimentation have affected the fringing mangroves in Cameroon, Gabon, DRC, and Congo. These factors have collectively led to loss of mangrove cover, shortage of harvestable mangrove products, reduction in fisheries, shoreline change, loss of livelihood, and increase in poverty (UNEP, 2007).

3.2. Floristic composition and Distribution

Structural attributes (species composition, tree height, basal area, stand densityetc.) of the mangroves of Central Africa are provided in (Table 7, Table 8). Out of the 8 mangrove species described in Central Africa, 5 were encountered during the present study (Table 7). The dominant and prominent species is *Rhizophoraracemosa*that occur in expansive pure stands across the countries. There were only two species that were found in Congo and DRC. These results are in conformity with earlier surveys (e.g. UNEP, 2007; Ajonina, 2008; Ajonina*et al.*, 2009); and confirm Central African mangroves as being of generally species poor as compared to the Indo-west pacific mangroves that may have up to 52 species (Tomlison, 1986;Duke, 1992; Spalding *et al.*, 2010). Common mangrove associates that were encountered include *Hibiscus* sp., *Phoenix* sp, and *Acrostichumaureum*

There is no obvious zonation that is displayed by the dominant mangrove species in Central Africa.

However, one will find the seaward side as well as creeks mostly occupied by *R. racemosa*, whereas*R. mangle*, *A. germinams*, and *Acrostichumaureum* mosaic covers the middle and outer zones. In a few places in Cameroon, we found the invasive *Nypa* palms growing in association with *R. mangle* and *R. racemosa* on creek margins.

Table 7: Mangrove woody species found in the pilot areas

Mangrove species	**Country**			
	Cameroon	Gabon	Congo	DRC
Avicenniagerminans	X	x	x	x
Conocarpus erectus	X	x		
Laguncularia racemosa	X	x		
Rhizophora harissonii		x		
Rhizophora mangle		x		
Rhizophora racemosa	X	x	x	x
Associatedspecies				
Hibiscus sp	X	x		
*Phoenix*sp.		x		
Total	**5**	**8**	**2**	**2**

3.3. Stand density, volume and biomass

Table 8 provides vegetation inventories for Central Africa mangroves. The average stand density ranged from a low of 450 tree/ha in heavily exploited forest of Republic of Congo, to a high of 3255.6 tree/ha in pristine stands of Cameroon. In most un-degraded plots, the stem density decreased exponentially with increasing diameter. These are typical reversed 'J' curves for stands with a wide range of size classes and by inference also age classes (Figure 5). This pattern was, however, distorted in heavily exploited mangroves stands in the region where size classes above 30 cm were literally missing.

Standing volume ranged from a low of 213.0 m^3/ha in RoC to a high of 427.5 m^3/ha in Cameroon; corresponding to above ground biomassvalues of 251.3 and 504.5 Mg/ha respectively. Together withthe deadwoods, the total vegetation biomass in the study area ranged from a low of 393.5 Mg/ha in Congo to a high of 825.0 Mg/ha in Cameroon (Table 8).

Table 8: Structural characteristics of undisturbed mangroves in Central African (All stems with DBH>1.0 cm inside PSPs plots were measured).

Country	Tree density (trees/ha)	Max height (m)	Mean diameter (cm)	Basal Area (m^2/ha)	Stand volume (m^3/ha)	Above Ground Biomass (Mg/ha)	Below Ground Biomass (Mg/ha)	Dead woods (Mg/ha)	Total Biomass (Mg/ha)
Cameroon	3255.6	52.1	4.6	25.1	427.5	504.5	305.7	14.8	825.0
Gabon	1466.7	41	9.5	24.5	288.9	340.9	150.9	20.5	512.3
Congo	1666.7	25.2	7.7	18.8	213	251.3	121.9	20.3	393.5
DRC	1266.7	27	9.1	24.5	346.9	409.3	184.6	68.6	662.6

Extract of calculation from Ajonina (2008) as follows:

AGB = BEF_{ABG}*stand volume,

BEF = 1.18, BGB = BEF_{BGB}eqn * trunk volume = (1.385*Diam^-0.4331)*trunk volume.

Where BEF_{BGB}Equation = (1.385*Diam^-0.4331)

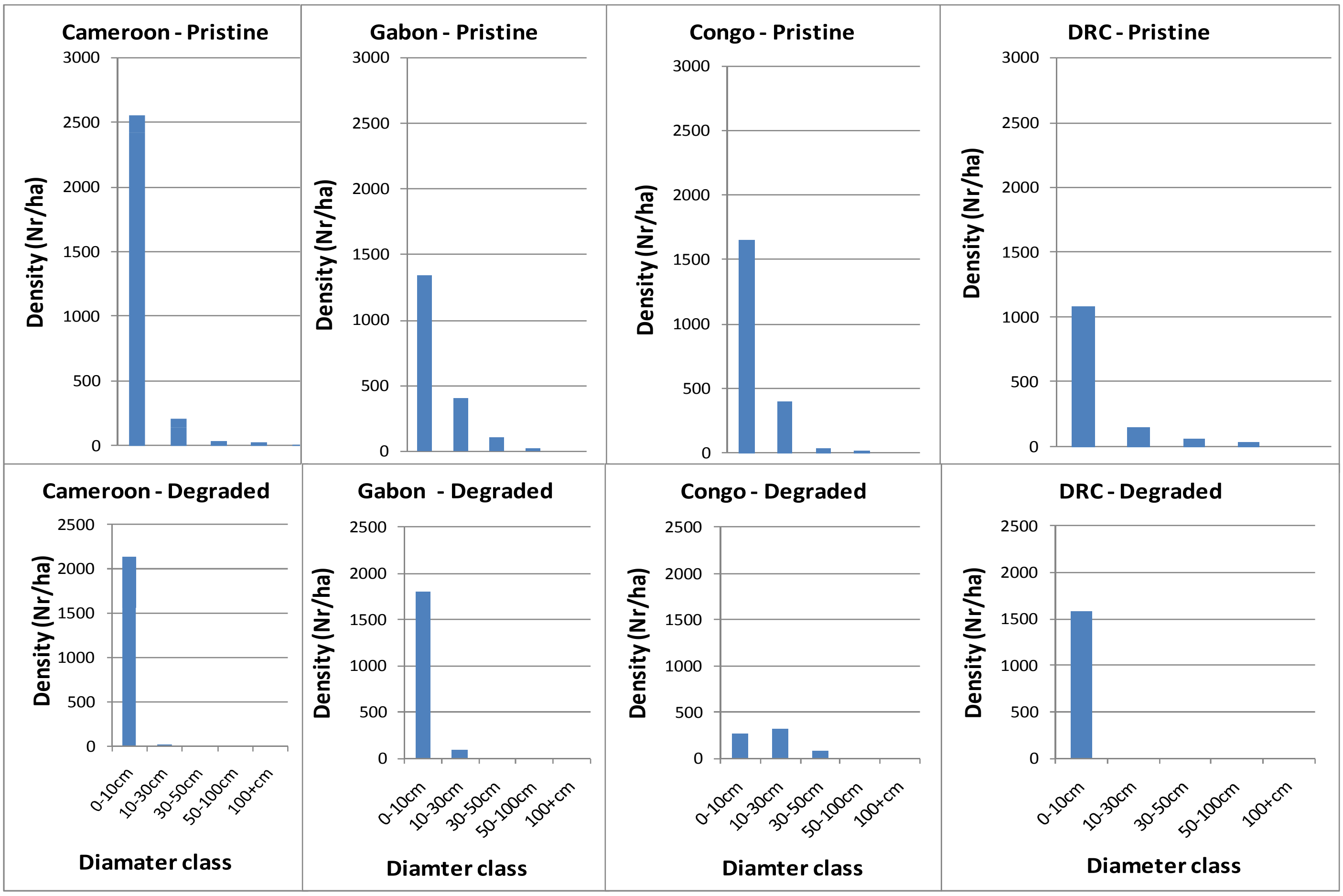

Figure 5: Stem class distributions in Central African mangrove forest

3.4. Carbon stocks

Soil Organic Carbon

There was high variability in the amount of soil organic Carbon ($p < 0.05$) with pristine sites showing higher carbon concentrations than degraded forests.Across the region, the average quantity of soil organic-C amounted to 827.2 ± 169.9 Mg/ha. The pristine stands recorded the highest amount of average SOC of 967.4 ± 57.6 Mg/ha (Table 9), followed by heavily and moderatel degraded sites that recorded an average SOC of 773.6 ± 162.9Mg/ha and 740.6.± 189.6 Mg/ha respectively. The results are in comformity with high content of organic Carbon that is associated with mangrove sediments (Donato *et al.*, 2011 found an average of 864 Mg/ha in the Indo-Pacific). Alluvial deposition from multiple rivers flowing through the mangroves into the Atlantic ocean could explain high organic carbon content in the soils whose mangroves are in degraded conditions. There was high variation in SOC in the 50-100 cm depth as compared to the rest of the zones (Table 9, Figure 6)

Table 9:Soil Organic Carbon (SOC) along the different forest conditions in Central Africa mangroves

Forest condition	Soil Depth (cm)				
	0-15	15-30	30-50	50-100	Total (Mg C/ha)
Pristine	157.8 ± 22.8	182.4 ± 70.7	230.5 ± 39.9	396.7 ± 108.6	967.4±57.6
Moderately exploited	130.1 ± 18.1	147.0 ± 33.6	156.6 ± 58.4	306.8 ±195.5	740.6 ±189.6
Heavily exploited	169.1 ± 34.5	140.0± 45.6	167.2± 86.3	303.9± 198.0	773.6± 162.9

Total Ecosystem Carbon

Total ecosystem carbon pool is derived from adding different Carbon pools. In mangrove environment, litter is insignificant carbon pool as part of it is eaten or buried underground by crabs hence accounted as sediment carbon. In this study four major pools were therefore considered; viz.,Carbon from above ground biomass, below ground root biomass, deadwood, and the soil organic carbon(Table 10).Total ecosystem carbon in non-degraded system was estimated at 1520.22 ± 163.93 Mg/ha with 982.49 Mg/ha (or 65%) in below ground component (soils and roots) and 537.73 Mg/ha (35.0%) in the above ground biomass(Figure 6).Total ecosystem carbon stocks differed significantly ($p< 0.05$) with forest conditions. The lowestecosystem carbon of 807.8 ± 235.5 Mg/ha was recorded in moderately degraded, translating to CO_2-equivalent of of 2961.8 Mg/ha. (807.8 ± 235.5 Mg/ha) (Table 10).

Although it is clear that undisturbed forests contain the largest amounts of carbon, the difference between moderately degraded and highly degraded systems is less clear. The relatively high carbon contents of degraded systems could be explained by the fact degraded systemsare receiving carbon input from outside the system through flood water, alluvial deposits and tides. High soil carbon figures in highly degraded as well as moderately degraded forests of Congo and DRC were influenced by peri-urban setting that suffers pollution effects. Furthermore, the relatively high carbon deposits in soils of degraded systems shows that not all soil carbon is oxidized and emitted to the atmosphere when the system becomes degraded, but some of it actually remains sequestered in the soil. The significant difference in carbon stocks between non-disturbed and moderately disturbed systems points to the possibility that mangroves release carbon stocks relatively quickly after degradation, even if degraded moderately, and that it is important for mangroves to remain in completely undisturbed states if they are to maintain maximum carbon values.

Table 10 Total ecosystem carbon stocks, partitioning and Carbon dioxide equivalent of Central Africa mangroves under different perturbation regimes

Pools	Degraded		Moderate		Non-disturbed	
	Trees Mg/ha	SE	Mg/ha	SE	Mg/ha	SE
Aboveground						
Live component	123.3	179.7	58.0	50.4	467.1	70.0
Dead component	16.4	18.1	6.1	3.7	70.6	85.2
Total Aboveground	**139.6**	**181.4**	**64.1**	**49.9**	**537.7**	**116.5**
As % total	**14.1**	**16.6**	**7.2**	**4.0**	**35.1**	**4.2**
Belowground						
Tree-roots	12.1	18.8	3.1	1.4	15.1	4.2
Total Soil	773.6	162.9	740.6	189.6	967.4	57.6
Total Belowground	**785.7**	**149.8**	**743.6**	**190.9**	**982.5**	**60.8**
As % total	**85.9**	**16.6**	**92.8**	**4.0**	**64.9**	**4.2**
Total ecosystem carbon stock (Mg/ha)	**925.4**	**137.2**	**807.8**	**235.5**	**1520.2**	**163.9**
CO_2.e of the ecosystem (Mg/ha)	3393.0	51.9	2961.8	46.0	5574.1	65.3

Carbon pools of trees (above ground) were calculated as the product of tree stand biomass multiplied 0.5.CO_2e value is derived by multiplying C-stocks by 3.67, the molecular weight ratio of CO_2 to C.

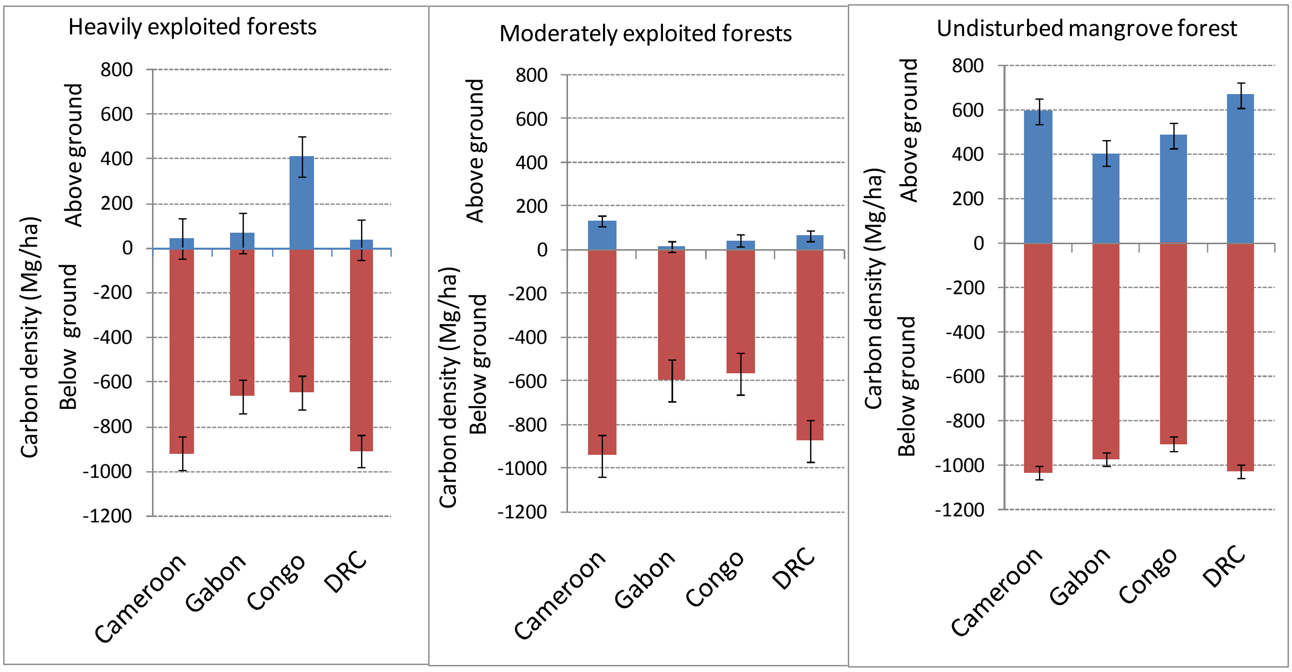

Figure 6: Partitioning of carbon stocks within mangrove forests of different exploitation regimes in Central Africa

Comparison with adjacent Central African Rainforests of the Congo Basin

Ecosystem C storage reported in the mangroves of Central Africa is among the largest for any tropical forest (IPCC, 2007). We made comparisons of mangrove C stocks with some of the reported carbon stocks of the terrestrial Congo basin rainforest (Figure 7). For consistence, we have only utilized above ground biomass; as most of the studies in terrestrial forests lacked below ground Carbon stocks. Above ground C pools were 209 Mg/ha in Dja Biosphere Reserve (Djuikouo*et al.*, 2011), 188 Mg/ha Campo Ma'an National Park (Kanmegne 2004), and 178.5 Mg/ha in Korup National Park (Chuyong(unpublished data)); all in Cameroon. The average above ground C-pool for pristine rainforest in Central Africa was 154Mg/ha. The above ground Carbon stocks of terrestrial rainforest are less than an average 268.9 MgC/ha of the mangroves sampled in this study underscoring the value of mangroves as C stocks.

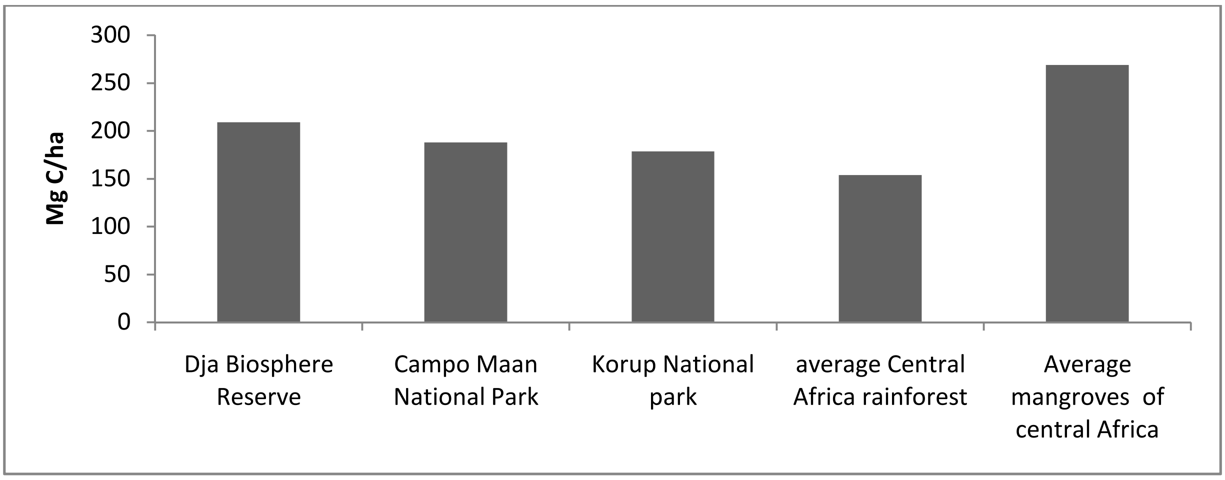

Figure 7: Above ground C stocks of selected terrestrial rainforest in Congo basin and the mangroves sampled in this study.

3.5. Carbon sequestration in Central African mangrove forests

Forest dynamics: Growth and biomassaccumulation

Net growth wasbetter in medium exploited forests (ME)than in heavily exploited (HE) and un degraded (UND) (Figure 8, Table 11). This implies that there is a threshold level for exploitation to guarantee stand development. FAO (1994) recommends a minimum of 12 trees/ha parental mangrove trees (standards) be retained during harvesting operations to act as seed bearers for the next generation. Although it is still early to foretell the nature of future forest in Central Africa mangroves, mortality rate observed in the present study is in conformity with the FAO (1994) values of 50% loss observed during the 1-10 years growing period.

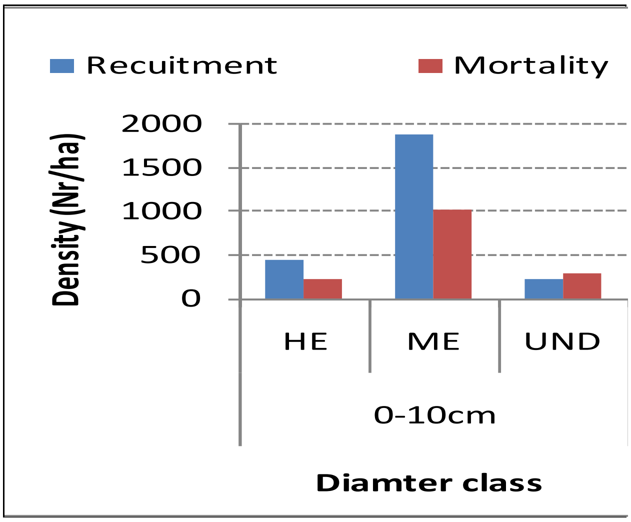

Figure 8: Recruitment and mortality in mangrove forests

Apart fromCameroon, growth data was not available for other mangrove areas in the region. Mean annual diameter increment (MAI) for primary and secondary stems under different management regime was 0.15 cm/yr. This translates to above and below ground annual biomass increment of 12.72 Mg/ha/yr and 3.14 Mg/ha/yr respectively. The values are consistence with published productivity data in Malaysia (Ong*et al.*, 1993), Thailand (Komiyama, 2006), andKenya (Kairo*et al.*, 2008). As expected, heavily degraded forests had the lowest biomass increment; whereas the moderately exploited and undisturbed forestshad better rates of growth (Table 11).

Table 11: Biomass accumulation in the Central African Mangrove forests (Figures are annual incrementsunder different exploitation regimes)

Disturbance Regimes	Mean periodic annual increment				
	Diam (cm/yr)	Basal area (m^2/yr)	Volume ($m^{3/}$yr)	AGB (tonnes/ha/yr)	BGB (tonnes/ha/yr)
Heavilyexploited	0.34	0.05	0.35	0.38	0.40
Moderatelyexploited	0.42	1.67	9.66	10.43	3.35
Un-disturbed	0.06	0.02	25.34	27.36	5.67
All regimes	0.15	0.56	11.78	12.72	3.14

Carbon sequestration

Carbon sequestration rates were found to vary with forest conditions (Table 12). Above ground components (AGC) had proportionately higher sequestration rates (6.36 MgC/ha/yr) compared to below ground carbon pools (BGC). Undisturbed forests sequestered on average 16.52 MgC/ha/yr against 0.39 Mg C/ha/yrand 6.89MgC/ha/yr by heavily and moderately degraded systems respectively. Mean sequestration rate for all forest conditions was 7.93 Mg C/ha/yr; a figure comparable to similar studies elsewhere (Donato*et al.*, 2011).

Table 12: Carbon sequestration in mangrove forests under different exploitation regimes

Exploitation regime	Biomass (MgC/ha/yr)		
	AGC	BGC	Total
Heavilyexploited	0.19	0.20	0.39
Moderatelyexploited	5.21	1.68	6.89
Undisturbed	13.68	2.84	16.52
Average	6.36	1.57	7.93

3.6. Valuation of other ecosystem services

Fisheries

Average output of fresh fish from mangrove area in the four pilot areas is summarized in Table 13). The value of mangrove fisheries in the four countries – Cameroon, Gabon, Congo and DRC, is US$ 12 825/ha/yr (or 6.4 million francs CFAper ha/yr).This is significantly lower than the US$ 37, 500/ha/yrfish and crab fishery reported by Aburto-Oropeza*et al*., (2008)from the fringing Gulf of California mangroves in Mexico. Large volumes of fish caught in mangroves are justified by the nursery and habitat functions provided by mangroves.

In Cameroon, the fish species with highest yearly production are *Hepsetusodoe*(4.1 tons/ha/yr) and *Ethmalosa fimbriata*(7.3 tons/ha/yr). In Gabon, the richest fishing grounds of the region, the highest production per species is *Sardinella sp.* (85 tons/ha/yr). Similarly in the Republic of Congo the highest catch reported is for *Liza sp.* (20 tons/ha/yr) and *Barbodes* sp.(18 tons/ha/yr); whereas in DRC it is *Lates niloticus* (7 tons/ha/yr). See Annex 3 for more information. It is clear from these results that mangroves are highly important for the livelihoods and food security in the region due to the important role they play for fisheries and production of commercially important species.

Shoreline protection

Estimates for protective functions of mangroves in rural and urban areas are presented in Table 14 and 15. Obviously the avoided damages are much higher in urban settings than rural settings, with urban mangroves protecting an average of US$151,948 worth of infrastructure per ha whilst rural mangroves protect an average of US$7,142 worth of infrastructure per ha. However, it is unreasonable to assume that mangroves can offer full protection of all coastal infrastructure, or that all coastal infrastructure is actually at risk of flooding or erosion. A more detailed risk analysis would be necessary to determine which infrastructure is best protected by mangroves, but we can assume a conservative estimate of between 25 and 50% of the value of infrastructure actually being protected by mangrove ecosystems. For rural areas this protective function may be higher as infrastructure could be more at risk and mangrove stands are more intact.

Table 13: Valuing mangrove ecosystems for fisheries production in Central African coast from Cameroon to Congo (values are in Fcfa – current exchange rate of 500Fcfa to 1 USD)

Country	Yearly production/ha of mangroves [a]				
	Quantity (tonnes)	Total price (Fcfa)	US Dollars[b]	StdError (Fcfa)	StdError (US Dollars)
Cameroon	22	6 466 048	12 932	741 707	1 483
Gabon	109	7 713 141	15 426	1 994 185	3 988
Congo	83	4 270 756	8 542	252 978	506
DRC	36	7 200 000	14 400		-
Average	63	6 412 486	12 825	996 290	1 993

*Sources: OCPE fisheries report 2005 & 2008; Association de Peche de Mouanda (APAMABY personal communication, August 2012).
[a]Based on artisan fishing efforts of 292 days (Gabche, 1997)
[b] 1 US$ = 500 Fcfa

In comparison to this, the replacement method analyzes the cost of replacing the protective function of mangroves by a seawall. For Central Africa, this was estimated atUS$11,286/ha (Table 16). There is very little literature comparing the protective function of seawall and mangrove ecosystems against storms and coastal erosion, however Rao*et al.,* (2012) show that mangroves are 5 times more cost-effective than seawalls as a coastal adaptation option because of the long-term costs of maintaining a sea-wall and the multiple benefits that mangroves provide through other ecosystem services (e.g. food security from fisheries). Therefore even if it is assumed that seawalls offer higher protection than mangroves, a combined approach of engineering and ecological options can be more cost-effective and sustainable. Furthermore, seawalls are often prohibitively expensive to build in rural areas and long-term expensive maintenance is necessary. Seawalls can also have impacts on sediment dynamics, reducing sediment availability and thus affecting the health of adjacent coastal ecosystems. Mangroves on the other hand only need investment in protection and management, cheaper than engineering maintenance, and provide other values too. Mangroves are a viable adaptation option, and should be considered part of Central Africa’s solution to adapting to higher storm intensity and coastal erosion in the future (Rao *et al.,* 2012).

Table 14: Evaluating shoreline protection function of mangroves in rural areas in Central African coast from Cameroon to DRC

Country/Zone/Site/Type of infrastructure	Cost/ha			
	Fcfa		US Dollars*	
	Cost	SE	Cost	SE
Cameroon				
Region du littoral				
Houses (wooden, simple)	2 436 000	342 000	4 872	684
Institutional (schools, spiritual, etc)	2 000 000	123 000	4 000	246
Roads (usually non tarred including bridges)	120 000	43 000	240	86
Total Region du littoral	**4 556 000**	**410 903**	**9 112**	**822**
Average Cameroon	**4 556 000**	**410 903**	**9 112**	**822**
Gabon				
Province de l'Estuaire, commune de Coco-Beach				
Houses (wooden, simple)	820 000	70 000	1 640	140
Roads (usually non tarred including bridges)	100 000	43 000	200	86
Total Province de l'Estuaire, commune de Coco-Beach	**920 000**	**110 955**	**1 840**	**222**
Province de l'Estuaire, Commune de Libreville			-	-
Houses (wooden, simple)	168 000	23 000	336	46
Roads (usually non tarred including bridges)	40 000	1 350	80	3
Total Province de l'Estuaire, Commune de Libreville	**208 000**	**64 000**	**416**	**128**
Average Gabon	**564 000**	**89 394**	**1 128**	**179**
Congo				
Département de Pointe Noire				
Houses (wooden, simple)	15 492 000	443 173	30 984	886
Roads (usually non tarred including bridges)	40 000	1 560	80	3
Total Département de Pointe Noire	**15 532 000**	**420 622**	**31 064**	**841**
Département du Kouilou			-	-
Houses (wooden, simple)	1 419 000	142 227	2 838	284
Total Département du Kouilou	**1 419 000**	**142 227**	**2 838**	**284**
Average Congo	**8 475 500**	**308 719**	**16 951**	**617**
DRC				
Province du Bas-Congo, district de Boma				
Houses (wooden, simple)	688 400	335 800	1 377	672
Total Province du Bas-Congo, district de Boma	**688 400**	**335 800**	**1 377**	**672**
Average DRC	**688 400**	**335 800**	**1 377**	**672**
Average rural mangroves	**3 570 975**	221 164	7 142	442

Table 15: Evaluating shoreline protection function of mangroves in urban areas in Central African coast from Cameroon to DRC

Country/Zone/Site/Type of infrastructure	Cost/ha			
	Fcfa		US Dollars*	
	Cost	SE	Cost	SE
Cameroon				
Region du littoral				
Electricity (transmission poles, etc)	280 000	60 000	560	120
Houses (simple, one storey, multi-stories)	15 584 000	3 143 591	31 168	6 287
Institutional (schools, markets, sports, military, etc)	256 128 000	51 193 602	512 256	102 387
Roads (tarred and non tarred including bridges)	824 000	262 758	1 648	526
Telecommunication (Poles, transmission stations, etc)	19 200 000	2 400 000	38 400	4 800
Total Region du littoral	**292 016 000**	**14 957 870**	584 032	29 916
Average Cameroon	**292 016 000**	**14 957 870**	**584 032**	**29 916**
Gabon				
Province de l'Estuaire, Commune de Libreville				
Electricity (transmission poles, etc)	100 000	31 000	200	62
Houses (simple, one storey, multi-stories)	3 380 000	411 208	6 760	822
Total Province de l'Estuaire, Commune de Libreville	**3 480 000**	**351 648**	6 960	703
Average Gabon	**3 480 000**	**351 648**	**6 960**	**703**
Congo				
Département de Pointe Noire				
Electricity	100 000	28 000	200	56
Houses (wooden, simple, one storey, multi-stories)	6 000 000	500 000	12 000	1 000
Total Département de Pointe Noire	**6 100 000**	**1 008 850**	12 200	2 018
Average Congo	**6 100 000**	**1 008 850**	**12 200**	**2 018**
DRC				
Province du Bas-Congo, district de Boma				
Electricity (transmission poles, etc)	100 000	25 000	200	50
Houses (wooden, simple, one storey, multi-stories)	1 200 000	105 000	2 400	210
Roads (tarred and non tarred including bridges)	1 000 000	75 000	2 000	150
Total Province du Bas-Congo, district de Boma	**2 300 000**	**338 296**	4 600	677
Average DRC	**2 300 000**	**338 296**	**4 600**	**677**
Average urban mangroves	**75 974 000**	**9 099 707**	**151 948**	**18 199**

Table 16: Estimate cost of constructing a sea wall within mangrove areas of central Africa (The sea wall with reinforced concrete materials with height 5m)

Country	**Cost CFA**	**US Dollars**
Cameroon	9 000 000	18 000
Gabon	6 000 000	12 000
Congo	4 000 000	8 000
DRC	3 571 500	7 143
Average	**5 642 875**	**11 286**

Source: Field survey within these countries)

Mangrove wood products

Average annual household consumption of mangrove wood products including fuelwood, construction, etc. is estimated at 55.56 m^3/yr (or 49.53 tonnes/yr) for the four countries (Table 17). The highest consumption is in Cameroon where there is massive mangrove harvesting for fish smoking (Ajonina and Usongo, 2001; Feka et al., 2009; Feka and Ajonina, 2011). Ajonina and Usongo (2001) estimated 125.60m^3/household/yr and per capita consumption of 15.93m^3/pers/yr for the village communities within and adjacent to the mangroves of the Douala-Edea coastal area. In a similar study in Ghana, Forest Trends (2011) estimated household consumption of 15.83 m^3/yr and 97.44 m^3/yrfor cooking and fish smoking respectively. These estimates are significantly higher than FAO per capita estimate of 1.0m^3/pers/yr (approximately 6-10 m^3/household/yr).

From these data, we can see that mangrove wood is a major source of fuel for coastal communities in Central Africa, and extremely important for livelihoods, especially in connection with food security and source of energy. Sustainable harvesting of mangroves; improved fish smoking stoves, and moving away from fuelwood as the major source of energy are all possible steps to be implemented through REDD+ programmes in order to improve the sustainability of mangrove resources in the region.

Table 17: Annual household fuelwood consumption withinthe Central African countries. Values were obtained based on annual extrapolation of estimates of exhaustion times (given by the households) of measured stocks of harvested mangrove wood from random sample of 20 households within each country.

Country/site	**Yearly household consumption (m^3/yr)**	**SE**	**Yearly household consumption (tonnes/year)**	**SE**
Cameroon				
Littoral Region (Basal naval, Youpwe, Bois de Singe, Song Ngonga)	78.90	24.63	70.22	21.92
Gabon				
Province de l'Estuaire, commune de Coco-Beach (Emone)	42.30	19.95	37.64	17.75
Congo				
Département de Pointe Noire (Louya)	47.26	2.32	42.06	2.07
RDC*				
Parc Mangrove de Muanda	48.00		42.72	
General Average	**55.66**	**17.50**	**49.53**	**15.57**

*Sources: OCPE FisheriesReport (2005, 2008) Association de Pêche de Mouanda (APAMABY personal communication, August 2012).

Tourism

Though there was a scarcity of data on recreation value of mangroves, available information indicate that mangroves of Central Africa are also important tourisms sites; receivingon average1,044 visitors per year (Table 18). In Republic of Congo, some840 visitors were recorded in the Mazra Club Touristique mangrove siteof the Republic of Congo. These relatively low numbers of visitors show that mangroves are not priority tourism areas for these countries, and that terrestrial ecosystems such as rainforests or other wildlife sanctuaries are bigger attractions. Furthermore, some countries such as DRC generally do not have highly developed tourism industries due to political and infrastructural challenges. Tourism infrastructure in the mangroves of Central Africa is not yet fully developed and the potential has not yet been fully realized; especially given howglobally important, spectacular and gigantic these ecosystems are. Payments for ecosystem services (PES) schemes could explore improving ecotourism opportunities and income in the region.

Table 18: Visits tomangrove sites within Central Africa

Country	Site	Area (ha)	Average nr visitors/ month	Yearly total	Mean visit/ha mangrove /yr	Source of data
Cameroon	Ebojie Marine turtle	200	10	120	0.6	Visit records kept by Association Nationale de Protection des Tortues Marines du Cameroun « Kud'A Tube »
Gabon	NA	NA	NA	NA	NA	NA
Congo	Mazra Club Touristique	100	70	840	8.4	Mazra Club Touristique records
DRC	Parc Mangrove	500	7	84	0.168	Conservation Service of Parc Mangrove Muanda
Total		800	87	1044	1.305	

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

Despite the challenges faced during the implementation of this project, important conclusions about the mangroves of Central Africa can be drawn:

- There are approximately 437 340 ha of mangroves in the Central Africa's countries of Cameroon, Gabon, Congo, Equatorial Guinea, Sao Tome and Principe, DRC and Angola; 90% of which occurs in Cameroon, Gabon, Congo and DRC.
- Mangrove forests play an important role in the protection of coastal areas (shoreline and seashore protection, stabilization of coastal and shoreline substrate) against natural disasters such as floods. Besides, they serve as habitats for fish and other wildlife, mitigate climate change through Carbon sequestration thereby ensuring ecological and food security for more than 30% of the population of countries along coastal areas of Central Africa region.
- Data presented in this report indicate mangrove deforestation and degradation in Central Africa region to exceed 1.8% per annum.
- Major threats impacting on Central Africa mangroves are urbanization, over-exploitation of wood products and pollution resulting from industrial, agro-industrial and oil exploration activities.
- Mangrove forests in Central Africa are Carbon rich ecosystems with carbon stocks in natural undisturbed forests estimated to be more than 2-3 times that of adjacent tropical rainforest. More than 80% of carbon stocks in natural undisturbed mangrove forests are stored in the soil.

4.2. Recommendations

Results and conclusions obtained in the study, allow us to drawseveral recommendations regarding mangroves of Central Africa.

- There is need to relate mangrove REDD+ and PES issues in future management options.
- Need for monitoring of permanent mangrove forest plots to gauge not only dynamics of carbon but also general mangrove ecosystem dynamics (growth, mortality, recruitment) for research, carbon and other PES initiatives)
- Environmental impact assessments of development projects within the coastal areas should be carried out. To ensure sustainable development of coastal areas, conservation of mangroves should be implemented with within the overall framework of integrated management of coastal areas.
- Integrating mangrove protection in coastal and marine protected area network. Managing a network of mangrove and marine protected areas including marine (sea-ward) extensions of existing coastal parks to conserve biodiversity and for mangrove to play fully its role including as hatchery and nursery grounds for aquatic fauna. Such protected areas should include mangrove specific action objectives.
- Policy and legal protection of mangrove forests. Presently there exists no policy specific to mangrove in the region. One possibility could be the inclusion of mangroves into Abidjan Convention – potentially extension of Mangrove Charter for West Africa
- More allometric study of African mangrove forests
- Increase awareness generation initiatives for mangroves
- Strengthening of existing networks and partnerships. Existing networks and partnership especially African Mangrove Networks (AMN), UNEP REDD+ Central African Mangroves,

Western Indian Ocean (WIO) Mangrove Network (WMN) etc. should be strengthened in order to generate a large-scale impact of mangrove forest protection and restoration initiatives through reforestation and sustainable management techniques as well as building capacities in various domains of mangrove conservation and sustainable management.

- Other specific actions that can reduce the overharvesting of mangroves in the region include:
  - Use of improved mangrove wood energy stoves for fish smoking and cooking;
  - Alternative energy use such as carbon briquettes, icing plants, to reduce fuel wood use;
  - Improved enforcement of existing protected areas (currently deforestation rates in protected areas is similar to outside protected areas, showing very little enforcement); and
  - Inclusion of mangroves in national forest definition and REDD+ readiness plans

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ANNEXES

Annex I. List of People Contacted

Congo

Germain KOMBO
Deuxième Conseiller
Ambassade du Congo
NAIROBI - KENYA
Tél: (+254) 787771324/
(+242) 05 512 55 45/05 558 74 85/ 06 678 53 19
Email : kombo_g@yahoo.fr

Jean Felix ISSANG
Conseiller Principal, Responsable de l'Unite Energie/Environnement
Tel : (242) 06 660 85 76/06 875 00 08
Email : jean-felix.issang@undp.org

Marcel MPOUNZA
Coordonateur National
Programme Africain d'Adaptation / PNUD-Congo
Tel : (+242) 05 568 80 37
Email :marcel.mpounza@undp.org

MFOUTOU Gaston
Directeur de la Conservation des Ecosystèmes Naturels
Ministère du Développement Durable de l'Economie Forestière et de l'Environnement
(+242) 05 666 59 94/05 553 72 04
Email: gastonmfoutou@yahoo.fr

Jerôme MOKOKO
Directeur adjoint
WCS-Congo
Tel : (+242) 05 55117 85
Email :jrmokoko@wcs-congo.org

Jean Pierre KOMBO
Coordonnateur du Projet Grand Ecosystèmes Marins du Courant de Guinee (GCLME)
Point Focal Convention d'Abidjan
Tel : (+242) 05 521 55 69
Email :jeanpierrekombo@yahoo.fr

Mme RoselineAkenzenee OGNIMBA
Chef de Service Conservation des Ecosystèmes Aquatiques
Direction Générale de l'Environnement
Ministère du Développement Durable, Economie Forestière et Environnement
Tel : (+242) 05 764 55 55
Email : oroselineblanche@yahoo.fr

Pierre Justin MAKOSSO
2e Adjoint
Mairie de PN
Tel : (+242) 05 553 72 04/06 681 74 74

Jean Simplice MADINGOU
Direction des forets
Tel : (+242) 066252498/044366507
Email : mjeansimplice@yahoo.fr

Antoine BITA
Direction de l'environnement
Tel : (+242) 055497477

Basile NIAMATELE
Conservateur adjoint
Parc National de Conkouati-Douli
Tel : (+242) 069442490
Email : niambasile@yahoo.fr

Roland Missilou BOUKAKA
Conservateur, Chef se site
Parc National de Conkouati-Douli
Tel : (+242) 055497477
Email : Missilou_roland@yahoo.fr

DRC

M. Vincent KASULU SEYA MAKONGA,
Directeur de développement Durable
Point Focal National Changement Climatique
Point Focal Opérationnel FEM
Ministère de l'Environnement Conservation de la Nature et Tourisme
Tél : (+243) 99 99 05 957 / 081 45 10 594
Email : seyamakonga@hotmail.com

Pasteur Cosma B. WILUNGULA
Administrateur Directeur Général (ADG)
ICCN (Institut Congolais pour la Conservation de la Nature)
13 Av. Cliniques
C/Gombe, Kinshasa, BP 868 Kin 1
Tél : +243 99 80 44 118/81 700 54 75
Email : pdg.iccn@yahoo.fr , bawicosma@gmail.com
Website : www.iccn.cd

Marcel Michel G. COLLET
Directeur et Chef de Site
Parc Marin des Mangroves
Président
Les Serpents du Congo
Maître de Recherche
UniKin - Centre Anti-Venimeux
Tel : + 243-81-9918530/99-9918530
Email : parcdesmangroves@gmail.com

M. Urbain ASANZI
Conservateur du Parc Marin des Mangroves de Moanda, ICCN (Institut Congolais pour la Conservation de la Nature)
Tél : (+243) 081 40 05 333

M. Louis NGUELI MPAYI
Sous-Officier de Garde en charge de l'Ecotourisme
Parc Marin des Mangroves de Moanda,
ICCN (Institut Congolais pour la Conservation de la Nature)
Tél : (+237) 081 90 46 217/ 089 95 96 180

M. Peter LUKAMBA LUNDENGO,
Secrétaire Général de l'ONG OCPE
(Observatoire Congolais Pour l'Environnement)
Tél: (+243) 081 39 97 611 / 99 37 29 915
Email : peterocpe@yahoo.fr

M. Samuel MBUNGU NDAMBA,
Coordonnateur de l'ONG ACODES
(Action Communautaire de Développement et d'encadrement Social)
Tél : (+243) 81 51 57 908
Email :sammbungu@yahoo.fr

Gabon

Constant ALLOGO,
Directeur Exécutif du CADDE
(Centre D'Action pour le Developpement Durable et l'Environnement)
Point Focal CARPE
(Central African Regional Programme for Environment)
CARPE, IUCN Gabon
Tél: (+241) 07352574
Email : allogoba@yahoo.fr

M. Bernard Henri VOUBOU
National Programme Officer, PNUD
(+241) 07152162/07152157
Email : bernard.voubou@undp.org

Léandre M EBOBOLA
Directeur de l'Environnement et de la Protection de la Nature
Ministère des Eaux et Forêts
Tél: (+241) 06233110
Email : dgegabon2@yahoo.fr

Mme Marie AYITO
Directeur des Ecosystèmes Aquatiques Ministère des Eaux et Forêts
Tél: (+241) 07399424
Email : luman_1er@yahoo.fr

M. Félicien Joël BODINGA,
Directeur adjoint des Ecosystèmes Aquatiques
Ministère des Eaux et Forêts
Tél: (+241) 07777207
Email : dingafejo@yahoo.fr

Dr Emmanuel ONDO ASSOUMOU
Enseignant (Département de Géographie, Université Omar BONGO)
Tél: (+241) 07261408
Email : ondoassoumou@yahoo.fr

Annex II. Country Account: Carbon stocks partitioning

Cameroon

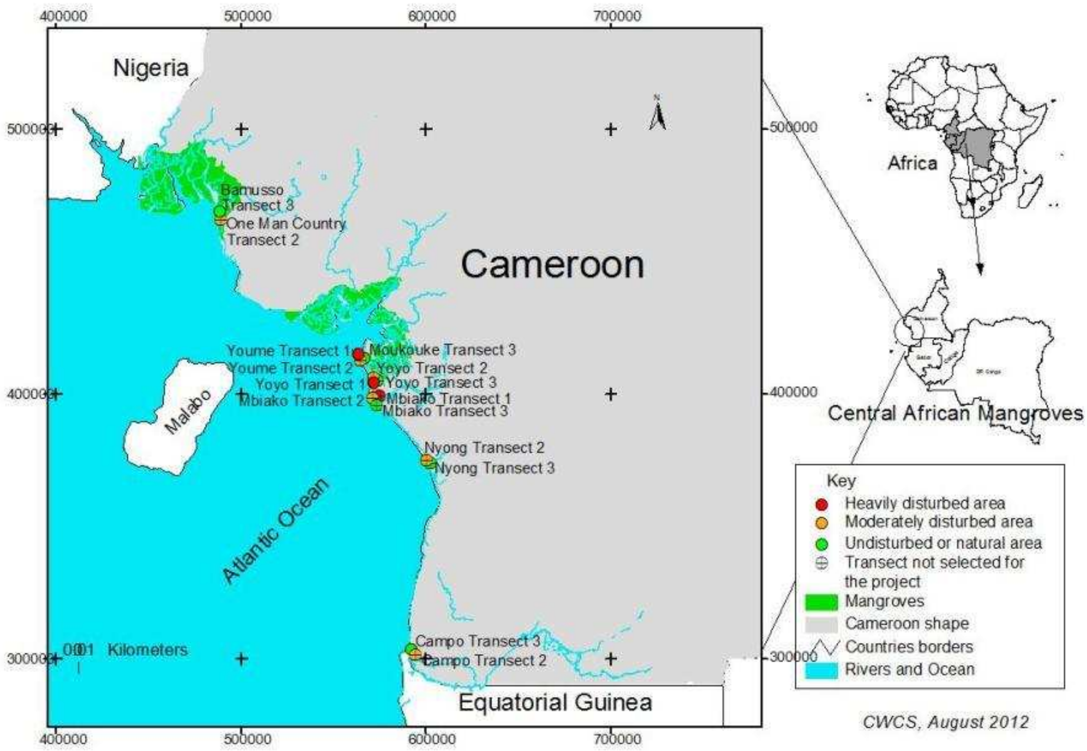
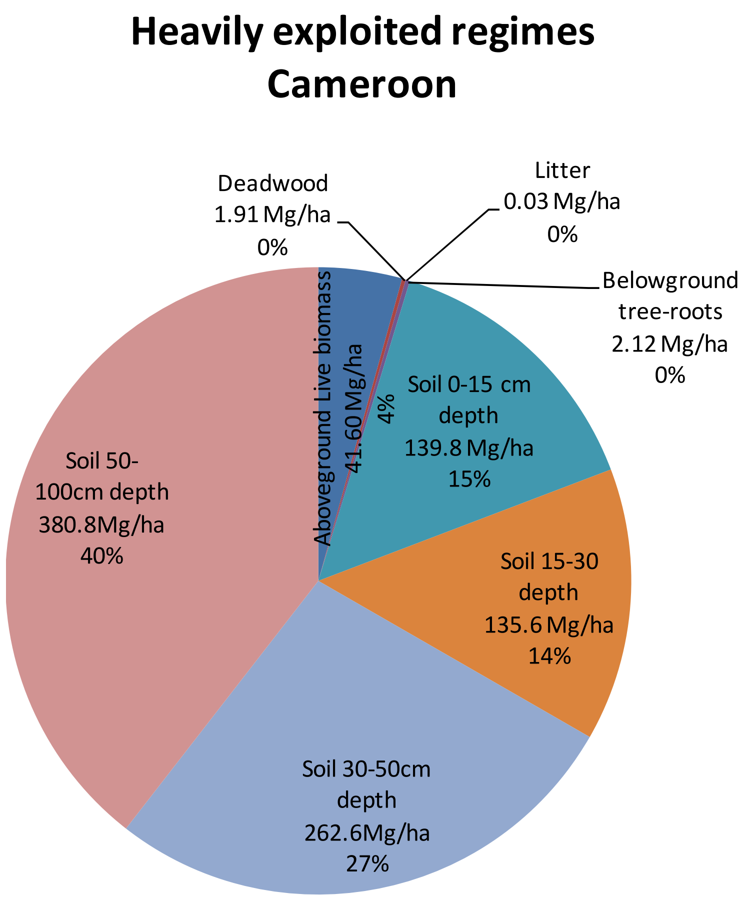
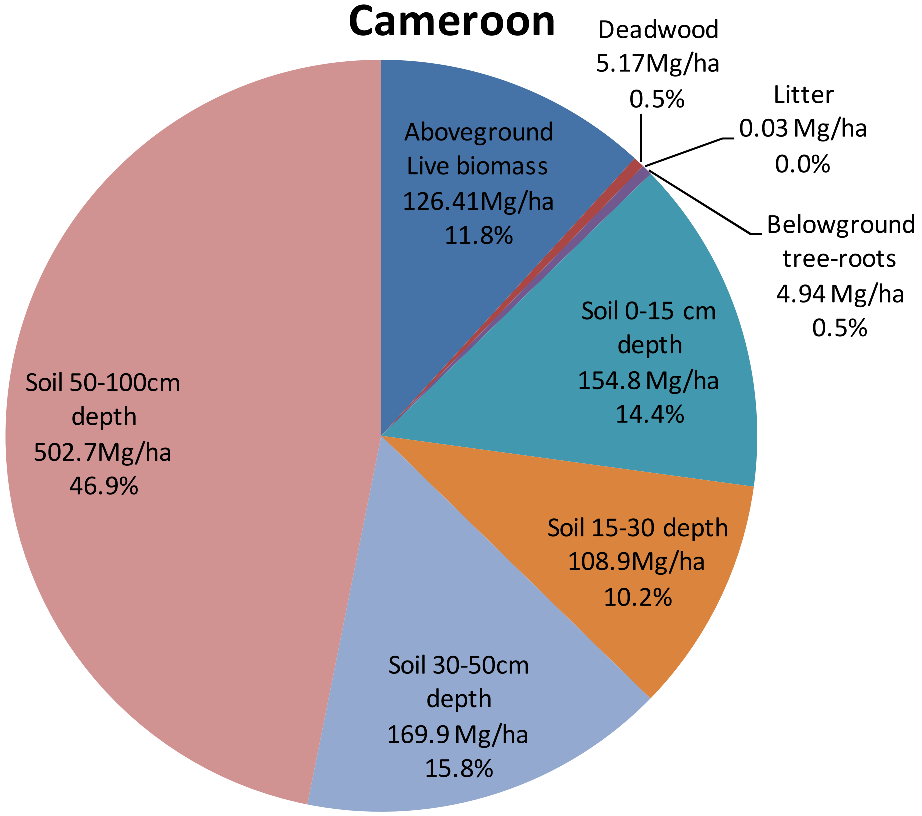


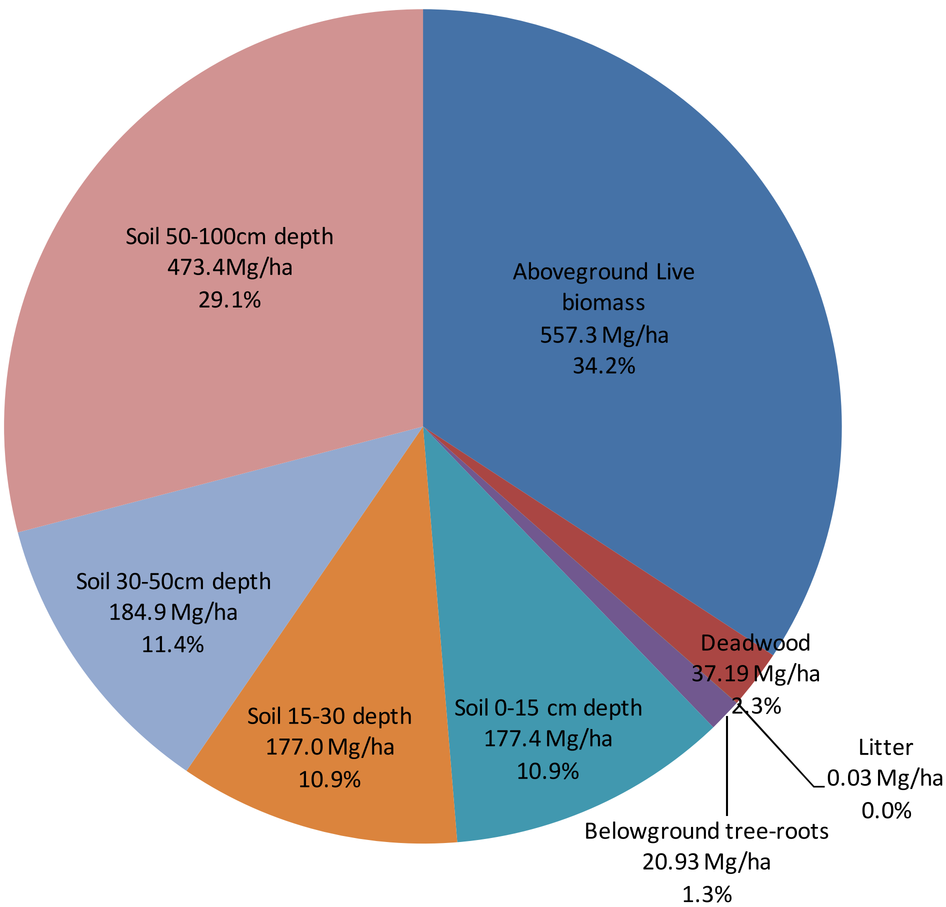
Figure 1a: Location of selected mangrove sites in Cameroon



Moderately exploited regimes Cameroon



Undisturbed regimes Cameroon



Gabon

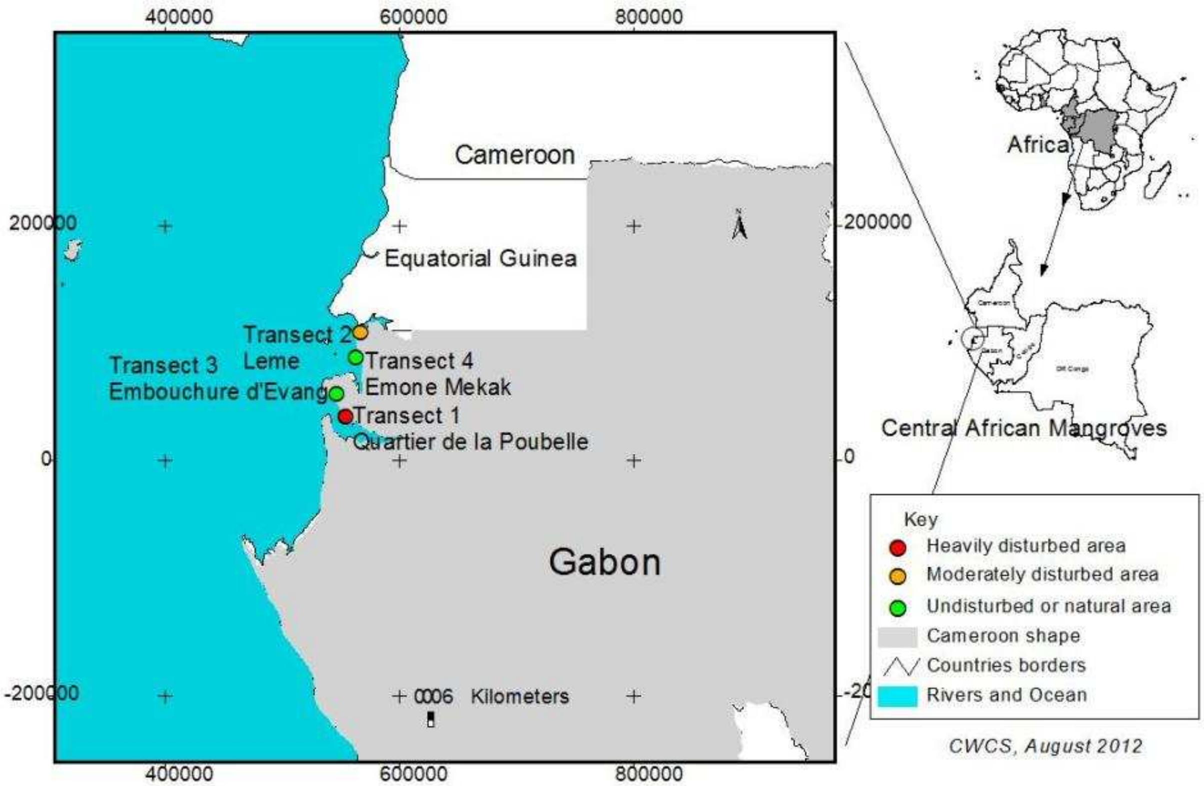
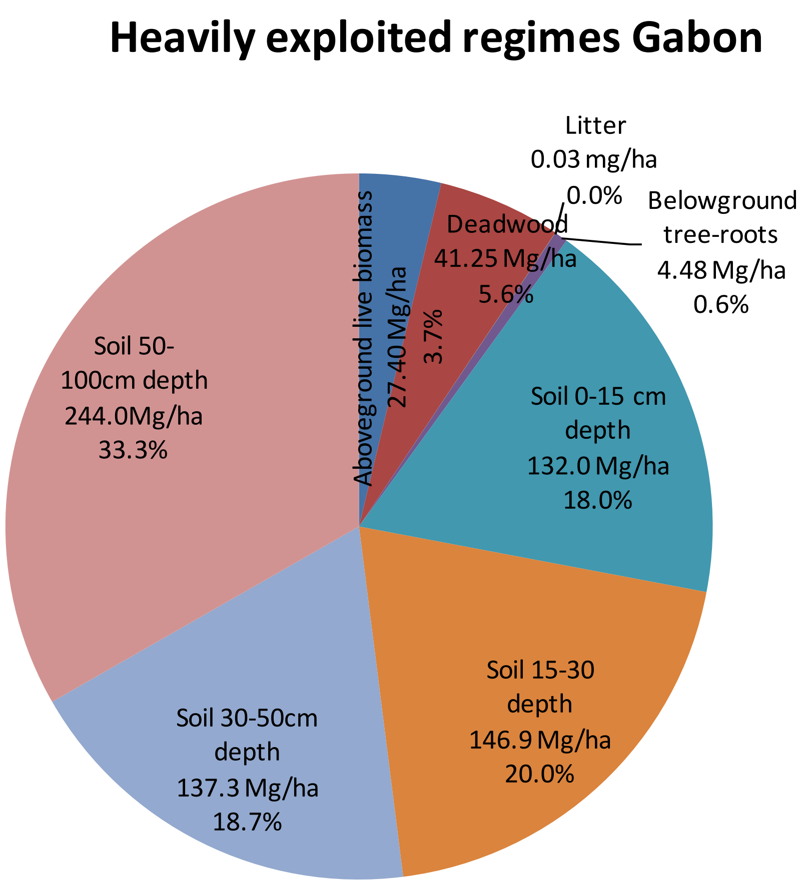
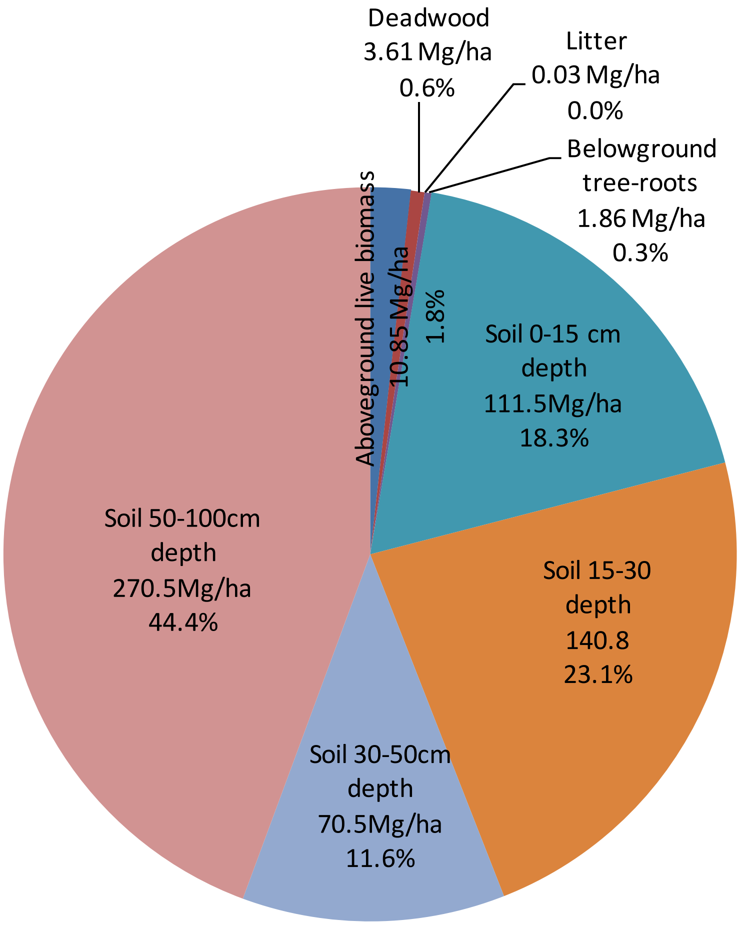


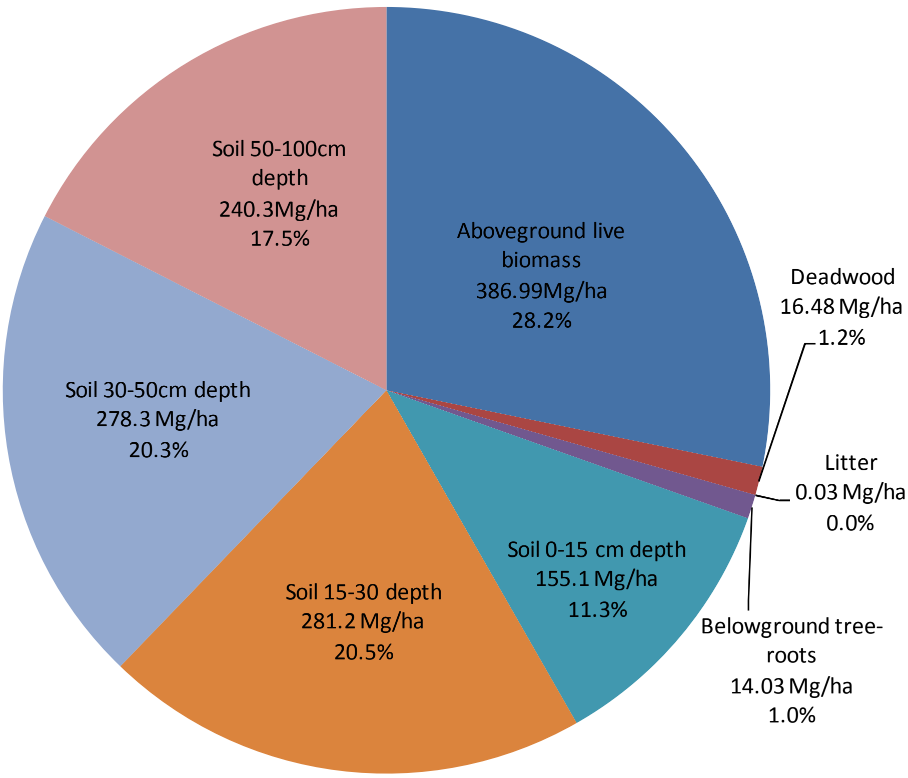
Figure 1b: Location of selected mangrove sites in Gabon



Moderately exploited regimes Gabon



Undisturbed regimes Gabon



Congo

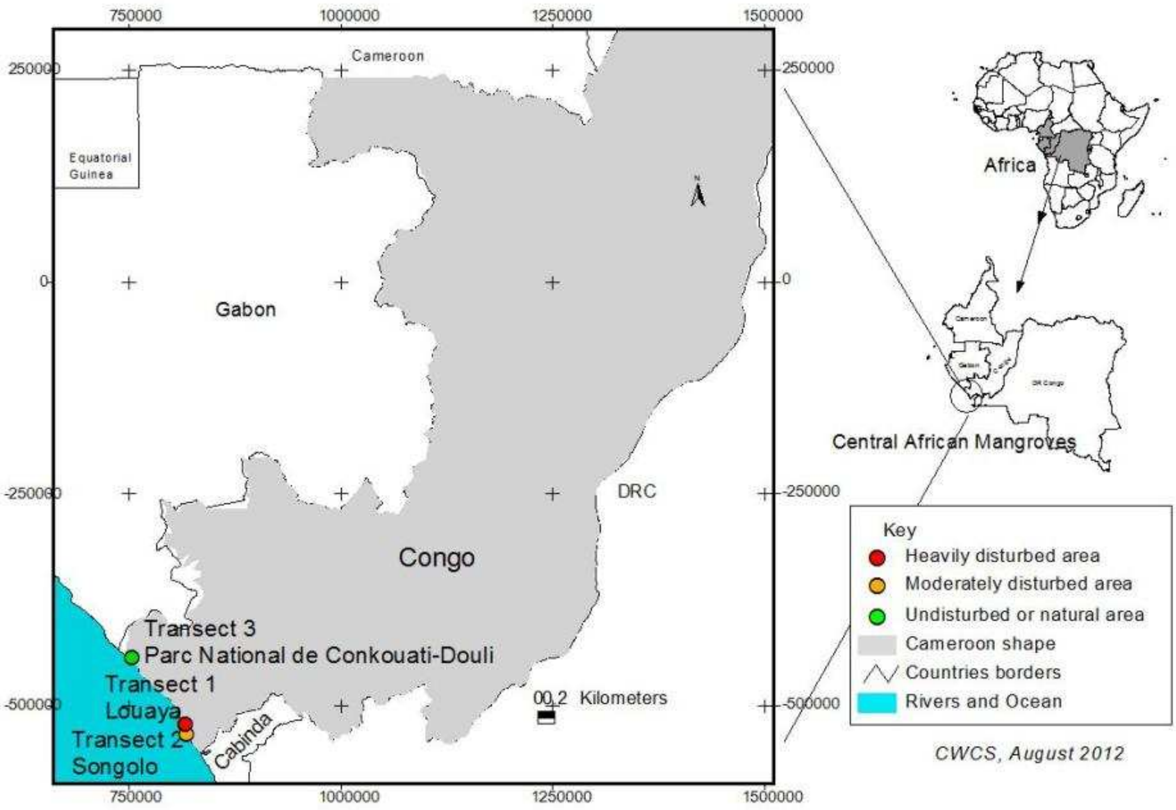
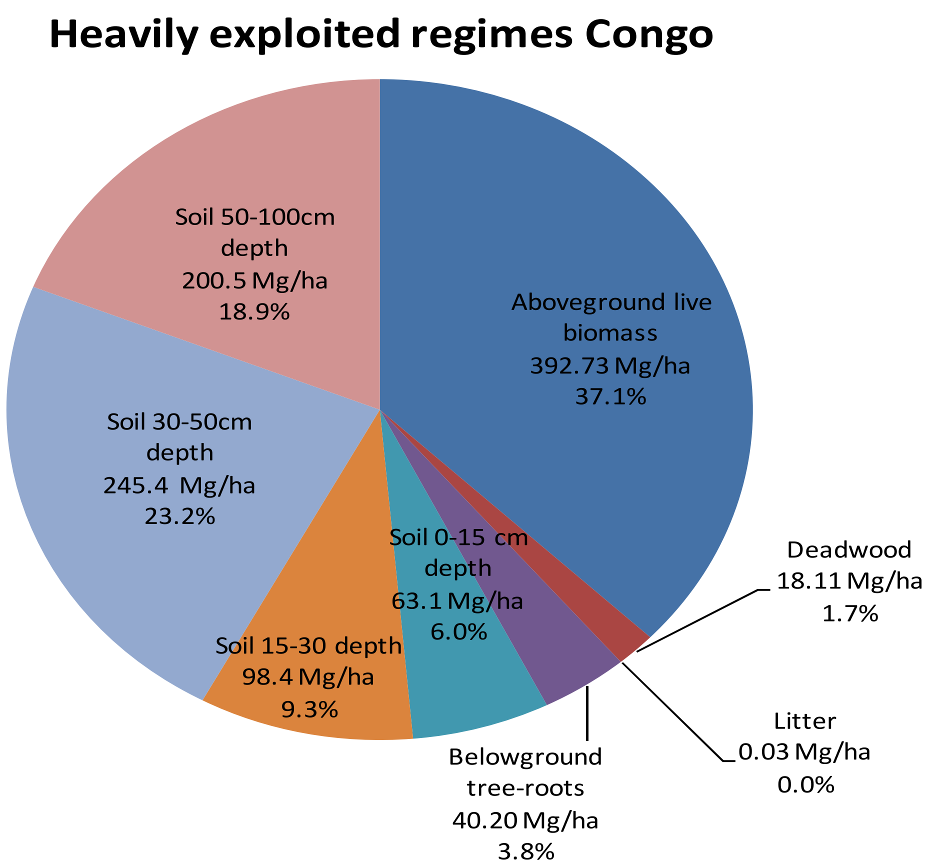
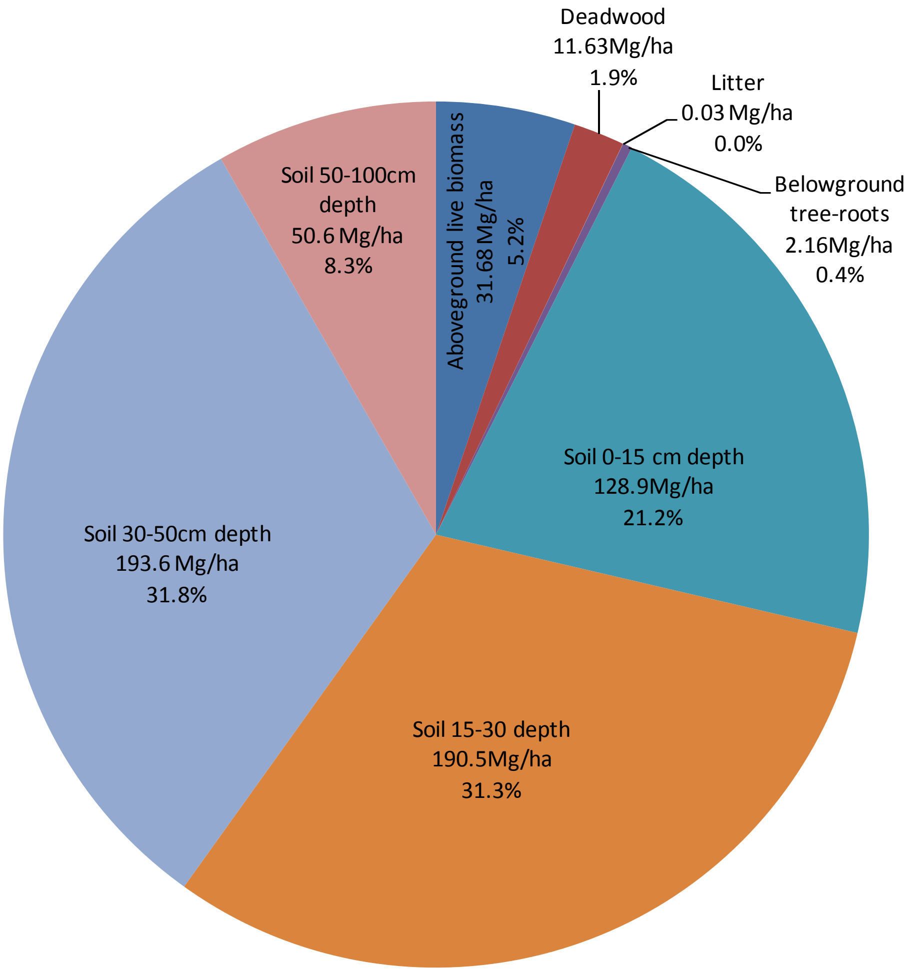


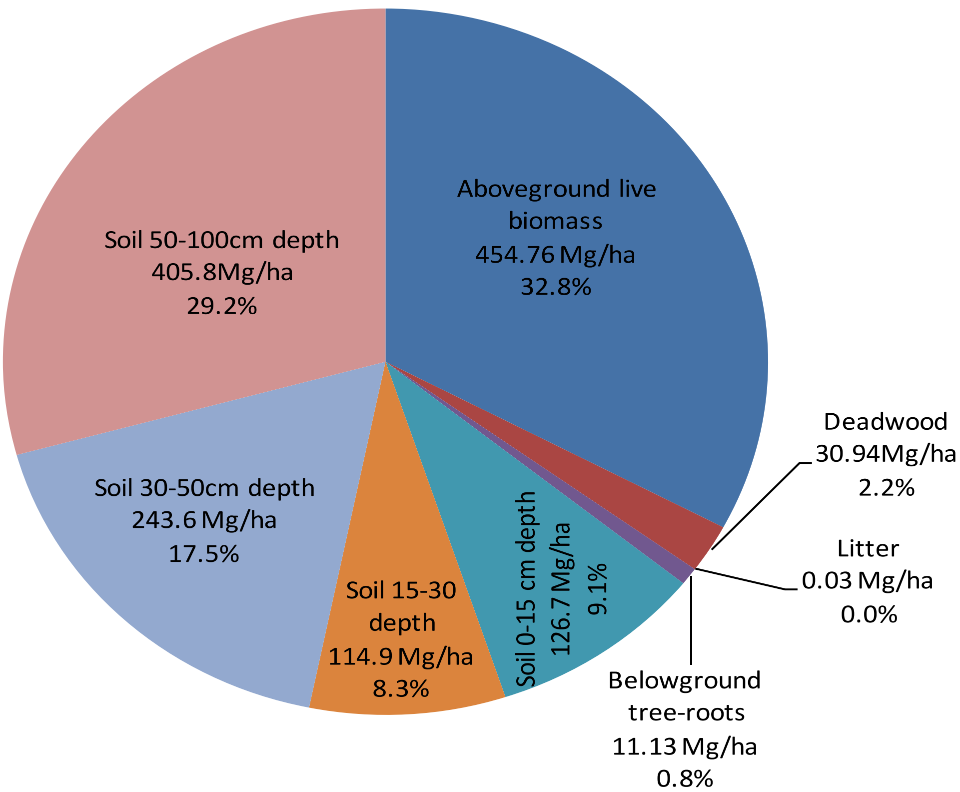
Figure 1c: Location of selected mangrove sites in Congo



Moderately exploited regimes Congo



Undisturbed regimes Congo



DRC

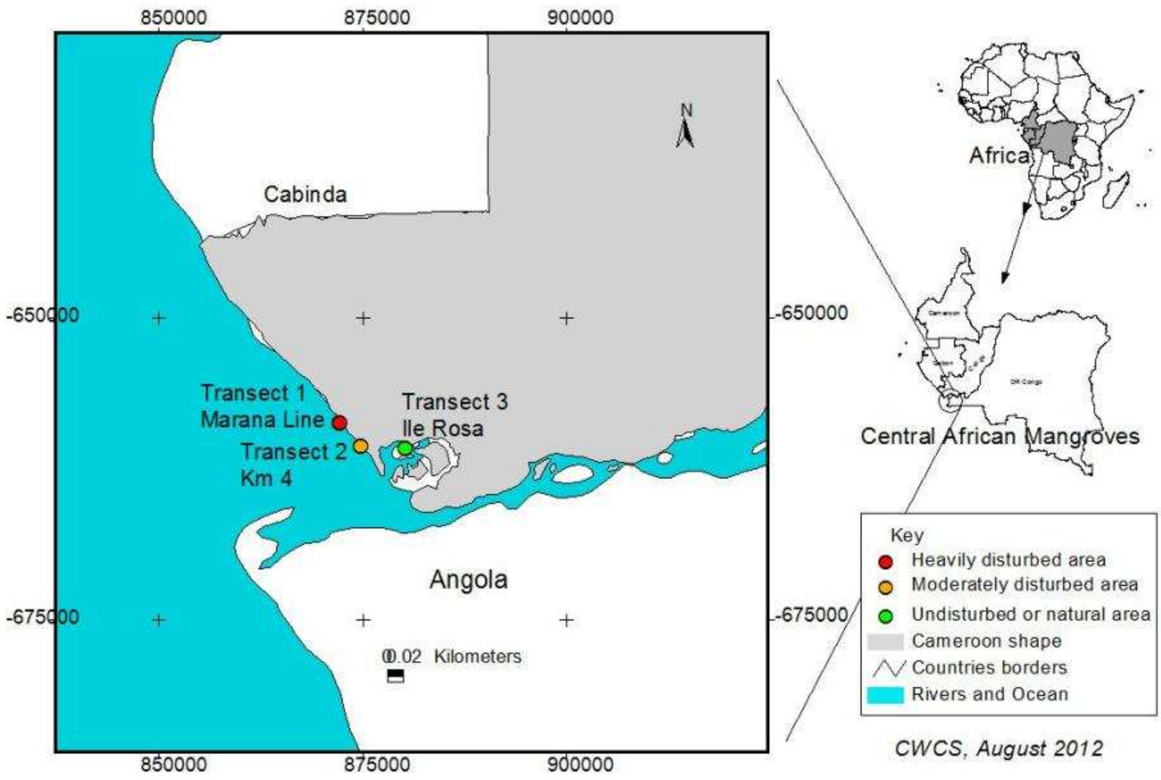
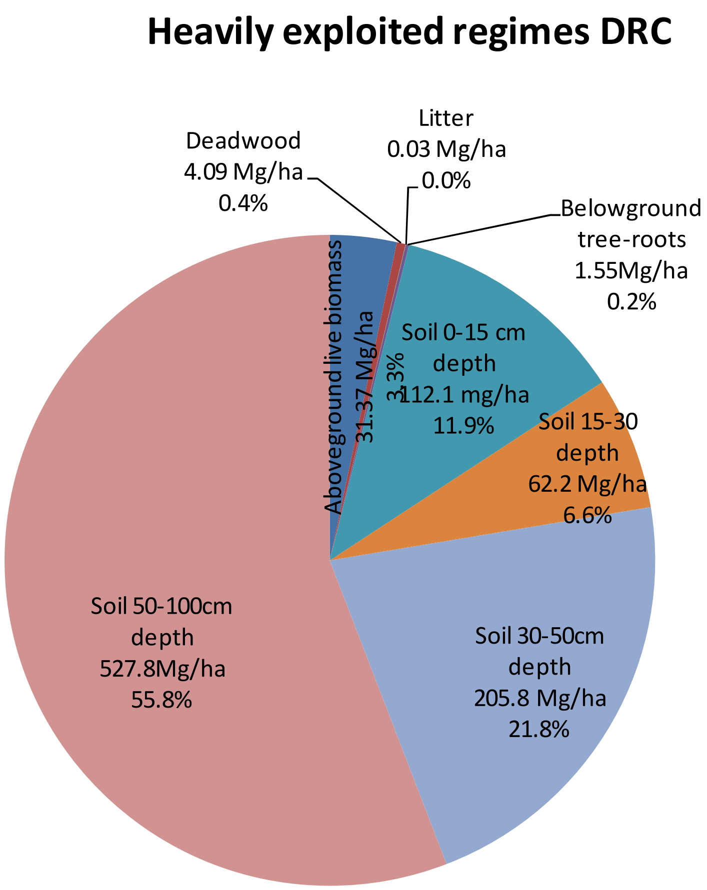
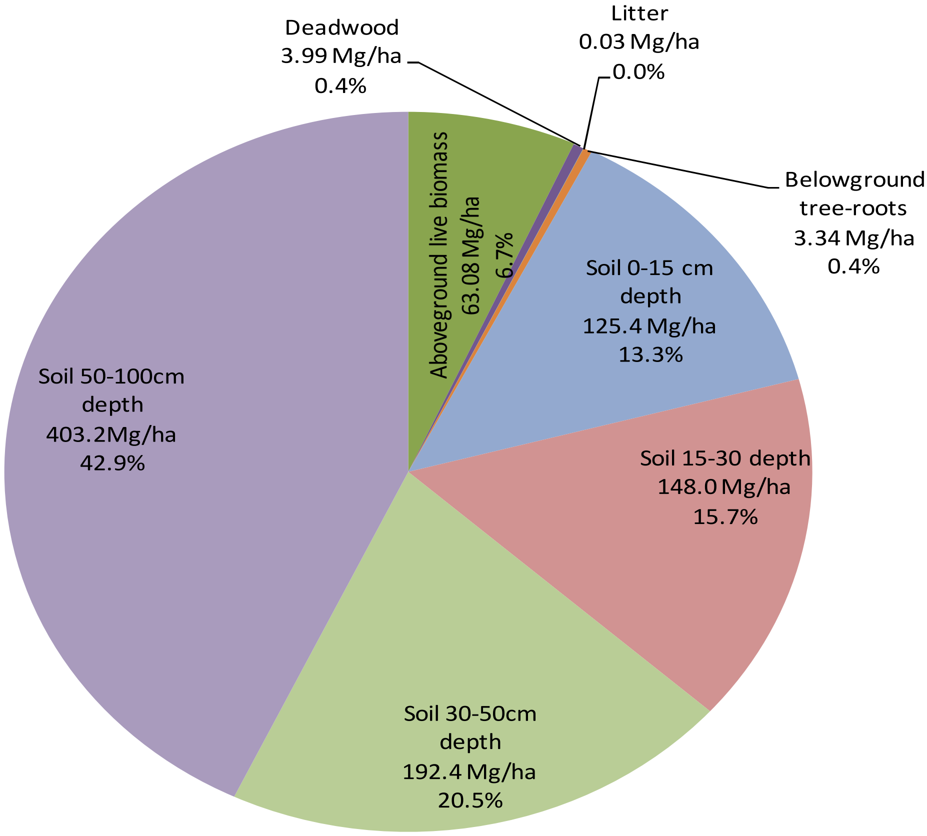


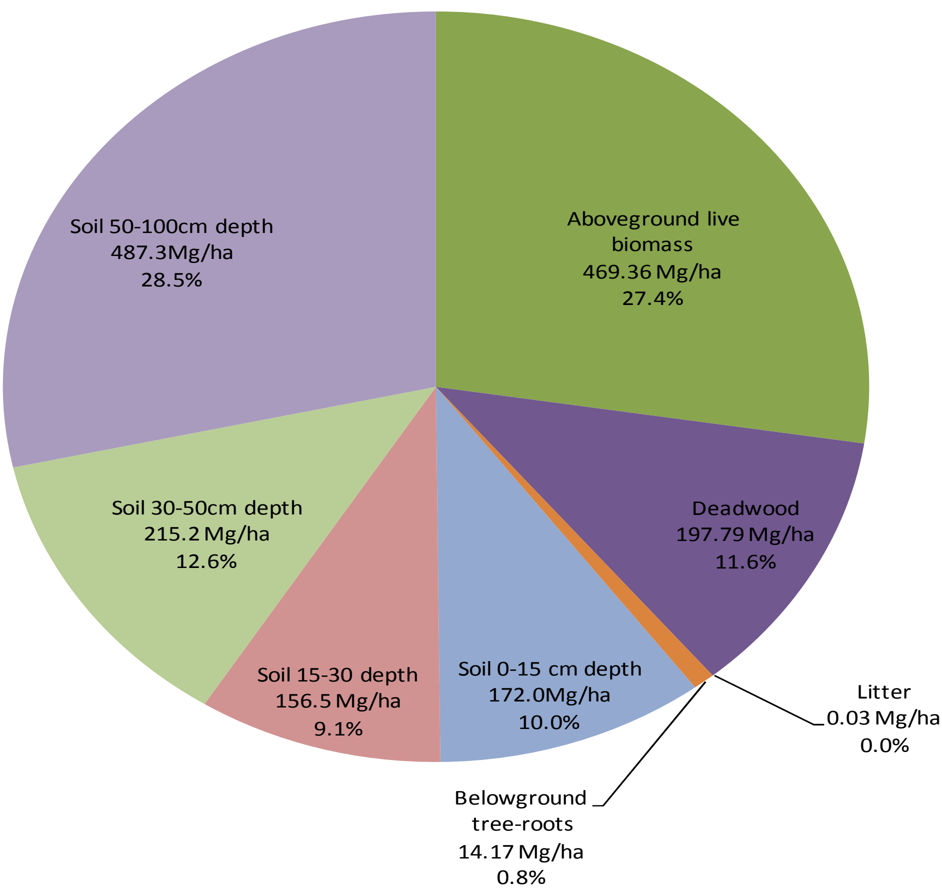
Figure 1d: Location of selected mangrove sites in RDC



Moderately exploited regimes DRC



Undisturbed regimes DRC



Annex III. Other mangrove ecosystem services

Fisheries production in Central African coast from Cameroon to Congo

Country/site/species	Daily production									Yearly production[a]		
	Fresh fish			Smoked/dry fish			Total			Total		
	Quantity (Kg)	Total price/ha (Fcfa)b	Std Error (Fcfa)	Quantity (Kg)	Total price/ha (Fcfa)	Std Error (Fcfa)	Quantity (Kg)	Total price/ha (Fcfa)	Std Error (Fcfa)	Quantity (tonnes)	Total price/ha (Fcfa)	Std Error (Fcfa)
Cameroon												
Region du littoral (Base navale, Song Ngonga)												
Bar/Bar *Pseudotolithus* sp	7.0	1 568					7.0	1 568		2.0	457 856	-
Brochet/ Pikes *Hepsetus odoe*	14.0	9 408					14.0	9 408		4.1	2 747 136	-
Capitaine/Captain *Lates niloticus*	5.0	1 000					5.0	1 000		1.5	292 000	-
Carpe/Carp *Barbodes* sp	0.0	504					0.0	504		0.0	147 168	-
Crevette/ Shrimps *Panaeus* sp	2.0	120	36	1	88	36	3.0	208	120	0.9	60 736	35 066
Dorade/ Sea beam *Coryphaena hippurus*	7.0	1 764					7.0	1 764	667	2.0	515 088	194 685
Ethmalosa/Bonga *Ethmalosa fimbriata*				25	4 020	1990	25.0	4 020	804	7.3	1 173 840	234 768
Machoiron/ Catfish *Arius* sp	11.0	2 904					11.0	2 904	876	3.2	847 968	255 672
Sole/ Sole *Cynoglossis* sp	4.0	768					4.0	768	384	1.2	224 256	112 128
Total Region du littoral	**50.0**	**18 036**	**973**	**26**	**4 108**	**991**	**76.0**	**22 144**	**2540**	**22**	**6 466 048**	**741 707**
Average Cameroon	**50.0**	**18 036**	**973**	**26**	**4 108**	**991**	**76.0**	**22 144**	**2540**	**22**	**6 466 048**	**741 707**
Gabon										0	-	-
Province de l'Estuaire, commune de Coco-Beach (Emone										0	-	-
Sardinelle/Clupeids *Sardinella* sp	290.0	256 667	1291				290.0	256 667	15072	85	74 946 667	4 401 020
Total Province de l'Estuaire, commune de Coco-Beach	**290.0**	**256 667**	**1291**				**290.0**	**256 667**	**15072**	**85**	**74 946 667**	**4 401 020**
Province de l'Estuaire, commune de Libreville (Ambowe)										0	-	-
Bar/Bar *Pseudotolithus* sp	15.0	1 350					15.0	1 350	349	4	394 200	101 782
Crevette/ Shrimps *Panaeus* sp	30.0	4 000	1750				30.0	4 000	730	9	1 168 000	213 247
Mulet/Mullet *Liza* sp	17.0	1 156					17.0	1 156	280	5	337 552	81 868
Sardinelle/Clupeids *Sardinella* sp	22.0	976	88				22.0	976	208	6	284 992	60 760
Total Province de l'Estuaire, commune de Libreville	**84.0**	**7 482**	**531**				**84.0**	**7 482**	**816**	**25**	**2 184 744**	**238 375**
Average Gabon	**374.0**	**132 074**	**2769**				**374.0**	**132 074**	**6829**	**109**	**7 713 141**	**1 994 185**
Congo										0	-	-
Département de Pointe Noire (Louaya)										0	-	-
Carpe/Carp *Barbodes* sp	30.0	266	5				30.0	266	49	9	77 672	14 181
Crabe/ Crab *Cardisoma* sp	7.0	21	1				7.0	21	8	2	6 132	2 318
Mulet/Mullet *Liza* sp	70.0	1 561	87				70.0	1 561	187	20	455 812	54 480
Sardinelle/Clupeids *Sardinella* sp				23	324	15	23.0	324	68	7	94 608	19 727
Silure/Catfish *Clarias gariepinus*	28.0	366	27				28.0	366	69	8	106 872	20 197
Total Département de Pointe Noire	**135.0**	**2 214**	**32**	**23**	**324**	**15**	**158.0**	**2 538**	**202**	**46**	**741 096**	**58 958**
Département du Kouilou (Parc National de Concuati)										0	-	-
Carpe/Carp *Barbodes* sp	60.0	8 820	646	1	250		61.0	9 070	1161	18	2 648 440	339 098
Crevette/ Shrimps *Panaeus* sp	3.0	395	163	0.5	120		3.5	515	275	1	150 380	80 381
Machoiron/ Catfish *Arius* sp	24.0	3 440	40	4	4 000		28.0	7 440	1406	8	2 172 480	410 560
Mulet/Mullet *Liza* sp	17.0	2 680	1220	3	1 000	300	20.0	3 680	823	6	1 074 560	240 279
Sardinelle/Clupeids *Sardinella* sp	0.5	9		14	6 000	840	14.5	6 009	1578	4	1 754 555	460 769
Total Département du Kouilou	**104.5**	**15 344**	**358**	**22.5**	**11 370**	**649**	**127.0**	**26 714**	**2370**	**37**	**7 800 415**	**692 175**
Average Congo	**239.5**	**8 779**	**155**	**45.5**	**5 847**	**433**	**285.0**	**14 626**	**866**	**83**	**4 270 756**	**252 978**
General Average	**663.5**	**158 889**	**1136**	**71.5**	**9 955**	**390**	**735.0**	**168 844**	**6228**	**215**	**49 302 509**	**1 818 550**
DRC*												
Capitaine/Captain *Lates niloticus*										7	1 440 000	
Catfish/*Chrysichtys* sp										2	360 000	
Malemfu										4	720 000	
Orphies/*Strongylura senegalensis*										3	500 000	
Others										21	4 180 000	
Average DRC										**36**	**7 200 000**	
General Average	**663.5**	**158 889**	**1136**	**71.5**	**9 955**	**390**	**735.0**	**168 844**	**6228**	**63**	**6 412 486**	**996 290**

*Sources: OCPE fisheries report 2005 & 2008; Association de Peche de Mouanda (APAMABY personal communication, August 2012)

[a] Based on artisan fishing efforts of 292 days (Gabche, 1997)

[b] 1 US$ = 500 Fcfa

Annex IV. Field data collection sheets

Projet UNEP-REDD Mangroves Central Africa implemented by CWCS

Mangrove Permanent Sample Plots /*Placettes Permanentes de Mangroves* Page ____ / ____

Sheet /*Fiche* N°1: Tree Inventory / *Inventaire des arbres* (Main Field enumeration data sheet /*Fiche Principale d'énumération)*

Country *(Pays)* ________________ Village:____________Date:__________Time started *(heure de début)* :_______Time Ended *(heure de fin)* :________

Transect No:____Bearing *(Orientation)* :_____° Plot No *(Placette N°)* :____Subplot No *(Sous placette N°)* ___Subplot size *(Surface de la sous placette*) (m^2, ha): 100m^2 (0.01 ha)

Plot GPS co-ordinates *(Coordonnées GPS de la placette)* :___°___'___" N;____°___'___" Low Tidal cycle/Cycle de marée basse (1)de______à______(2)de______à______

Observer (s) *(Observateurs)* ____

Tree No	Com. name	Coordinates		Code	No of. stems	Stilt root Ht	Stem Diam abv stilt root with Code in small letter/*Diametre de tige hors des racines avec code en lettre minuscule* (cm)																						Other plants/	Problem	Clinometry/*Clinometrie*				Direct	Code description/
Arbre No	*Nom local*	X (m)	Y (m)		*Nbre de Tiges*	*Ht racine* (m)	1° Stem /tige	Cde	1	Cde	2	Cde	3	Cde	4	Cde	5	Cde	6	Cde	7	Cde	8	Cde	9	Cde	10	Cde	*Autres plantes associées*	Description	Dist (m)	Grd level/ *Debut racine* (%)	Crwn Pt/ *Debut brnches* (%)	Tt Ht/ *Cime* (%)	Total Ht (m)	*Description du code*
																																				M: Multiple stems/
																																				Tiges multiples
																																				L: Stem leaning/
																																				Arbre penché
																																				S: Last stilt root
																																				inaccessable
																																				thus measurement
																																				from next accessible
																																				stilt root or from
																																				alternative height/
																																				Dernier racine
																																				inaccessable
																																				donc mésure au
																																				niveau de la
																																				suivante ou à une
																																				hauteur alternative
																																				H: Tree for height
																																				measurement/
																																				mésure de la
																																				hauteur
																																				Y: Stem prostrate/
																																				Tige couchée
																																				P: Problem
																																				requiring further attention/
																																				Problème requérant plus
																																				d'attention
																																				O: Others (please
																																				specify)/Autres (specifier)

Projet UNEP-REDD Mangroves Central Africa implemented by CWCS
Mangrove Permanent Sample Plots *(Placettes Permanentes de Mangroves)*

Page ____ / ____

Sheet /*Fiche* N°2: Tree Mapping *(Micro cartographie des arbres)*
Country *(Pays)* __________________Village:______________Date:__________Time started *(heure de début)* :______Time Ended *(heure de fin)* :_______
Transect No:______Bearing *(Orientation)* :_______° Plot No *(Placette N°)* :_____Subplot size *(Surface de la sous placette*) (m2, ha): 100m² (0.01 ha)
Plot GPS co-ordinates *(Coordonnées GPS de la placette)* :____°____'____" N;____°____'____" E

Observer (s) *(Observateurs)* ____

Observer (s)____

Subplot No_____

Y	1	2	3	4	5	6	7	8	9	10
10										
9										
8										
7										
6										
5										
4										
3										
2										
1										
X	1	2	3	4	5	6	7	8	9	10

Subplot No_____

Y	1	2	3	4	5	6	7	8	9	10	
10											10
9											9
8											8
7											7
6											6
5											5
4											4
3											3
2											2
1											1
X	1	2	3	4	5	6	7	8	9	10	

Projet UNEP-REDD Mangroves Central Africa implemented by CWCS
Mangrove Permanent Sample Plots *(Placettes Permanentes de Mangroves)*
Sheet /*Fiche* N°3: Seedlings Inventory (in 15 square quadrats of 1m²) /
Inventaire des plants (dans 15 Carrés de 1m²)
Country *(Pays)* ___________________ Village:_______________Date:_____________ Page ____ / ____
Plot GPS co-ordinates *(Coordonnées GPS de la placette)* :____°____'____" N;____°____'____" E
Observer (s) *(Observateurs)* ____

Transect N°	Plot N° *(Placette N°)*	Sub plot N° *(Sous placette N°)*	Square quadrat N° *(Carré N°)*	Species *(Espèces)*	N° of living seedlings *(Nb de plants vivants)*	N° of dead seedlings *(Nb de plants morts)*	Middle diameter *(diamètre central)* (cm)	General seedlings height *(Taille générale des plants)* (m)

Projet UNEP-REDD Mangroves Central Africa implemented by CWCS
Mangrove Permanent Sample Plots *(Placettes Permanentes de Mangroves)*
Sheet /*Fiche* N°4: Roots Inventory (in 15 square quadrats of 1m^2) /
Inventaire des racines (dans 15 Carrés de 1m^2)
Country *(Pays)* ________________ Village:____________Date:___________ Page ____ / ____
Plot GPS co-ordinates *(Coordonnées GPS de la placette)* :____°____'____" N;____°____'____" E
Observer (s) *(Observateurs)* ____

Transect N°	Plot N° *(Placette N°)*	Sub plot N° *(Sous placette N°)*	Square quadrat N° *(Carré N°)*	Species *(Espèces)*	N° of living roots *(Nb de racines vivantes)*	N° of dead roots *(Nb de racines mortes)*	Middle diameter *(diamètre central)* (cm)	General roots height *(Taille générale des racines)* (m)

Projet UNEP-REDD Mangroves Central Africa implemented by CWCS
Mangrove Permanent Sample Plots *(Placettes Permanentes de Mangroves)*
Sheet /*Fiche* N°5: Dead wood Inventory *(Inventaire du bois mort)*
Country *(Pays)* ________________ Village:___________Date:___________ Page ____ / _
Plot GPS co-ordinates *(Coordonnées GPS de la placette)* :____°____'____" N;____°____'____" E
Observer (s) *(Observateurs)* ____

Transect N°	Interval N° *(Intervalle N°)*	Plot N° *(Placette N°)*	Sub plot N° *(Sous placette N°)*	Standing dead wood? *(Bois mort débout?)*		Species *(Espèces)*	diameter (diamètre) (cm)	Height *(Taille)* (m)
				Oui	Non			

Projet PNUE d'Evaluation des bénéfices multiples de l'écosystème de Mangroves dans le bassin du Congo implémenté par CWCS

…………………………………………………………….

Sheet /*Fiche* N°6: Evaluation of multiple benefits of mangrove ecosystems/
Evaluation des bénéfices multiples de l'écosystème de mangroves

Termes de références des enquêtes

INTRODUCTION

Dans le carde du Projet PNUE d'évaluation des bénéfices multiples de l'écosystème de Mangroves dans le bassin du Congo, il est prévu une phase d'enquêtes socio-économiques. L'objectifétantd'évaluer :

- le service de protection de mangroves contre l'érosion
- le service de protection des espèces de poissons de mangroves
- le service de fourniture du bois de chauffe de mangroves
- le service de tourisme dans les mangroves

METHODOLOGIE

Les enquêtes devraient être réalisées avec une méthodologie préétablie comme suit :

1. Les services de protection de mangroves contre l'érosion

- Méthode de replacement : inventaire et coût des maisons et infrastructures sur une bande de 500m à partir des mangroves
- La collecte des données sur les types de localités (Villes, Villages, Campements de pêche, etc.)
- La collecte des données sur les types de maisons (En paille, en bois, en dur, en étage, etc.)
- La collecte des données sur les types d'infrastructures (Routes, électricité, points d'eau, etc.)
- Méthode d'évaluation des coûts subis par l'incidence des inondations, et autres catastrophes naturelles autour des zones de mangrove à travers les réunions avec les populations.

Pays : ………………………………………………..
Date : ………………………………………………..
Nom de l'(des) enquêteur (s) :……………………………………………………………..
Nom du site :………………………….……… **Dimensions du site :** Longueur max (km) ………. Largeur max (km) ..…….

Type de localité	**Nombre**	**Pop totale**	**Noms (Liste des localités)**	**Types de maisons**	**Nombre de maisons**	**Coûtmoyen par maison**
Campe-ments de pêche				En Paille		
				En bois		
				En dur		
Villages				En Paille		
				En bois		
				En dur		
Villes (Grandesc onstruc-tions)				En Paille		
				En bois		
				En dur simple		
				En dur 1 étage		
				En dur 2 étages		
				En dur 3 étages		
				En dur 4étages		
				En dur + de 4 étages		

Pays : ………………………………………………..
Date : ………………………………………………..
Nom de l'(des) enquêteur (s) :………………………………………………………………..
Nom du site :……………………………….……… **Dimensions du site :** Longueur max (km) ………. Largeur max (km) ..…….

Type de localité	**Types d'infrastructures**		**Unités**	**Quantitéd'unités**	**Coûtmoyen par unité**	**Coût total**
Campements de pêche	Route non bitumée		Km			
	Route bitumée		Km			
	Point d'eau potable		nb			
	Electricité		Km			
	Télécommunications	Ligne	km			
		Antenne	nb			
	Autres …………………….					
Villages	Route non bitumée		Km			
	Route bitumée		Km			
	Point d'eau potable		nb			
	Electricité		Km			
	Télécommunications	Ligne	km			
		Antenne	nb			
	Autres …………………….					
Villes	Route non bitumée		Km			
	Route bitumée		Km			
	Point d'eau potable		nb			
	Electricité		Km			
	Télécommunications	Ligne	km			
		Antenne	nb			
	Autres …………………….					

Questionnaire auprès des pêcheurs

Pays : ………………………………………………..
Date : ………………………………………………..
Nom de l'(des) enquêteur (s) :………………………………………………………………..
Nom du site :……………………………….……… **Dimensions du site :** Longueur max (km) ………. Largeur max (km) ..…….
Nombre total de pêcheurs dans le site ………………………………………..

Identification de Pêcheurs												Date de début d'activités dans le site	Espèces de poissons péchées	Mois d'activités dans l'année (de Jan. à Déc.)	Nbre de mois d'activité	Prises par jour (qnté en nbre de pirogues)	Prises par mois (qnté en nbre de pirogues)	Perception des tendances ↑ ↓ →	Problèmes
No	Nom	Sexe(M/F)	Age (années)	Nationalité	Tel :	Type (motorisée ?) **oui/Non**	Nb. de pirogues	Spécificités de la pirogue			Capacité de la pirogue (en quantité de poisson)								
								Largeur (m)	Longueur (m)	Profondeur (m)									
1																			
2																			

Identification de Pêcheurs												Date de début d'activités dans le site	Espèces de poissonspéchées	Mois d'activité dans l'année (de Jan à Déc.)	Nbre de mois d'activité	Prises par jour (qnté en nbre de pirogues)	Prises par mois (qnté en nbre de pirogues)	Perception des tendances	Problèmes
No	Nom	Sexe(M/F)	Age (années)	Natio-nalité	Tel :	Type (motorisée ? **oui/Non**	No. depirogues	Spécificités de la pirogue			Capacité de la pirogue (en quantité de poisson)								
								Largeur (m)	Longueur (m)	Profondeur (m)									
1																			

Quelques observations supplémentaires sur la pêche :

Field data processing

An example of Excel spreadsheet used forrecording data from permanent sample plots (after Ajonina, 2008)

I. Main Data Sheet

Zone	Village/Site	Tsc	Plot No	SubPlot No	X	Y	Tree No	Com. name	Stems(1)	Stems(2)	Stems(3)	Code(1)	Code(2)	Code(3)	SR-Ht	D(1)	D(2)	D(3)	Otherplts(1)	Otherplts(2)	Otherplts(3)
1	Youmè	1	1	1	0.9	0.2	1	wm	6	6	3	M	MTH	Md	1.30	27.2	28.3	28.6			
1	Youmè	1	1	1	1.8	0.5	2	wm	2	2	2	M	MTHPomr	M	1.30	25.5	25.6	26.4			
1	Youmè	1	1	1	2.5	4.7	3	wm	1	1	1				1.30	1.1	1.3	1.5			
1	Youmè	1	1	1	2.7	4.3	4	wm	3	1	1	M	Dd		1.30	2.9	0.0	0.0			
1	Youmè	1	1	1	4.8	5.2	5	wm	2	1	1	M	d	d	1.30	2.8	2.8	3.8			
1	Youmè	1	1	1	4.1	5.8	6	wm	4	3	3	M	MdH	Md	1.30	6.7	7.1	7.4			
1	Youmè	1	1	1	3.5	5.6	7	wm	2	3	2	M	MTH	M	1.50	1.2	1.3	0.0			
1	Youmè	1	1	1	0.2	5.4	8	wm	8	6	5	M	MHd	MTd	1.30	3.5	3.7	4.5			

D (1) = Dbh during measuring year 1, D (2) = Dbhduring measuring year 2, etc stem (1) = Nr of stems year 1, etc other plants (1) = other plants associated measuring year 1, etc TSC 1=heavy exploited, TSC 2=moderately exploited, TSC 3= Undisturbed

II. Multi-stemmed Tree Data Sheet

Zone	Village/Site	Tsc	Plot No	SubPlot No	Tree No	Species	BrNo(1)	D-br(1)	BrNo(2)	D-br(2)	BrNo(3)	D-br(3)
1	Youmè	1	1	1	1	wm	0	27.2	0	28.3	0	28.6
1	Youmè	1	1	1	1	wm	1	1.5	1	1.6	1	1.7
1	Youmè	1	1	1	1	wm	3	1.3	3	2.4	3	2.8
1	Youmè	1	1	1	1	wm	2	1.1	2	1.2	d3	0.0
1	Youmè	1	1	1	1	wm	4	1.2	4	1.4	d3	0.0
1	Youmè	1	1	1	1	wm	5	8.5	5	8.6	d3	0.0
1	Youmè	1	1	1	2	wm	0	25.5	0	25.6	0	26.4
1	Youmè	1	1	1	2	wm	1	8.5	1	9.6	1	9.4
1	Youmè	1	1	1	4	wm	1	1.0	1	2.1	1	2.8
1	Youmè	1	1	1	4	wm	0	2.9	D02	0.0	D02	0.0
1	Youmè	1	1	1	4	wm	2	1.1	d2	0.0	d2	0.0
1	Youmè	1	1	1	5	wm	0	2.8	0	2.8	0	3.8
1	Youmè	1	1	1	5	wm	1	1.4	d2	0.0	d2	0.0
1	Youmè	1	1	1	6	wm	0	9.7	0	7.1	0	7.4
1	Youmè	1	1	1	6	wm	1	3.3	1	5.3	1	5.7
1	Youmè	1	1	1	6	wm	2	2.2	d2	0.0	d2	0.0
1	Youmè	1	1	1	6	wm	3	1.3	d2	0.0	d2	0.0
1	Youmè	1	1	1	7	wm	1	1.3	1	1.3	1	1.4
1	Youmè	1	1	1	7	wm	e1	0.0	2	1.2	2	1.7
1	Youmè	1	1	1	7	wm	0	1.2	0	1.3	D03	0.0

BrNo (1) = Branch Nr, during measuring year 1, BrNo (2) = Branch Nr during measuring year 2, etc BrNo0=main stem .BrNo1, 2, 3.... Are consecutive secondary stems from main stem