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*Full Length Research Paper*

# **Source predictions of polycyclic aromatic hydrocarbon (PAHs) concentration in water, sediment, and biota (FISHES) from Ethiope River, Delta State, Southern Nigeria**

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**This study was carried out to predict the source of the sixteen priority polycyclic aromatic hydrocarbon (PAH) compounds in water, sediment, and biota samples from River Ethiope, Delta State, Southern Nigeria. The samples were extracted using soxhlet extraction and analysed with GC/FID. Results obtained for total concentration of the sixteen priority PAHs ranges from 0.185 to 3.679 mg/kg (sediment), 0.000 to 27.353 µg/l (water), and 0.053 to 6.060 µg/kg (biota samples). The result indicated that the concentration level in the water, sediment, and biota are considerably low. Although the PAH were below the USEPA standard, the observed levels can cause adverse effects for lower dwelling aquatic organisms, which are exposed to the sediments daily. Therefore, persistent monitoring and strict adherence to responsible waste discharge should be upheld by all manufacturing and agro-industries in the catchment of the river to avoid deleterious effects on biodiversity and to ensure the safety of the consumers. From the source prediction, the results obtained show the sources are quite similar across the sample sites. This is an indication that the PAHs in the water samples are mostly of pyrogenic origin, except the water samples from Abraka site 2, which are petrogenic. All river sediment samples show pyrogenic origins.**

**Keywords:** Source prediction, polycyclic aromatic hydrocarbons (PAHs), combustion, River Ethiope.

## **INTRODUCTION**

Polycyclic aromatic hydrocarbons (PAHs) are a class of ubiquitous organic compounds consisting of two or more fused aromatic rings. They are mostly hydrophobic and are capable of bio-accumulating in animal and human

tissues (Zheng et al., 2007). PAH is one of the several pollutants released into the environment during crude oil exploration and production. However, studies have revealed that there are also natural sources of PAHs

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(Abdel-Shafy and Monsour, 2016). Other sources of PAHs are from pyrolytic activities involving industrial and commercial burning of fuel or hydrocarbons in oil, certain cooking practices such as broiling of food over charcoal, frying and smoking (Teaf, 2008; Bayowa and Agbozu, 2016). PAHs from pyrolytic sources are produced due to incomplete combustion and have been shown to be a major source of PAHs intake by humans (European Food Safety Authority, 2008).

PAHs, which are classified as persistent organic pollutants commonly occurring in the environment are considered one of the most challenging organic contaminants to remediate (Edwards, 1983; Cerniglia, 1992; Weissenfels et al., 1992). This may be due to their toxic, mutagenic and carcinogenic properties; they pose a significant environmental risk to public health (Chen and Liao, 2006; Mekuleyi et al., 2018). The partitioning behaviour of PAHs between water, sediments, particulate, and dissolved organic material has been documented and severally predicted (Cornelissen et al., 2006). The toxicity of polycyclic aromatic hydrocarbons (PAHs) and their widespread distribution has led to more interest in the presence of these compounds in the aquatic and terrestrial environment (Aderemi et al., 2003).

In recent times, the water quality in water bodies in areas of industrial activities is to a great extent adversely affected by build-up of traffic-generated organic compounds on road surfaces, leading to their presence in water runoff and sediments. The accumulation of PAH metabolites is more toxic than the parent compound as stated by Christensen et al. (1997) and Nwineewii and Ibok (2014). Although largely insoluble in water, some of them are soluble and dissolve in water and sorb into groundwater from ash, tar or creosote improperly disposed of landfills. Waste products containing significant amounts of PAHs are indiscriminately dumped into water, on land or buried at subsurface sites. Airborne particulates resulting from PAHs activities are transported in the atmosphere and are usually deposited in soils and sediments of the aquatic system (Christensen et al., 1997; Christensen and Bzdusek, 2005; Nwineewii and Ibok, 2014). In general, PAHs dissolved in pure water are accumulated in sediments, and these sediments which surround the biota may play an important role in the uptake of PAHs by some species. The fraction of freely dissolved PAHs is usually assumed to be readily available for uptake by organisms.

When PAHs enter into an aquatic environment, they may remain in water or accumulate in organisms and migrate as water flows. Meanwhile, sediment acts as a local scale collector for environmental contaminants (Froehner et al., 2018; Cardoso et al., 2019). PAHs adsorbed on the sediment would be retained in sediment for a long time or released into water columns causing secondary pollution. Therefore, it is quite necessary to routinely monitor concentration levels of PAHs in an aquatic environment and evaluate their potential risks

(Olalekan et al., 2014). It is therefore necessary to assess the source of PAHs in the biota as their bioaccumulation in aquatic biota could serve as a good indication of pollution problems in the lagoon (Mitra et al., 1999).

The main aim of this study was to predict the source and assess the level of PAHs in water, sediment and biota (fishes) from River Ethiope in the Niger Delta region of Southern Nigeria.

## MATERIALS AND METHODS

### Study area

The study area was River Ethiope in the Niger Delta area of Delta State, Nigeria, which is the second largest Delta in the world and the largest mangrove swamps in Africa. It spans over 20,000 km<sup>2</sup>. The Niger Delta region is located at latitudes 5°31'N and 5°33'N and longitudes 5°30'E and 5°32'E. The Niger Delta covers an area of 70,000 km<sup>2</sup> of marshland, creeks and tributaries that drains the River Niger into the gulf of Guinea in the Atlantic Ocean. The coastal region cuts across nine (9) states in Southern Nigeria. This region has an estimated population of over 30 million people, with fishing and farming as the primary source of livelihood and sustenance. Economic activities include oil and gas exploration and exploitation, fishing industries, agriculture and tourism.

### Sampling

Samples were collected across Ethiope River along its bank at six different locations as shown in Figure 1. A total of six samples each of water and sediment were collected, while four fish samples of two different species were collected at each location making a total of twenty four from the different sampling locations.

### Water samples

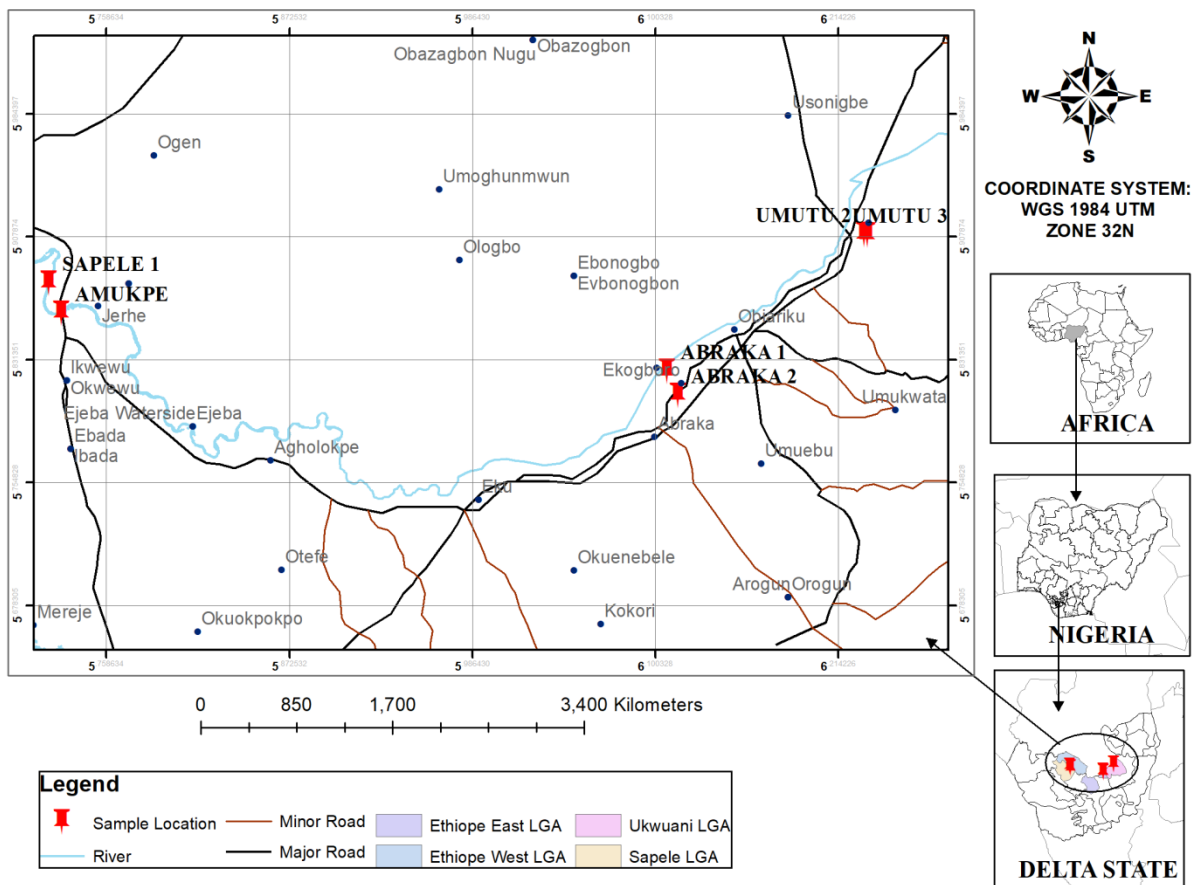
The grab sampling technique was employed for the collection of all the water samples at about 1 m below the surface using a 1.0 L amber bottle. The samples were collected and then stored in an ice chest and later moved to the laboratory, and then kept at <4°C until further analysis.

### Sediment samples

Sediment samples were collected from the same locations as water samples. Wet sediment samples were collected in the river bed with a Petite Ponar Grab sampler. Samples were put in clean glass bottles and kept in an ice chest during transportation, and then kept at <4°C in the laboratory while awaiting sample preparation and analysis.

### Fish samples

Fish samples of African Sharptooth catfish (*Clarias gariepinus*) and Redbelly Tilapia (*Tilapia zilli*) were purchased at each sampling location from fishermen. The samples were immediately kept in pre-cleaned polythene bags, which were sealed and stored in an ice box until further analysis. The samples were identified in the Department of Environmental Management and Toxicology, FUPRE, Delta State, Nigeria.



**Figure 1.** Map showing the sampling areas in River Ethiopia.

### Extraction of samples

The process of sample extraction in this study is similar to the extraction process carried out by Mekuleyi et al. (2018). As stated subsequently.

### Extraction and fractionation of PAHs in water samples

A total of 250 ml each of the water sample was transferred into a separating funnel. The pH was adjusted to <math>< \text{pH } 2</math>. The solution was then extracted twice with 15 ml methylene chloride. The extract was dried with 5 g anhydrous sodium sulphate and concentrated to 1 ml in a rotary evaporator. The concentrate was fractionated, first eluted with 10 ml hexane, and collected as aliphatic fraction, followed by elution with 15 ml methylene chloride, and collected as aromatic fraction. Both fractions were concentrated to 1 ml, capped in GC vials and stored in a refrigerator until analysis.

### Extraction and fractionation of sediment samples

Sediment samples were air-dried for 3 days and sieved with 0.5 mm mesh sieves (Ogunfowokan et al., 2003; Olalekan et al., 2014). A total of 10 g of the sediment sample was blended with 10 g of anhydrous sodium sulphate. The mixture was placed in an extraction thimble and refluxed for 4 h with 50 ml methylene chloride. Thereafter the solution was cooled, dried with 5 g

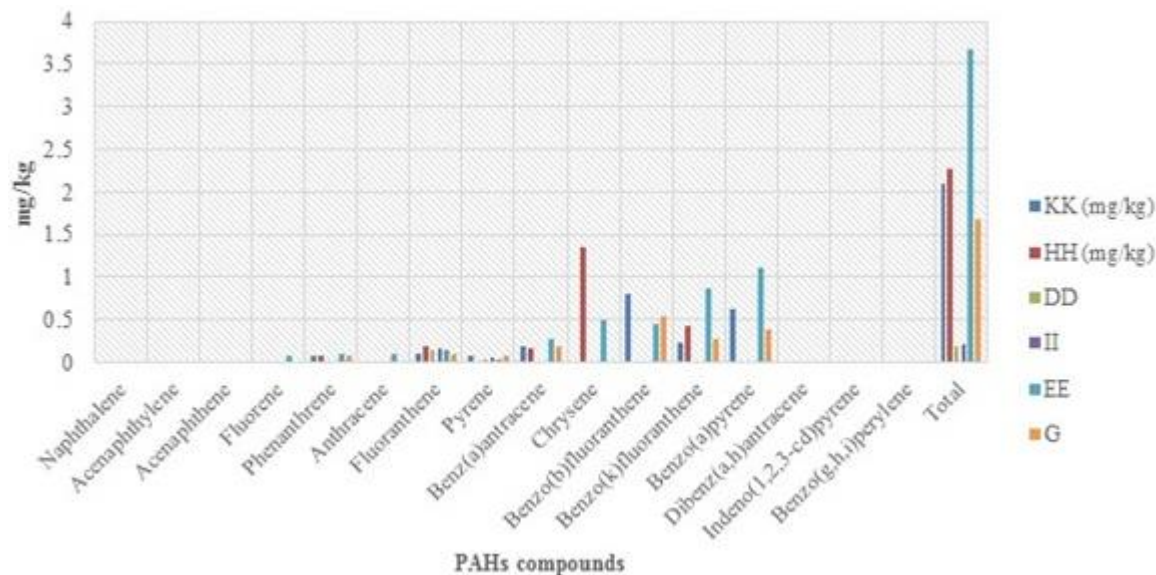
anhydrous sodium sulphate, and concentrated to 1 ml in a rotary evaporator. The concentrate was fractionated over silica gel column, first eluted with 10 ml hexane and collected as an aliphatic fraction, and then with 15 ml methylene chloride, and collected as aromatic fraction.

### Extraction and fractionation of fish samples

The fish sample was homogenized using a blender. A 2 g portion of each sample of the homogenate was saponified with 200 ml methanol/KOH (12% KOH in 95% methanol) solution in an ultrasonic bath at 60°C, for 30 min. The sample was cooled and filtered through glass wool into a separatory funnel. The filtrate was extracted twice with 100 ml hexane. The extract was washed with methanol/water (4:1) mixture, and then concentrated to 1 ml with a rotary evaporator. The concentrate was fractionated through a silica gel column, first eluted with 10 ml hexane to collect the aliphatic hydrocarbon fraction, and then with 15 ml methylene chloride to collect the aromatic hydrocarbon fraction. Both fractions were concentrated to 1 ml, capped in GC vials and stored.

### Analysis of samples

Analysis was done using Gas Chromatography coupled with FID (Thermo Scientific-Trace GC Ultra). A 2  $\mu\text{l}$  of the concentrated sample was injected by means of Hamilton micro syringe through



**Figure 2.** Distribution of specific PAHs compounds in various sediment samples.

rubber septum into the column. Separation occurs as the vapour constituent partition between the gas and stationary phases. The sample is automatically detected as it emerges from the column by a Flame Ionisation Detector FID. PAH quantification was carried out by CLARITY-GC interfaced software.

## RESULTS AND DISCUSSION

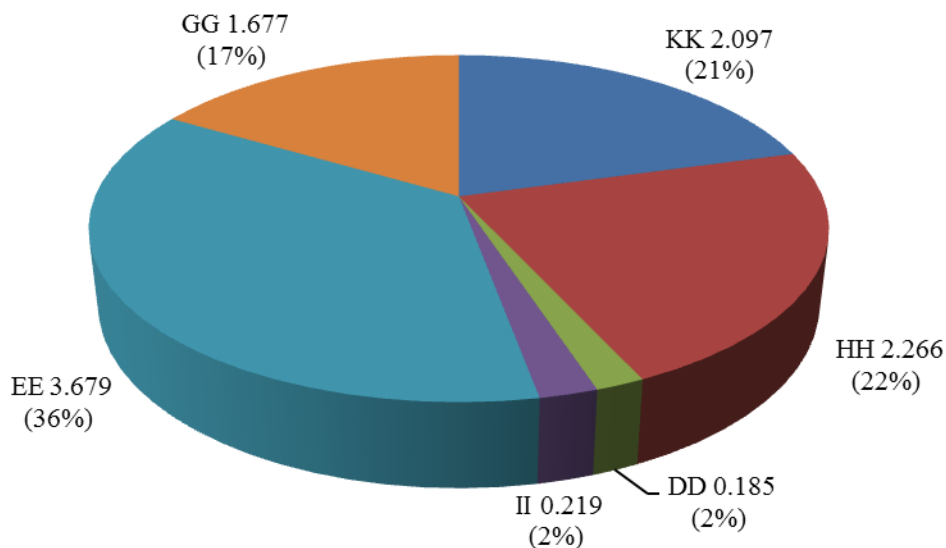
The results obtained from the analysis of the various PAHs concentration in water and sediment from River Ethiopie are as shown in Figure 2.

On the individual basis of the compound of PAHs analysed, it was observed that a good number of compounds were not detected (ND), which indicates either absence or that they were below the detection levels for each sample according to the instrument of detection used (Figure 2).

From the results obtained, six out of the sixteen PAHs compounds were found to be undetected (ND) across all the sampling points. These compounds are Naphthalene, Acenaphthylene, Acenaphthene, benzo (g, h, i) perylene, Indeno (1, 2, 3-cd) pyrene, and Dibenzo (a, h) anthracene. It is observed that 50% of the undetected PAHs are two ringed and three ringed PAHs compounds, which are Naphthalene (two ringed PAHs), Acenaphthylene, Acenaphthene, Anthracene, Phenanthrene and Fluorene (three ringed PAHs compound). They were below the detection limit which is contrary to the study carried out by Mekuleyi et al. (2018), although fluorene and anthracene were present in sample location EE with a concentration of 0.086 and 0.100 mg/kg, but is below the threshold limit of 1.617 mg/kg. Among the three ringed PAHs compounds present in the sediment sample, phenanthrene was the most persistent having a

concentration above detection limit in four sampling locations (KK, HH, EE, and G) with values of 0.089, 0.088, 0.111 and 0.087 mg/kg. At the control point, values for three-ringed PAH could be said to be evenly distributed among the sample locations due to their values. Thus, it could be said that higher ringed PAHs were detected more than lower ringed PAHs in the sampled locations. Due to the presence of other ringed PAHs, it could be deduced that Naphthalene, Acenaphthylene, and Acenaphthene may be present in very low concentration below detection limit or may have been evaporated since they are volatile or degraded by microbial actions of microbes in the sediment, thus cannot not be detected when analysed due to its lower molecular weight when compared with other compound present (Bayowa and Agbozu, 2016). In addition, it could be said to be as a result of volatilisation or biodegradation as these are the major removal process for lower molecular weight PAHs in aquatic environments (Neff et al., 2005; Bayowa and Agbozu, 2016).

The four-ringed PAHs analysed in this study were fluoranthene, chrysene, benzo (a) anthracene and pyrene. Their value ranged from <0.000 to  $\leq 1.358$  mg/kg. Four-ringed PAHs have been classified as semi-volatile compounds and could be said to possess characteristics in between the lower molecular weight and higher molecular weight PAHs (Neff et al., 2005; Bayowa and Agbozu, 2016). Their character however is mostly determined by those of the substrates to which they are attached and the medium (Neff et al., 2005; Bayowa and Agbozu, 2016). Fluoranthene and pyrene are the major PAHs compounds present in all sample locations, with values ranging from 0.104 to 0.179 mg/kg and 0.035 to 0.083 mg/kg, this may be due to their



**Figure 3.** Percentage distribution of total PAHs concentration in the sediment from various sample locations.

unique characteristics. This finding is similar to the study carried out at Limpopo province by Olalekan et al. (2014). Benz (a) anthracene was also present in all sample locations ranging from 0.164 to 0.284 mg/kg, with an exception of sample location DD and II where it was found to be undetected (ND). Chrysene on the other hand was only present at two sample locations (HH and EE) with a value of 1.358 and 0.488 mg/kg, respectively but was below the detection limit in other locations.

Five to six-ringed PAHs and above are classified as the higher molecular weight fractions when compared with other PAHs compounds analysed for this study. Those analysed in this study includes: benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, indeno(1,2,3)cd pyrene and benzo (g, h, i) perylene. Their values ranged from 0.234 to 1.118 mg/kg. Three of these compounds were below the detection limit for all sample locations. Benzo (b) fluoranthene which was detected in three sample locations with values of 0.443 mg/kg (EE), 0.540 mg/kg (GG) and 0.795 mg/kg (KK) which was the maximum concentration in the sediments analysed. A similar result was obtained in EE, GG, and KK for benzo (a) pyrene, with a value of 1.118 mg/kg which is the highest concentration of the five-six ringed PAHs compound, 0.390 and 0.619 mg/kg, respectively.

As shown in Figure 3, the highest percent of PAHs in the sediment was found to be sampling location EE with 36%. HH and KK had a percent of 22 and 21%, respectively, while GG with a 17% was a fourth addition to the total concentration of PAHs compounds present in the sediment of River Ethiope analysed. DD and II which were sparsely distributed to a percent value of 4 and 2%, respectively was of minute contribution to the total concentration observed.

These findings suggest the differences in the natural and anthropogenic activities at the various sampling locations. It could be said that locations with higher concentrations of PAHs may be more contaminated due to industrial and domestic activities in such area (Banan et al., 2018; Olayinka et al., 2018), although they are within threshold limits and may not pose health threat but proper monitoring measures can be put in place in sample locations such as KK, GG, EE and HH, which were observed to be the major contributors of high concentration of poly aromatic hydrocarbons (PAHs). The concentration may increase over time in the sediments which may then pose detrimental effects on biota and humans when they interact with the polluted aquatic environment.

At sample location AW1, total concentration was 0.667 µg/L with only the four member-ringed PAHs compounds found within and above the detection limits (Figure 4). The result obtained at this location were fluoranthene (0.185 µg/L), pyrene (0.065 µg/L), and chrysene (0.417 µg/L), which happens to be the maximum concentration at the location. While other PAHs compounds analysed were below the detection limits. The total concentration of PAHs compounds at sample location UW4 was 6.761 µg/L, having values ranged from 0.071 to 3.453 µg/L. It was observed to have the highest number of PAHs compound analysed from a sample location, with a total number of 11 compounds which cut across two-six ringed PAHs compounds.

From the results obtained, it was observed that the 16 PAHs compounds analysed at sample locations UM3 and AMW were below the detection limits (ND), this may be as a result of the less contaminating human activities around these regions, which includes peasant farm practices, thus making these locations less contaminated



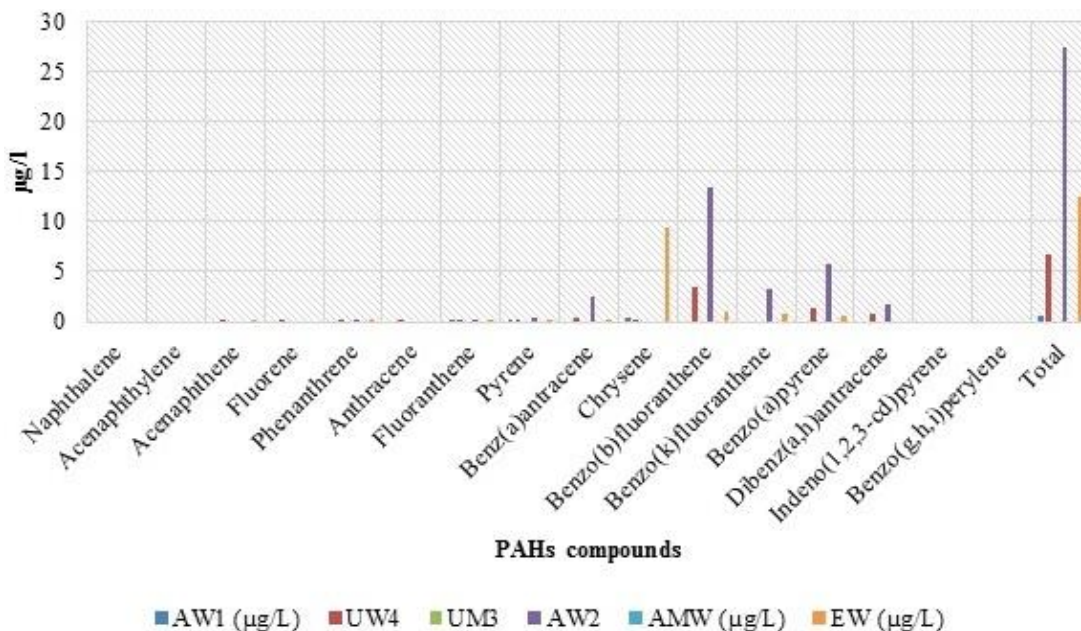


Figure 4. PAHs compounds in various water sampling stations.

(USEPA, 2002; Olayinka et al., 2012). At sample location EW, concentrations of the PAH compounds ranges from 0.096 to 9.375 µg/L and gave a total concentration of 12.487 µg/L. The highest concentration of 9.375 µg/L was chrysene, which happens to be the second maximum concentration of PAHs compounds in all sample sites after benzo(b)fluoranthene (13.438 µg/L), found at sample AW2 location.

Figure 5 shows the total concentrations of PAHs distribution from the various sample locations, with the percentage distribution of the PAHs ( $\Sigma$ PAHs = 100%). The highest percent of PAHs in the water analysed from River Ethiopie is found to be 58% in location AW2. Locations EW and UW4 had a percent of 27 and 14%, respectively, while AW1 with a percent was the fourth addition to the total concentration of PAHs compounds present in the water sample of River Ethiopie. The percentage distribution at sample location AW1 was sparsely distributed in minute quantity to the total concentration observed.

While AMW and UM3 were of no contribution to the total PAHs concentration present in all the sample locations. Thus, the general distribution of PAHs compound in descending order of the water samples across all sample locations can be expressed as AW2 > EW > UW4 > AW1 > AMW=UM3.

### PAH in biota samples

The total concentration of the PAHs in the various sample locations of the two different species of fishes (*C. gariepinus* and *T. zilli*) varies from one location to

another. As shown in Figure 6, there is similarity between the two species.

The occurrence of pollutants in the fish samples depends largely on environmental concentrations of PAH compounds and on the physiology and ecological characteristics of the species (Meador et al., 2006). This could explain the reason for the slight variation of concentrations in the two different species (*C. gariepinus* and *T. zilli*). The total PAH Concentrations reported in this study shows that Abraka 1 had the highest value of 6.06 µg/kg in *T. zilli* while the lowest value of total PAH concentration was at Umutu 1 with a value of 0.053 µg/kg. Total concentration of PAH at Umutu 2, Abraka 2, Amukpe and Sapele in *T. zilli* were 1.492, 3.882, 3.724 and 5.636 µg/kg, while total PAH concentrations in *C. gariepinus* for these locations were 1.995, 2.016, 2.801 and 4.755 µg/kg. The PAH concentration of *C. gariepinus* at Umutu 1 and Abraka 1 had values of 0.756 and 4.218 µg/kg. The results stated here show that the total concentrations of PAH at various locations were generally similar which may be as a result of pollution from related sources. Although the low concentrations indicate no danger to the studied biota samples but may cause risky effects on lower dwelling aquatic organisms and may also lead to bioaccumulation in fish over time.

### Source identification

PAHs can be used as anthropogenic geochemical tracers and are used to identify the origins of pollutants (Olalekan et al., 2014). The sources of PAHs are widely considered to be very important for studying the transportation and

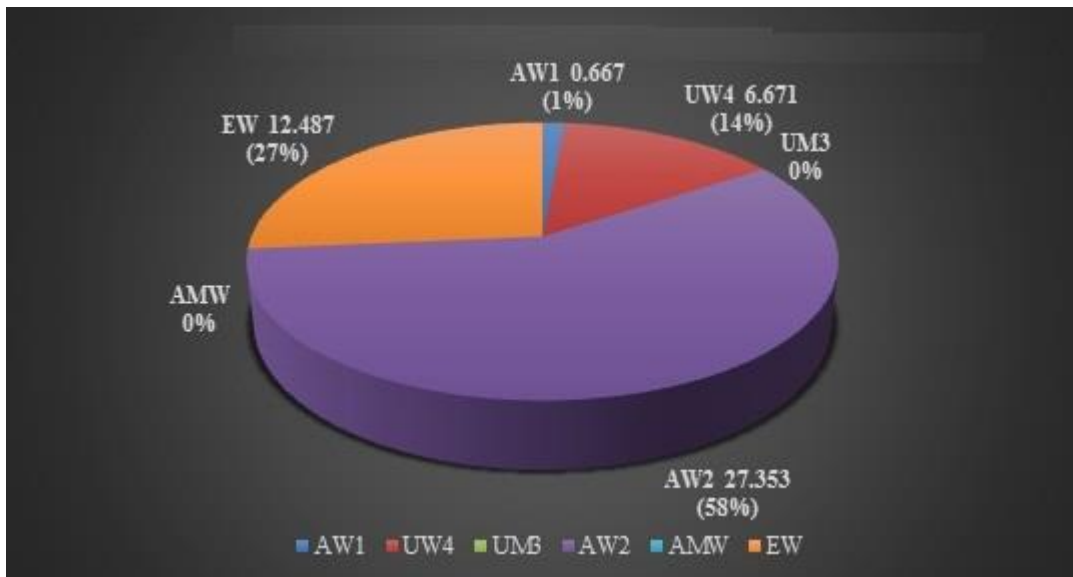


Figure 5. Percentage distribution of total PAHs concentration in the various sample locations.

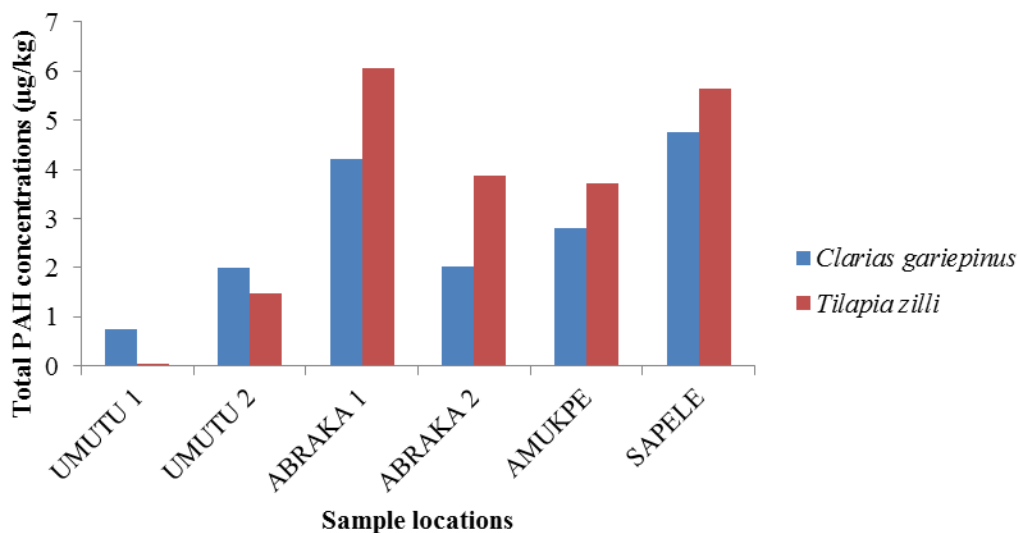


Figure 6. Distribution of total PAHs concentration in the two fish species.

fate of pollutants in the environment. The isomer ratios are effective indicators for identifying PAH sources because the isomers from the same source undergo the same mitigation process, since the distributions of the homologues are strongly associated with the formation mechanisms of carbonaceous aerosols with similar characteristics to organic species. The ratios of the specific individual PAHs can provide information about anthropogenic sources of PAHs (Zhang et al., 2018). Considering the aforementioned established facts, the implication of the results of this work is hereby presented and interpreted accordingly.

### PAHs diagnostic ratios

PAH sources have been predicted using diagnostic ratios conventionally and reported in several studies (Yunker et al., 2002; Agbozu et al., 2017). PAHs of molecular mass 178 and 202 are commonly used to distinguish between combustion and petroleum sources (Agbozu et al., 2017). These ratios include but not limited to Ant/Ant + Phe; Fluo/Fluo+Pyr, BaA/BaA+Chry and Ind/Ind+BghiP. The Fluo/Fluo+Pyr ratio presumes that ratios in the range  $\geq 0.4$  and  $\leq 0.5$  indicate petroleum combustion, ratios  $< 0.4$  indicate petroleum sources while ratios  $> 0.5$  indicate

**Table 1.** PAHs diagnostic ration for sediment and water samples.

Sampling location	PAHs diagnostic ration for sediment and water samples			
	BaA/BaA+Chry sediment	Flu/Flu+Pyr sediment	BaA/BaA+Chry water	Flu/Flu+Pyr water
Umutu 2	1	0.57	0	0.74
Umutu 3	0.1	0.75	0.57	0.64
Abraka 1	1	0.82	0	0
Abraka 2	0	0.78	1	0.36
Amukpe	0.37	0.77	0	0
Sapele 1	1	0.56	0.03	0.58

grass, wood and coal combustion; however, mean ratio for Australian crude oils is  $> 0.4$ , and a few oils have very high proportions of Fluoranthene (Agbozu et al., 2017). BaA/BaA+Chry presume that ratios  $< 0.2$  are of petroleum origin, ratios in the range  $\geq 0.2$  and  $\leq 0.35$  as mixed sources and  $> 0.35$  as combustion sources. PAHs diagnostic ratio was calculated from the readings and the result is shown in Table 1.

In this study fluoranthene/(fluoranthene + pyrene) ratios (Yunker et al., 2002; Olalekan et al., 2014) and BaA/BaA+Chry were calculated for all the samples (Table 1). From Table 1, diagnosis of the PAHs ratios showed that Flu/Flu+Pyr for sediment samples within Ethiopie River ranging from 0.56 to 0.82. This shows PAHs from here to be of combustion origin from grasses, coal and wood. While the Flu/Flu+Pyr for the water samples ranged from 0 to 0.74 within the Ethiopie River. This shows PAHs from here to be of petroleum and combustion origin from grasses, coal and wood. The BaA/BaA+Chry ratio for the water samples ranged from 0 to 0.1 within the Ethiopie River; this indicates that the PAHs are of mixed sources and combustion sources. While the BaA/BaA+Chry ratio for the sediment samples ranged from 0 to 1.0 within the Ethiopie River. This also shows PAHs from Ethiopie River to be of mixed sources which are petroleum sources, petroleum combustion sources and grass wood and coal combustion sources. From this analysis, it could be said that PAHs in sediment and water samples within Ethiopie River were majorly of combustion sources from mixed origin which could be petroleum or grass wood and coal origin; also at the control point the PAHs were of combustion origin (Teaf, 2008).

From Figure 7, the Flu/(Flu+Pyr) ratios indicate that the sources of PAHs are of petroleum and combustion origin from grasses, coal and wood (Yunker et al., 2002; Olalekan et al., 2014). For the water samples which ranged from 0 to 0.74 within the Ethiopie River which show PAHs to be of petroleum and combustion origin from grasses, coal and wood. Sampling station Abraka 1 and Amukpe indicated petroleum sources with a source ratio of 0 while the other sampling station shows combustion origin from grasses, coal and wood. The

source ratio for the sampling stations is as follows: Umutu 2 (0.74), Umutu 3(0.64), Abraka 2 (0.36), Sapele 1 (0.58). While for the sediment samples which ranged from 0.56 to 0.82 within the Ethiopie River show PAHs to be mainly of combustion origin from grasses, coal and wood. The source ratio for the sampling stations is as follows: Umutu 2 (0.57), Umutu 1 (0.75), Abraka 1 (0.82), Abraka 2 (0.78), Amukpe (0.77), Sapele 1 (0.58). The maximum source ratio for both water and sediment samples are Umutu 2 (0.74) and Abraka 1 (0.82), respectively.

The ratios of BaA/BaA+Chry are also as shown in Figure 8. For the water samples which ranged from 0 to 1 within the Ethiopie River which show PAHs to be of petroleum and combustion origin from grasses, coal and wood. All sampling stations except Umutu 3 and Abraka 2 indicated combustion origin from grasses, coal and wood while the other sampling station indicated petroleum sources with a source ratio within the range of 0 and 0.03. The source ratio for the sampling stations is as follows: Umutu 2 (0), Umutu 3 (0.57), Abraka 2 (1.0), Sapele 1 (0.032), Abraka 1 (0), Amukpe (0). While for the sediment samples which ranged from 0 to 1 within the Ethiopie River also indicate the sources of PAHs shown to be of petroleum and combustion origin from grasses, coal and wood. Two sampling stations indicated petroleum sources, which are Umutu 3 and Abraka 2 with source ratio 0.1 and 0, respectively. The other four sampling stations indicated from combustion origin (Zhenhua et al., 2017). The source ratio for the sampling stations is as follows: Umutu 2 (1.0), Abraka 1 (1.0), Amukpe (0.37), Sapele 1 (1.0).

## Conclusion

The sixteen priority individual compounds of polycyclic aromatic hydrocarbon concentrations in the water, sediment and biota from Ethiopie River are considerably low and below risky levels. Although, the polycyclic aromatic hydrocarbons were below the threat level which indicated no danger status from the consumption or dermal contact for humans but the concentration level can cause adverse effects for lower aquatic organisms

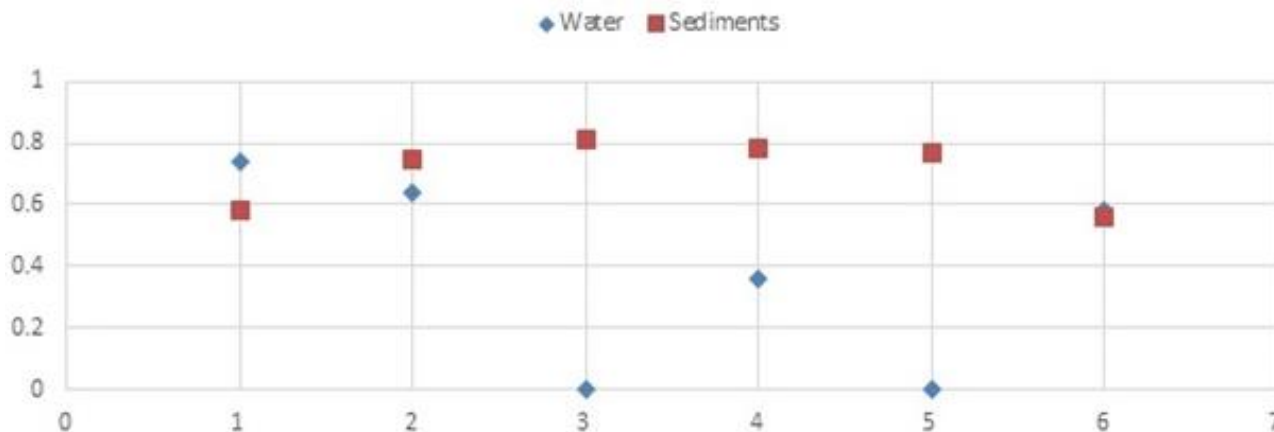


Figure 7. Source identification of PAHs (Flu/(Flu+Pyr)) in the various sampling points of water and sediments samples.

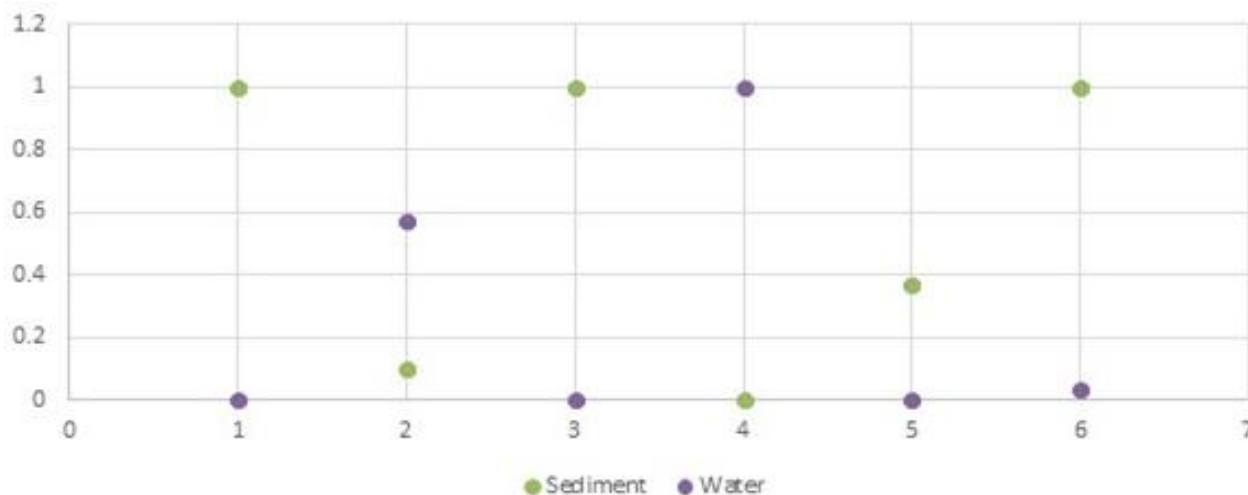


Figure 8. Source identification of PAHs (BaA/BaA+Chry) in the various sampling points of water and sediments samples.

which are exposed to the sediments on a daily basis. Therefore, persistent monitoring and strict adherence to responsible waste discharge should be upheld by all manufacturing and agro industries in the catchment of the river in order to avoid deleterious effects of the biodiversity in these water bodies as well as ensuring safety of the consumers. From the source prediction, the results obtained show the sources are quite similar with some sample locations indicating the PAHs in the water and sediment samples are of petroleum and combustion origin from grasses, coal and wood. This is in line with car washing and other commercial activities within the vicinity and upstream of the site.

**CONFLICT OF INTERESTS**

The authors have no conflict of interests.

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*Full Length Research Paper*

# **Framework for assessing the level of stakeholders' involvement and governance in mangrove management: Case of selected local communities in the south west coastal Atlantic Region, Cameroon**

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**Mangrove forest management is becoming increasingly difficult due to increasing pressure from burgeoning mangrove fuel wood dependent coastal population justifying the urgent need for a multi-dimensional participatory approach that brings together all stakeholders into a broad management and governance framework. This paper investigates, analyzes and puts stakeholders' participation within the framework for mangrove ecosystem management in local communities of Bimbia-Mabeta areas, a prominent mangrove deforestation hotspot in Cameroon. Results from data collected from a survey of three chosen communities and analyzed using relevant statistical tools showed the level of involvement and intervention in the management process of two categories of stakeholders: direct stakeholders (primary) being exploiters and indirect stakeholders (secondary - providing service control, law and enforcement; and tertiary - mainly ecological service beneficiaries). Their respective incomes per annum derived from mangrove resource exploitation activities ranged from 500.000 to 750.000 fcfa (\$1000 - 1500) per person for direct exploiters; and indirect (municipal services) 180.000 to 1.800 000fcfa (\$360 to 3600) and 360000 to 1.080 000 fcfa (\$720-2160) for government services. A matrix and map was constituted to categorize and appreciate stakeholders in terms of their roles, responsibilities, interests, influence for mangrove restoration and level of impact of mangrove degradation on their livelihoods. Perspectives for elaboration of appropriate management and stakeholders' engagement plans for more efficient governance to enhance sustainable management of mangroves through integrated, multidisciplinary and ecosystem approaches are further discussed.**

**Key words:** Mangrove ecosystem management, stakeholders' involvement, stakeholder's matrix, stakeholder's map, stakeholders' engagement plan, good governance, Cameroon.

## **INTRODUCTION**

Mangroves are salt tolerant woody halophytes that fringes most tropical and subtropical coastal environments worldwide (Alongi, 2002). They are classified among the

most carbon-rich ecosystems in the world (Lefebvre and Poulin, 2000; Feka and Manzano, 2008). They are the world's most productive ecosystems having a high

primary production, high rates of recycling and provide a high supply of nutrient source that supports many complex food chains (Lefebvre and Poulin, 2000; Feka and Manzano, 2008). They play critical roles in livelihood sustenance and ecological securities of rural economies especially communities inhabiting coastal zones with substantial mangrove stands (Alongi, 2009; Ajonina et al., 2014). This is through functions such as high biodiversity reservoir, fisheries production, timber production, shoreline protection, pollution abatement and high carbon sequestration rates superior to adjacent inland tropical forests. The mangrove ecosystem contributes towards stabilizing and mitigating the effects of climate change (Alongi, 2009; Ajonina et al., 2014). Mangroves are heavily used traditionally and commercially worldwide by local communities as a source of fuelwood and charcoal for cooking and heating, wood for construction of houses, huts, fences, bridges as well as timber for furniture and many other products (Kathiresan and Bingham, 2001; Alongi, 2002). In spite of their critical roles, mangroves have been considerably undervalued in the past (Primefact, 2008), negatively perceived as hostile, smelling, muddy, “wastelands” as well as breeding grounds for mosquitoes encouraging the clearing, degradation or otherwise loss of many mangrove forests (Primefact, 2008; Forkam et al., 2019). This has also contributed to very little public and scientific attention paid to mangrove compared to the colourful coral reefs or tropical rain forests (Dittmar et al., 2006). Approximately one fifth of the world’s mangrove ecosystems are thought to have been lost since 1980 due to diverse pressures from multiple local stakeholders for livelihood sustenance (Hanneke et al., 2012). The destruction of the mangrove ecosystem is not a recent issue and is positively related to human population density (Alongi, 2002).

Today, despite increasing awareness regarding the value and importance of mangroves, the destruction and degradation at alarming rates of mangrove forest one of the most threatened tropical ecosystem continues to take place in many parts of the world for a variety of economic as-well-as political motives (Polidoro et al., 2010 in Ndongmo, 2019) leading to the decline in the surface area of the world’s mangroves (Konoyima and Johnson, 2019). According to Konoyima and Johnson (2019), the distribution of mangroves has decreased globally, with some 2,260 nationally designated and 285 internationally recognized sites worldwide containing about 41% of the world’s remaining mangroves. Valiela et al. (2001) found that for all continents, present-day mangrove forest area is substantially smaller than the original area, with a world average loss of 35% since 1980s translating into an overall areal loss rate of 2.1% per year. During same

period, Macintosh and Ashton (2002) also found that in some areas, mangroves are protected by law but the lack of enforcement coupled with economic incentives to reclaim land has resulted in deliberate destruction and consequent decline in the surface area of the world’s mangrove by about 50% and regionally with Asia and Africa losing 61 and 55% respectively. Thomas et al. (2017) elucidated that the high carbon content of mangroves, coupled with their financial value in terms of the ecosystems services that they support, makes them an important asset for carbon trading initiatives through the REDD+ climate change adaptation mechanism. This thus forms the basis and justifications for various interventions aimed at the sustainable utilization, conservation and restoration of the mangrove forest in the face of heavy deforestation threats of human origin.

Africa which displays richness and diversity of cultures and peoples, geographical features and biodiversity hard to find elsewhere, hosts about 19% of the world’s mangroves, of which about 20,410 km (12% of the world’s mangroves and 59% of African mangroves) are located in West-Central Africa (Feka and Ajonina, 2011; Kauffman and Bhomia, 2017). This complexity in Africa has created great diversity in resource use and management by rural people (Barrow et al., 2002).

Cameroon is among the few countries in the world blessed with mangroves which cover over 30% of the country’s more than 590 km of coast stretching from the border with Nigeria contiguous with the mangroves of the Niger Delta in the north, to Equatorial Guinea in the south being the second largest coast in Central Africa after the coast of Gabon (Folack and Gabche, 2007). The mangrove coverage of more than 230 000 ha puts the country as the largest in Central Africa and the sixth largest in Africa (Ajonina et al., 2008; MINEPDED-RCM, 2017) with several stakeholders involved in mangrove resource management (FAO, 2018). These actors include at the international level NGOs; at the national level public administration with the involvement of several ministries comprising in particular: Ministry of Forestry and Wildlife “MINFOF”, Ministry of Environment, Nature Protection and Sustainable Development “MINEPDED”, Ministry of Fishery and Animal Husbandry “MINEPIA”, Ministry of Economy, Planning and Regional Development “MINEPAT”, Ministry of Agriculture and Rural Development “MINADER”, Ministry of Transport “MINTRANS”, Ministry of Mines, Industry and Technological Development “MINMIDT”, Ministry of Energy and Water Resources “MINEE” and Ministry of Scientific Research and Innovation “MINRESI”); at the local level local communities, councils and local authorities; non-governmental organizations; and the

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private sector. It must be noted that the exploitation of mangrove poses serious threats to the rich mangrove biodiversity, the environment and human well-being. At the coastline of Cameroon, around the Bimbia-Mabeta neighborhood, mangrove forests are not seen as a fundamental economic and ecological resource to be treasured; as such diverse livelihood activities have led to over-exploitation, degradation and even loss in some areas (Forkam et al., 2019). As there exist an important link between livelihood and environmental security which has been ignored in the past by mangrove stakeholders (as stakeholders focused mainly on the benefits derived from the mangrove ecosystem, neglecting their roles, rights and responsibilities to protect the mangrove), it is therefore imperative to identify and characterize the stakeholders as well as assessing their level of involvement to promote good governance in the management of the Bimbia-Mabeta mangrove.

The most effective way to examine local stakeholders' involvement in mangrove forest management, is essentially to identify them, have an understanding of their stakes, power relations, their interests and the ways in which the different stakeholders are able to compete for the power to control the mangrove resources. This will enable us understand their level of involvement (influence and/or impacts) in mangrove forest management. This is very important especially as the mangrove resource is the principal source of income for the local population of the Bimbia-Mabeta area. Hence it is very clear that man is at the center of mangrove degradation. Thus, the involvement of all stakeholders in mangrove management is therefore very important firstly, because according to Mukherjee et al. (2014), the number of people living within 10km of significant mangrove areas might have risen to 120 million by 2015, and that the bulk of this population resides in developing countries in Asia and West and Central Africa and largely dependent on mangrove resources for daily sustenance and livelihood. Secondly, the fact that mangrove is seen as open access resource available to the public (Buck, 1998). Kustanti et al. (2014) talks of common pool resources (CPR) as it brings together both direct *interest* and indirect or *power* enforcing stakeholders for success and cooperation.

According to Bourne (2005) and Jing et al. (2011), stakeholders are individuals, groups or institutions that can be negatively or positively affected by a proposed project or that can affect the outcome of the project (persons impacted by the project). On the other hand, Ramsar Convention (2007) defined stakeholder as any individual, group or community living within the influence of a site and who are equally said to be dependent on the site for their livelihood. An important critical element in any management approach is the involvement of all stakeholders, which include among others: local communities, non-indigenes, indigenous peoples, as well as various affected economic sectors at all stages of the process.

Good governance has been defined according to UN

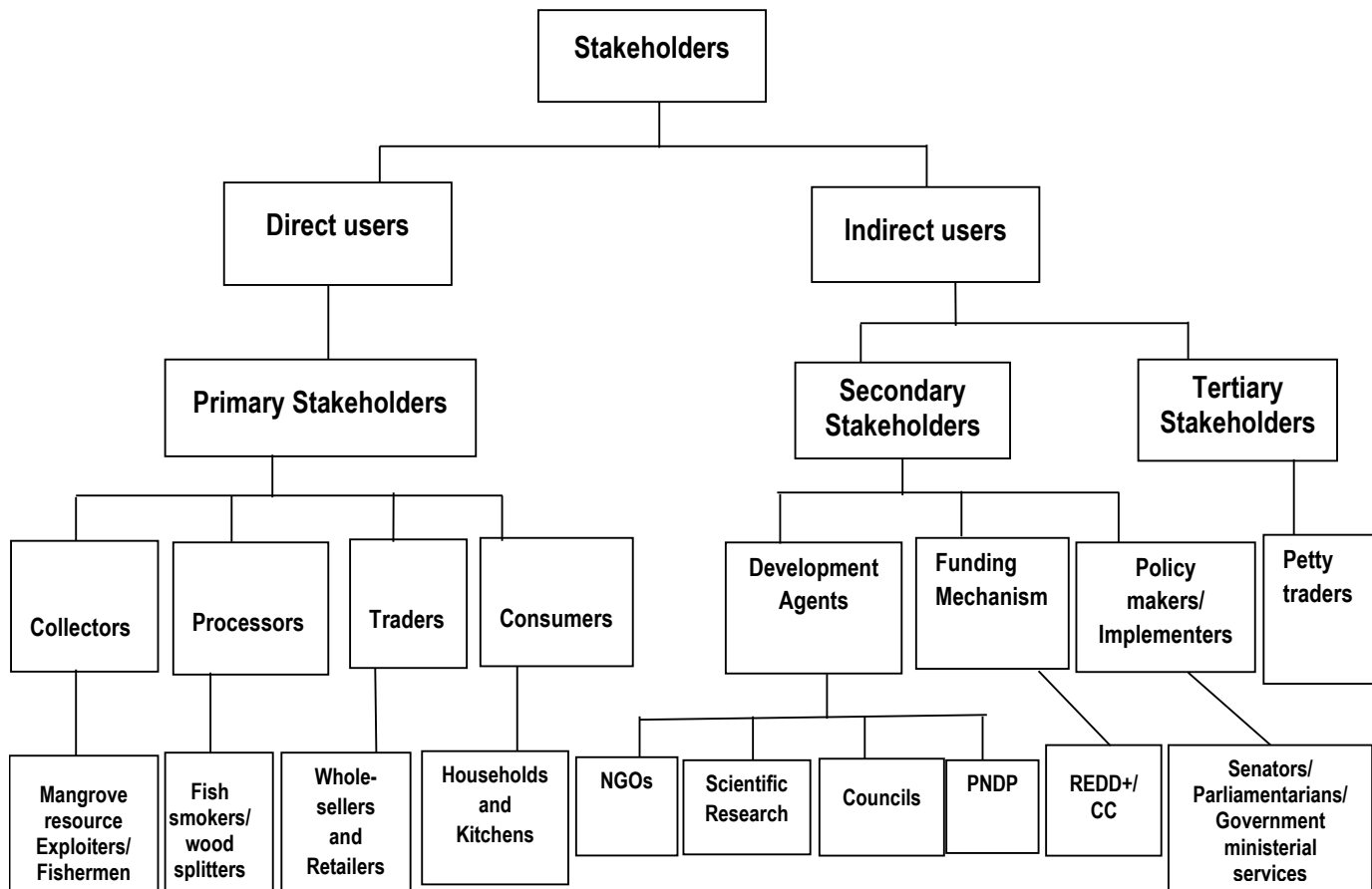
System Task Team on the Post 2015 and Keping (2017) in relation to the desired outcome to human development from a democratic view as a collaborative management mechanism processes and institutions, through which citizens, group, stakeholders show their interests, exercise their legal rights, attain their obligations and mediate their differences. This also pertains to institutions of governance, including public administration and public services connected, in particular, with the sound management of resources, delivery of and equitable access to public services, responsiveness to the views of citizens and their participation in decisions that concern them. Governance identifies the blurring of boundaries between stakeholder groups (government, NGOs, public sector, local communities etc.) and responsibilities for tackling social and economic issues; the power dependence involved in relationships between institutions involved in collective action; emphasizes the importance of autonomous self-governing networks of actors and shared responsibilities in public management; and recognizes the capacity to get things done without relying on the power of the Government to command or use its authority.

This study is aimed at elaborating a framework for identification, categorization, characterization and mapping of stakeholders involved in the management of the local mangrove resources. The study assesses their roles, rights, responsibilities, interests, level of impact on the degradation of mangrove resources, level of influence on mangrove restoration as well as their levels of income earned from their different incomes generating activities. The study equally elaborates a plan for stakeholders' participation so called stakeholder engagement plan (SEP) for effective governance towards sustainable management of mangrove forests in the Bimbia-Mabeta area in south western Cameroon. This piece of work could inform all mangrove stakeholders and other natural resource managers that the mangrove ecosystem is like a natural paradise that can get lost one day. It also highlights the growing reality that, unless humanity embraces the awesome responsibility of using, preserving and protecting the mangrove ecosystem, it will indeed disappear.

## METHODOLOGY

### Development of the conceptual framework for identification and categorization of stakeholders within the Bimbia-Mabeta mangrove communities in Cameroon

Several approaches have been used in the classification and categorization of stakeholders in the management of natural resources on planet earth. These different approaches or school of thoughts focus either on the importance, interests, benefits, relevance, needs, rights, and other natural advantages. Some classification approaches and school of thoughts will now be examined. Concerning interest, Krott (2005) observed rivalry between different interest groups attempting to utilize the benefits gained from mangrove as a common pool resource. This rivalry



**Figure 1.** Conceptual frame work constructed from: MacArthur (1997), Claridge (1997), Barrow et al. (2002), Krott (2005), Samoura et al. (2007), Eba’a Atyi et al. (2013), Kustanti et al. (2014) and FAO (2016).

which he observed between local stakeholders (interest) and political players (power) form the basis of his classification. Kustanti et al. (2014) on the other hand, inspired by the works of Krott (2005) decided to further work on “actors, interest, and conflicts in the sustainable management of mangrove forest”, and found that there exist two categories of mangrove stakeholders: *direct* and *indirect users*. According to them, the direct users are those directly exploiting the mangrove forest while the indirect users are those who are not in direct contact with the mangrove forest and are not directly exploiting the mangrove forest. Eba’a Atyi et al. (2013) and FAO (2016) found the works of Krott (2005) and Kustanti et al. (2014) to be relevant and decided to add more value to their work by further classifying fuelwood/wood fuel stakeholders into direct and indirect stakeholders. In their classification, the indirect stakeholders were grouped into government and traditional authorities while the direct stakeholders were categorized into collectors/producers, transporters, traders, consumers. Reviewing a paper entitled “stakeholder Roles and Stakeholder analysis in Project Planning” that focuses on stakeholders’ interest, MacArthur (1997), identified three categories of stakeholders which he grouped them into *primary*, *secondary* and *external stakeholders*. Furthermore, Claridge (1997) made allusion to the direct and indirect impacts of stakeholders on mangroves and synchronize their “interests and needs” to come out with the following classification: Local direct users’ communities, Local indirect users Communities, Remote direct Users Communities, Government Agencies, Supporters of Mangrove Users Communities and

Research and Academic Institutions. And the last and most fascinating is the approach that grouped mangrove actors in five categories according to their *needs* and *interests*. Samoura et al. (2007) categorized them as Social actors (village association and village committee), Economic actors (economic groups and entrepreneurs), Political actors (local elected authorities and prefectures), Research groups (technical government services, research institutes, NGOs and project organisations) and Environmental services (tourists services, international institutions, NGOs, environmental departments).

The conceptualisation of our framework was therefore based on the above school of thoughts which we articulated the identification and categorization of mangrove stakeholders around two subdivisions that is the direct and the indirect stakeholders (Figure 1). The direct stakeholders’ also known as primary stakeholders are those who are in direct contact with the mangrove forest and/or resources. That is those who are involved in the direct and indirect consumption of mangrove resources (livelihood sustenance). While the indirect stakeholders on the other hand are categorised into secondary and tertiary stakeholders that is those who are involved in promoting conservation, sustainable utilisation and restoration efforts through policy making and/or policy implementation, sensitisation, education/capacity building, participatory development programs, funding of developing projects and programs (secondary stakeholders) geared towards mitigating the impacts of the direct stakeholders as well as those enjoying the benefits of environmental services like climate regulation (tertiary stakeholders). From the

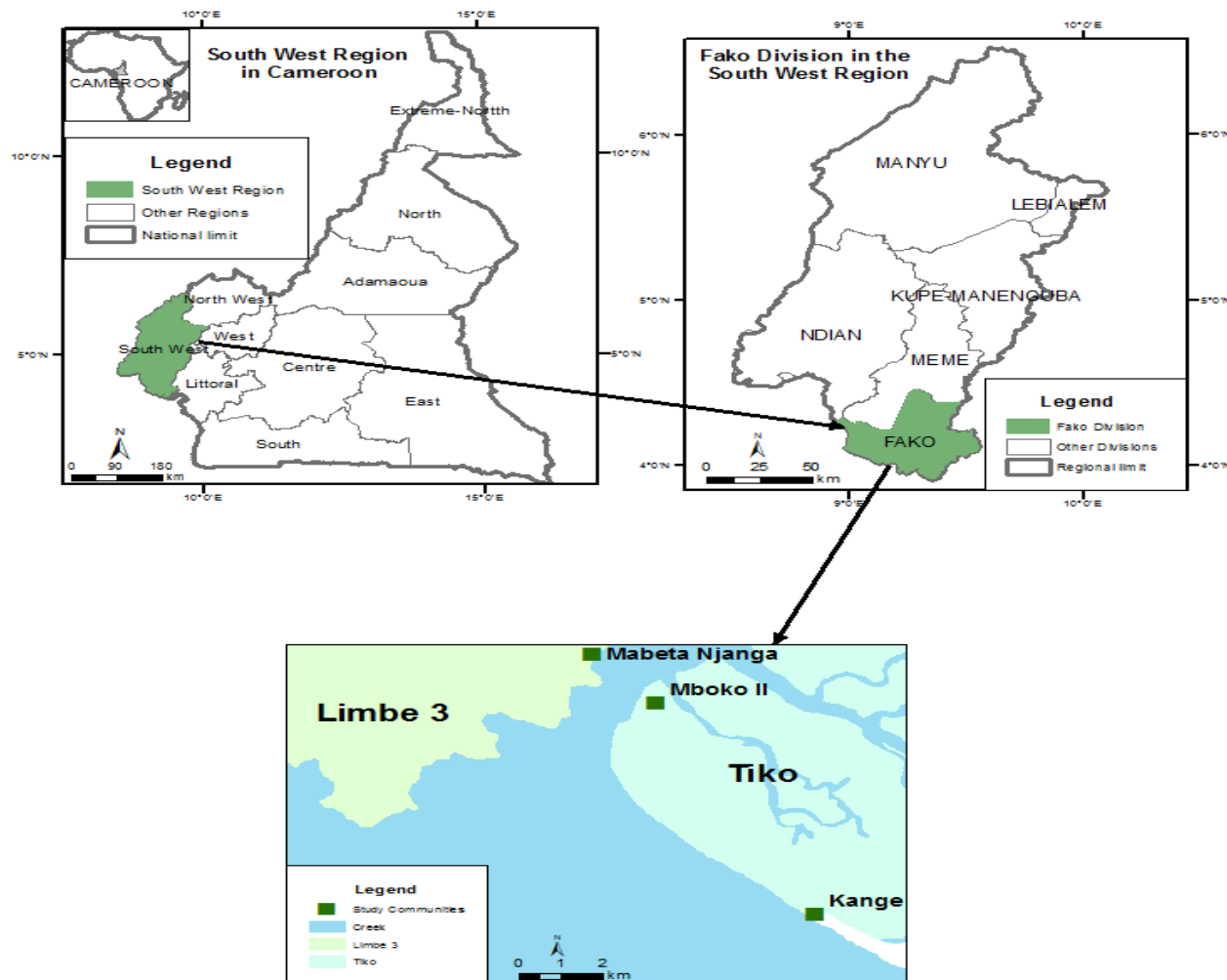


Figure 2. Land use Map of Limbe III Council.

block diagram, the direct stakeholders include among others: exploiters/collectors, transformers/ processors, transporters, traders and final consumers. While the secondary stakeholders on the other hand include: the Development agents which are the NGOs, Scientific research, Councils, and National Community Driven Development Program (PNDP); Funding mechanism as REDD+ climate change; Policy makers/implementers are the Senators and Parliamentarians, as well as government ministerial services and traditional authorities (indirect - secondary stakeholders). The petty traders are the indirect - tertiary stakeholders.

#### Description of study site

The South West Region of Cameroon is located between 9° 00' E to 16°00' E and 2°00' N to 7° 00' N and is bordered to the South by the Atlantic Ocean, to the West by the Federal Republic of Nigeria, to the North by the North West Region and to the East by the Littoral Region. The region has a surface area of 25 410 km<sup>2</sup> and a population of about 1,384289 estimated in 2010 (Agendia, 2010). This Region has 6 divisions with Fak0 being our division of interest since it is where the Bimbia-Mabeta communities of the Limbe III municipality are located. The Limbe III municipality is located in the

East coast of the Limbe town and is found within the Mount Cameroon region. It has an estimated surface area of 212 km<sup>2</sup>. The three communities chosen for the study are Mabeta-Njanga, Mboko II and Kange. The location map of the study areas that is the Limbe III council area derived from the map of the South-West Region and the sample sites can be seen in Figure 2.

#### Socio-economic surveys

The study was carried out on the local population of three communities living adjacent to mangroves at the Bimbia-Mabeta area that exploit and use mangroves. Both purposive and random sampling techniques were used during the surveys. The study communities were randomly selected from nine fishing camps situated adjacent to mangroves zone at the Bimbia-Mabeta area divided into three strata (3 fishing communities per stratum). The stratification was done as follows: stratum 1: (Dikolo, Mabeta-Njanga, Ijaw-Mabeta), Statum 2: (Mboko I, Mboko II, Mboma I) and stratum 3: (Mboma II, Anglophone Kange, Francophone Kange). This study area was purposively chosen because the area is an epicenter of mangrove exploitation for livelihood sustenance in Cameroon.

During this survey, 120 questionnaires were administered to the local population concerned directly or indirectly with mangrove exploitation within the three chosen communities. Before the administration of the questionnaire within these chosen communities, the local population and the development agents, policy makers and policy implementers (secondary stakeholders) as part of the targeted population because we consider the secondary stakeholders as Pro-Conservationists. That is those concerned with the putting in place of sustainable management strategies and mechanisms that will enhance conservation of the mangrove ecosystem. They were served with both structured and unstructured questionnaires to get from them the role they have played in promoting the conservation, sustainable utilization and restoration of the Bimbia-Mabeta mangrove ecosystem.

The three communities for consideration randomly selected from the nine fishing communities that are found within the Bimbia-Mabeta mangrove area were Mabeta-Njanga (3° 59' 57" N, 9° 17' 39" E) Mboko II (3° 58' 72" N, 9° 18' 06" E) and British Kange (3° 54' 63" N, 9° 20' 85" E).

#### Data collection procedure and analysis

Data collection was conducted using both qualitative and quantitative methods. The qualitative approach includes key informant interviews, focus group discussions. While the quantitative approach on the other hand was done using questionnaires (with open and close ended questions). The interviews for the qualitative approach were addressed exclusively to the indirect stakeholders notably: key traditional leaders, municipal and government service personnel within the study area with the aim of strengthening in-depth discussions and interactions geared towards investigating their role, rights, responsibilities, level of impact on mangrove degradation, level of influence on mangrove restoration as well as their annual income earning level. The quantitative approach on the other hand was carried out using questionnaires targeting the direct stakeholders notably the different households to whom 100 questionnaires were randomly administered to them using the simple random sampling technique. The random sampling selection procedure was facilitated by the information provided by the traditional leaders and councils authorities on the available number of houses in each community from where at least 30% of the population size was predetermined for assessment from physical visit and selection of houses facilitated by the linear settlement pattern. The relationship between a house and household was defined in this case as people irrespective of families, sleeping under one roof or living in the same house (Ekobo, 1995). In each household the questionnaires were administered to the head of the house to obtain information on their role, rights, responsibilities, annual income, level of impact on mangrove degradation and level of influence on mangrove restoration. Both surveys were conducted during the months of March and April 2016. Household surveys were heavily facilitated thanks to the intervention of field extension workers of the government services in charge of fisheries, forestry and wildlife.

#### Data analysis

Data collected was subjected to mainly descriptive statistical analyses (frequency tables, bar-charts, pie-charts, etc.) using the EXCEL statistical software package. Inferences were used to analyze the annual income earning levels of both direct users of mangrove resources and indirect users via fiscality (taxes) and notably contingency analysis using SPSS 17.0. Matrices and maps were constituted to categorize and appreciate the stakeholders in terms of their roles, responsibilities, interests, influence (for mangrove restoration) and the level of impact on mangrove degradation as well as the level of conflicts between different users.

## RESULTS AND DISCUSSION

### Identification and categorization of stakeholders within the Bimbia-Mabeta mangrove communities drawn from the conceptual frame work

Fitted into Table 1 are the various actors on the field in the conceptual framework already presented in Figure 1. As already indicated, stakeholders encountered were of two types depending on their level of influence in mangrove management (level of influence in conservation, sustainable utilization, restoration, and degradation). The direct stakeholders being *primary stakeholders* while the indirect stakeholders categorized into *secondary* and *tertiary stakeholders*. The *primary stakeholders* being both indigenes and non-indigenes of the local population and are characterized by collectors (fishermen and, mangrove exploiters), Traders (wholesalers and retailers) mainly Buyam-Sellam of fuel wood and fish respectively (mostly women) found streaming the mangrove areas for mangrove wood and caught fish (smoked fish or fresh fish in ice boxes), the transporters (hired engine propelled boats riders or hand pulled canoes and truck pushers), Processors (fish smokers, fuel wood splitters, paddle carvers and carpenters were seen) and Consumers (over 100 households). For the *secondary stakeholders*, the "Development Agents" encountered were NGOs such as Cameroon Wildlife Conservation Society (CWCS, 2015), Consortium Partners with Forests and Wetlands Consulting (FWC), Bimbia Bonadikombo Natural Resource Management Council (BBNRM), People Earth Wise (PEW) and Cameroon Mangrove Network (CMN); Research and Academic institutions were namely University of Buea, Limbe Nautical Fisheries Institute (LINAFLI) and Institute for Research in Agriculture and Development (IRAD); the Councils were mainly Tiko and Limbe III councils; and National Community Driven Development Program (PNDD). The "Policy Implementers" were identified as (Ministerial services of Forestry and wildlife "MINFOP", Environment, Nature Protection and Sustainable Development "MINEPDED", Fisheries, Livestock and Animal Husbandry "MINEPIA", Agriculture and Rural Development "MINADER", Tourism "MINTOUR" and Territorial Administration "MINATD"), while the Funding mechanism was mainly Reducing Emissions from Deforestation and Forest Degradation (REDD+). Though not in direct contact with the mangroves, that is not using mangroves directly, but concerned with putting in place sustainable management strategies for the conservation of the mangrove ecosystem and resources. In the tertiary stakeholders' category, another group of indirect interest stakeholders living at the proximity of the mangrove forest not equally exploiting mangrove directly but enjoying the indirect ecological benefit (positive externalities or green house benefits) were mostly petty traders such as shopkeepers (provision shops, coffee and tea shops).

**Table 1.** Matrix of categorization of stakeholders within the Bimbia-Mabeta mangrove communities from field observations.

Category	Description	Field observation
Direct users		
<b>(i) Primary stakeholders</b>		
Collectors	Mangrove resources exploiters, fishermen	Some 92 Mangrove resource exploiters with over 97 fishermen
Processors	Fish smokers, wood splitters	At least 66 fish smokers, 3paddle carvers and several wood splitters, and carpenters
Traders	Wholesalers, retailers	Mainly Buyam-sellam of fresh and smoked fish, as well as those trading with mangrove wood and fuel wood
Consumers	Households, kitchen	At least 350 households and kitchens from data obtained from the councils.
Indirect users		
<b>(ii) Secondary stakeholders</b>		
Development agents	NGOs, scientific research, Councils, National development programmes	<p><b>NGOs:</b> Cameroon Wildlife Conservation society (CWCS), Consortium Partners with Forest and Wetlands Consulting (FWC), Bimbia-Bonadikombo Natural Resource Management Council (BBNRM), People Earth Wise (PEW), Cameroon Mangrove Network (CMN);</p> <p><b>Scientific Research:</b> Several Research students and Interns from University of Buea, Limbe Nautical Fisheries Institutes (LINAFI), University of Dschang and Douala hosted by the Divisional and Sub divisional delegations of ministerial services and IRAD ;</p> <p><b>Councils:</b> Tiko and Limbe III councils (2);</p> <p><b>National Development programmes:</b> Participatory National Driven Development Programme (PNDP), (1)</p>
Funding mechanism	REDD+/climate change	Reduction Of Tiko-Limbe III Mangrove Deforestation And Degradation Through Integrated Sustainable Mangrove And Associated Coastal Forest Management supervised by PNDP
Policies makers/implementers	Senators, Parliamentarians , government ministerial services	<p><b>Ministerial services:</b> Ministry of Forestry and Wildlife (MINFOF), Ministry of Environment, Nature Protection and Sustainable Development (MINEPDED), Ministry of Fisheries, Livestock and Animal Husbandry (MINEPIA), Ministry of Tourism (MINTOUR), Ministry of Agriculture and Rural Development (MINADER), Ministry of Territorial Administration and Decentralization (MINATD)</p>
<b>(iii) Tertiary stakeholders</b>		
Petty traders	Shop keepers	Several Provision shops and coffee/ tea shops



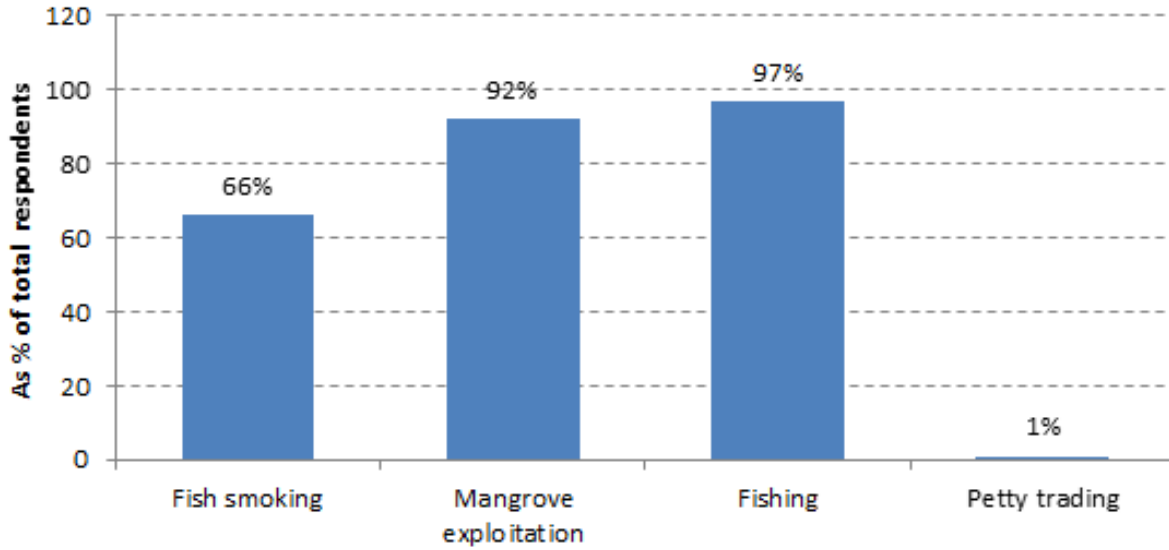


Figure 3. Activities of local direct stakeholders of the Bimbia-Mabeta mangrove area, Cameroon.

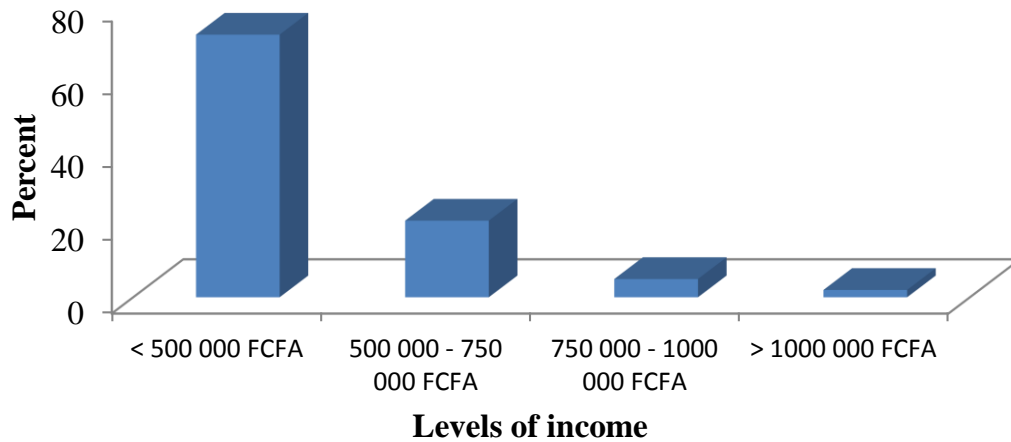


Figure 4. Annual income earning levels of the local direct primary stakeholders.

**of direct stakeholders and their activities within the Bimbia-Mabeta mangrove area**

The major activities actively carried out by some local stakeholders in the study area are presented in Figure 3. The majority of the respondents (97%) were involved in fishing followed by 92% in mangrove exploitation, 66% of the respondents involved in fish smoking while only 1% of the respondents were involved in petty trading and they obtained indirect benefits from the mangrove.

**Annual income levels of various stakeholders**

The annual income earning of the local direct primary stakeholders can be seen on Figure 4: Some 72% of the

respondents revealed that their annual income earned stood at less than 500.000fcfa (less than \$1000), 21% earned annual incomes ranging between 500.000-750.000fcfa (between \$1000-1500) while just about 5 and 2% of respondents earned annual incomes ranging between 750.000-1.000.000fcfa (between \$1500-2000) and greater than 1.000.000fcfa (greater than \$2000) respectively. The annual income earning level of the local stakeholders observed ranged from less than 500.000 to greater than 1.000.000fcfa with no noticeable influence on the conservation of the mangrove because the three activities (fishing, fish smoking and mangroves exploitation) were major activities that contributed towards mangrove degradation.

The annual earnings of the secondary indirect stakeholders especially the councils (development

**Table 2.** Income /revenue collected by the state (source: field surveys).

Department	Local Service in charge	Category of tax	Purpose	Unit price (Fcfa/\$)	Frequency of collection	Amount per year (FCFA/\$)
Ministry of Livestock, Fisheries and Animal Husbandry (MINEPIA)	Divisional delegation of livestock, fisheries and animal husbandry	Boat Registration/ownership tax	Fish production	5000 (9)	Annually	5000 (9)
		Fishing authorization tax	To carryout fishing activity	5000 (9)	Annually	5000 (9)
		Kitchen ownership authorization	To carryout fish smoking	5000 (9)	Annually	5000 (9)
		Sanitation tax	Sanitary inspection for crayfish	200Fcfa (0.4)	Daily	72000 (120)
		Sanitation tax	Sanitary inspection for fish	500 (1.0)	Weekly	24000 (40)
Ministry of Forestry and Wildlife(MINFOF)	Forestry Chief of post	Authorization tax (way-bill)	Transportation and fuel trade	1000 (2)/ Pickup truck	Daily	Unknown
Decentralized Territorial Collectivities	Council	Fuel wood depot tax	Land occupation for fuel wood parking	1000 (2)	Monthly	12000 (20)
		Kitchen tax	Fish smoking	1000 (2)	Monthly	12000 (20)

agents) and the different decentralized government services (MINFOF, MINEPIA, MINTOUR, MINADER etc.) (policy implementers) though difficult to obtain from most of them due to corrupt practices, were however reliably revealed from local informants through different categories of taxes they pay to municipal and government authorities especially the Forestry Chief of post, divisional delegation of Fisheries and animal husbandry and the councils. The taxes which were daily, monthly or annual collections ranged between 1000-3000Fcfa (\$2-5) per day for the forestry service, 500-5000Fcfa (\$1-9) per year for the fishery service and 500Fcfa (\$1) daily not regular to 1000fcfa monthly (\$2) on regular basis by the council service. Details of what is required by law in terms of taxes/revenue are summarized in Table 2.

### Stakeholders mapping

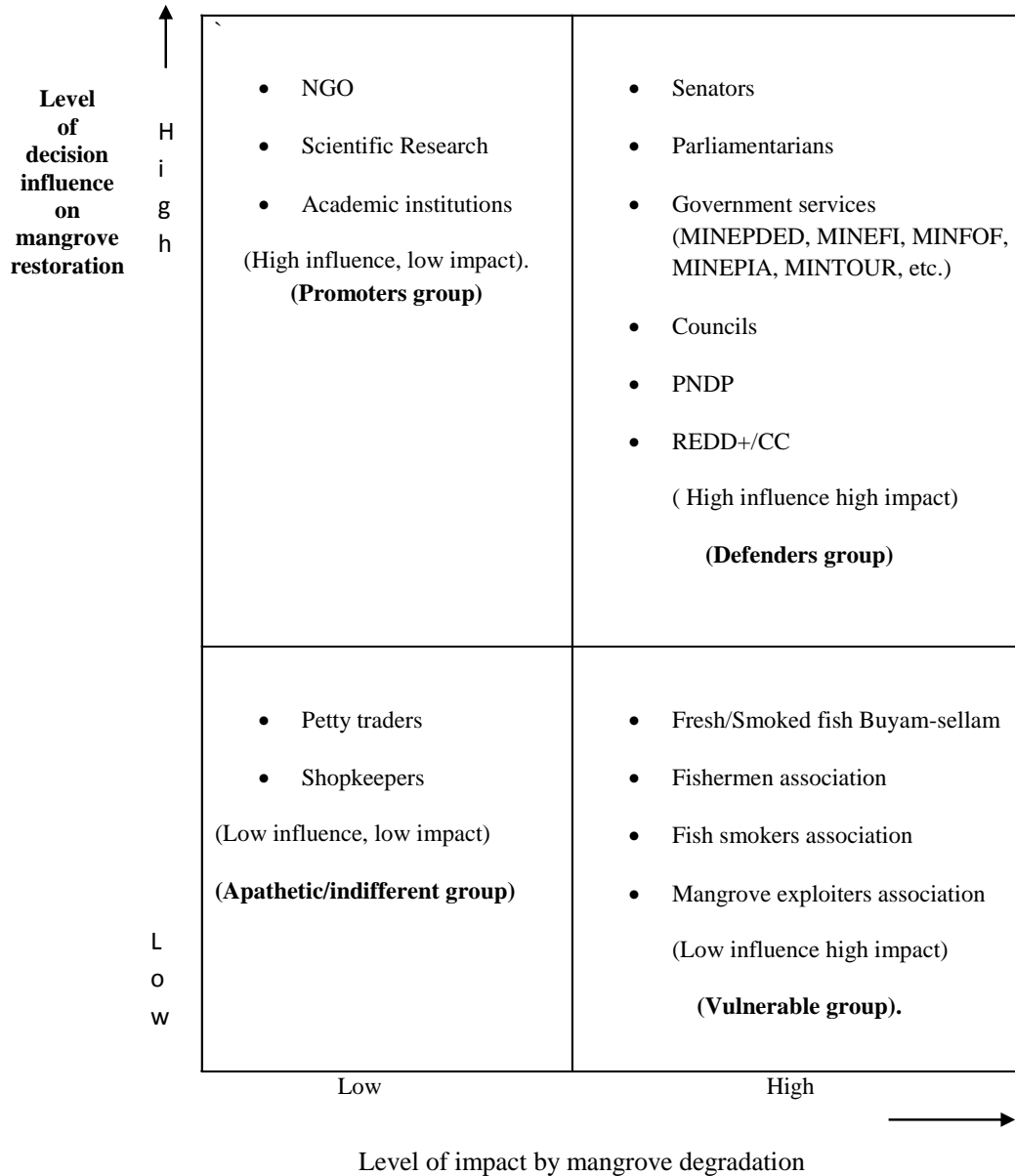
Categorization and mapping of stakeholders in

terms of their roles, rights, responsibilities, interests, level of impact on mangrove degradation and their level of influence on decisions for mangrove restoration are presented in Figure 5 and Table 3. It can be deduced that NGOs, Scientific research, academic institutions, have high influence on decision for mangrove restoration but less impacted by mangrove degradation. They are otherwise known as the “promoters”. They are closely followed by parliamentarians, Senators, MINEFI, PNDP, Councils, MINEPED MINFOF, MINEPIA, MINTOUR and REDD+ with high influence or power on decision for mangrove restoration yet are highly impacted by the degradation of the resource and are said to be the “Defenders”. The associations of fishermen, fish smokers, mangrove exploiters and fresh/smoked fish buyam-sellam with low capacity to influence mangrove restoration but highly impacted by mangrove degradation are termed “vulnerable group” While the petty traders and shopkeepers having correspondingly low influence and low

impact, are the “apathetic” of the four categories of stakeholders. Presented in Table 3 is a matrix synthesis of stakeholders, their roles, right, responsibility, interests, level of impact by mangrove degradation and their level of influence on mangrove restoration in accordance with the stakeholders’ categorization model shown in Figure 1.

### DISCUSSION

This study presents evidence supporting previous claims by Townsley (1998) and Reed (2008) that the first steps in almost every intervention and governance affecting the use of natural resources is the identification of individuals as well as groups holding some kind of “stake” or interest in that resource. Even though the several approaches used in the classification and categorization of stakeholders involved in the management of natural resources on planet earth focuses either on the importance, interests, benefits, relevance,



**Figure 5.** Mapping level of influence on mangrove restoration (Y-axis) and the level of impact by mangrove degradation (X-axis) by the various stakeholders in the Bimbia-Mabeta mangroves, SW Cameroon.

needs, rights, and other natural advantages, the likes of Krott (2005) classification was based on the rivalry he observed between different interest groups attempting to utilize the benefits gained from mangrove as a common pool resource (a rivalry observed between local stakeholders (interest) and political players or powers). Two main types of stakeholders are involved in the management of the mangrove with varying annual income earning levels. Judged from their level of influence on conservation, sustainable utilization, restoration, and degradation, they are grouped into direct or *primary stakeholders* and indirect stakeholders,

categorized into *secondary* and *tertiary stakeholders*. The direct (primary) stakeholders are collectors (fishermen, wood exploiters), traders (wholesalers, retailers), processors (fish smokers, wood splitters) and consumer (households), while the indirect stakeholders are Development agents, Policy makers (secondary) and Petty traders (tertiary). This result is in line with works of Claridge (1997) and Kustanti et al. (2014) on “actors, interest, and conflicts in the sustainable management of mangrove forest”, in which they found that two categories of mangrove stakeholders: *direct* and *indirect users*, as well as Eba’a Atyi et al. (2013) and FAO (2016), who also

**Table 3.** Synthesis matrix for stakeholders' roles, rights, responsibilities, interests, level of impact by mangrove degradation and their level of influence on mangrove restoration.

Stakeholders Category	Definition (local representative)	Role	Right	Responsibility	Revenue/benefits	Level of impact by mangrove degradation	Level of influence on mangrove restoration
<b>Primary stakeholders</b>							
1-Fishermen	Fishermen Association	Carryout fishing around mangroves	Their fishing activities around mangroves should be legal	Fishing should be sustainable	Revenue from fishing activities	High	Low
2-Fish smokers	Fish smokers Association	Fish smoking	Carryout fish smoking trade	Ensure continuous supply of smoked fish	Revenue from the sales of smoked fish	High	Low
3-Mangrove exploiters	Mangrove exploiters Association	To exploit mangroveresources	Exploitation of mangrove resources should be legal	Ensure sustainable exploitation	Revenue from exploitation of mangroves resources	High	Low
<b>Secondary stakeholders</b>							
1- Development agents	Non-Governmental Organisation	Support conservation efforts through integrating local community participation	Propose conservation strategies, Sustainable utilisation and restoration measures.	Organise Education, training and sensitisation workshops on the importance of mangroves and its resources	Tax exoneration, information, visibility	Low	High
	Scientific Research	Carryout research on different aspects of mangroves	Report research findingsand propose new conservation techniques and measures	Introduce new conservation measures and techniques	Information and visibility	Low	High
	Councils	Receive reveune from mangrove users	Stop illegal activities in the mangrove forest	Carryout rehabilitation and restoration project onmangrove forest	Tax and Potential carbon revenue	Low	High
	National Community Driven Development program (PNDP)	Charged with facilitating local councils in the process of development through facilitation for the elaboration of a councils development plan	To offer crucial technical and financial resources for councils	Supervised the councils initiate, implement and follow up their development through the elaboration and implementation of their communal development plan.	Tax and potential carbon revenue	Low	High

Table 3. Cont'd

	REDD+	Reduce greenhouse gas emissions and increase removal by limiting deforestation and forest degradation.	Collaborate with developing countries to reduce deforestation and forest degradation	Provide developing countries with financial incentives to take actions geared towards climate change mitigation.	Forest restored, forest carbon stocks conserved and greenhouse emissions reduced	Low	High
	REDD+						
3-Policy makers	Parliamentarians	Adopt laws and regulations governing the protection of mangrove and fragile zones	To know the state of mangrove from the ministries concern	Ensure the protection of mangroves and fragile zones	Information	Low	High
	Senators	Adopt laws and regulations governing the protection of mangrove and fragile zones	To know the state of mangrove from the ministries concern	Ensures the protection of mangroves and fragile zones	Information	Low	High
	Ministry of Environment, Nature Protection and Sustainable Development (MINEPDED)	Enure laws and regulations governing mangroves are enacted and enforced	Control or stop all mangrove activities which aren't conservation oriented	Monitor all activities carried out within mangrove forests and fragile zones	Potential carbon revenue	Low	High
	Ministry of forestry and wildlife (MINFOF)	Enure laws and regulations governing mangroves are enacted and enforced	Stop illegal exploitation of mangrove wood and wildlife	Monitor exploitation activities carried out within mangrove forest	Tax	Low	High
	Ministry of Fishery, Livestock and Animal Husbandry (MINEPIA)	Ensure that laws and regulations governing fisheries production are enacted and enforced	Stop illegal and unsustainable fisheries practices in and around mangrove areas	Monitor all activities linked to fisheries production in and around mangrove areas	Tax	Low	High
4-Policy implementers	Ministry of Agriculture and Rural Development	Ensure that laws and regulations governing agricultural activities are enacted and enforced	Prohibits unsustainable agricultural activities around mangrove (eg animal rearing) and promote sustainable practices (eg apiculture)	Monitor all activities linked to agriculture around mangrove areas	Information	Low	High
	Ministry of tourism (MINTOUR)	Ensure that laws and regulations governing tourist activities are respected	Discourage unsustainable touristic activities, promote sustainable tourism (eg birdwatch and boating round mangrove)	Monitor all touristic activities organised in and around mangroves	Income from tourism	Low	High
<b>Tertiary stakeholders</b>							
	Shopkeepers	Non	Non	Non	Non	Low	Low
1-Petty traders	Smoked fish "buyam-sellam"	Buy and sell smoked fish	Carryout smoked fish trade	Just buying and selling of smoked fish	Revenue from selling of smoked fish.	High	Low

revealed that, the direct users are those directly exploiting (collectors) alongside the intermediaries (transporters, traders, processors consumers) while the indirect users are those who are not in direct contact with the forest, that is the (traditional and official) authorities.

The results of this work is in line with previous studies conducted in several parts of west and Central Africa, Asia and South America like the works of Ajonina and Usongo (2001), Feka et al. (2009) and Feka and Ajonina (2011) in which they all found fish smokers, fishermen mangrove wood exploiters, sand extractors and agriculturists as direct users of mangrove resources. A claim which was further supported by Feka and Manzano (2008) and Hanneke et al. (2012) as their works were able to produce additional evidence to prove that fishermen, fish smokers and mangrove wood exploiters are direct users. They found that there exist a positive correlation between fishing, fish smoking and mangrove wood exploiters which influence the conservation of the mangrove ecosystem.

On the point of view of stakeholders roles, rights, responsibilities, benefits, level of influence on mangrove restoration as well as level of impacts of mangrove degradation, the study produces evidence that the roles, rights, responsibilities and benefits as well as level of influence on mangrove restoration and level of impacts of mangrove degradation vary from one stakeholder to another which is in accordance with the importance, needs and interest of mangrove resource to them. As seen on Figure 5 and Table 3, the study shows that direct and the tertiary indirect stakeholders (buyam-sellam of smoked fish) sustained high impact from mangrove degradation and low influence on mangrove restoration, while the indirect (secondary) stakeholders have high influence in mangrove restoration and with low impacts from mangrove degradation. This is in conformity with the works of MacArthur (1997); Barrow et al., (2002) and Samoura et al. (2007) that categorized them as; *Social actors* (village association and village committee), *Economic actors* (economic groups and entrepreneurs), *Political actors* (local elected authorities and prefectures), *Research groups* (technical government services, research institutes, NGOs and project organisations) and *Environmental services* (tourists services, international institutions, NGOs, environmental departments).

## CONCLUSION AND RECOMMENDATIONS

Thousands of people rely on the ecosystem services provides by mangroves at the Bimbia-Mabeta area for poverty alleviation and livelihood sustenance but have not yet identified that the best management method to ensure its sustainability is the involvement of stakeholders in the management process. Owing to the level of the impacts of degradation on the Bimbia-Mabeta mangrove with underlying causes deeply rooted in the complex

socio-cultural, economic and political contexts, identification of the different types of mangrove stakeholders in the area, their role in re-establishing ecological functions, their rights, responsibilities and benefits cannot be over emphasized. Since the world is becoming more integrated, and being the most important concept in modern society that strongly emerges in the field of natural resource management because of the complexity of the systems involved. This implies that in enhancing conservation of the mangrove ecosystem requires a more efficient and sustainable management strategy that will mitigate the negative impacts to obtain a significant positive impact in rehabilitating and restoring the mangrove resources. Much still needs to be done as far as this ecosystem is concerned to address the prevailing human threats at the Bimbia-Mabeta mangrove zone whose management is heavily hinged on multi-dimensional stakeholders' approach that brings together stakeholders from various sectors involved in mangrove management. This can only be done through research, sensitization (with more emphasis on public awareness raising and education legislative), capacity building, the introduction of new legislation and new governing bodies with clearer administrative roles on environmental issues, as well as the institution of a stronger conservation status for the Bimbia-Mabeta mangrove area so that it can gain its outstanding value. We are left spellbound by the works of World Bank, ISME, CENTER Aarhus (2003); Hanneke et al. (2012), who both highlighted the essential ingredients for the governance from effective involvement of all stakeholders as a critically important element in the management process where coordination and clear distribution of responsibilities among the different stakeholders necessary to ensure successful and sustainable management of mangrove, are achievable by establishing "*management plans*" with "*stakeholders engagement plans*" for all mangrove areas without which implementation of any management system involving different stakeholders can be ineffective. For this to be achieved, the following recommendations are proposed:

(i) *Need for appropriate separate legislation for mangroves.* Adherence to appropriate laws and good institutions is the basis of good governance. Legislation on environment and natural resources is still general and let alone not specific to mangroves. Mangroves by the nature are also hiding grounds of all sorts of criminals since it is no man's land. There is therefore need for appropriate separate legislation for mangroves to curb corruption, 'ill' intentions of some stakeholders and governments' agencies to rob off the livelihood of rural stakeholders while failing to make alternative sources of livelihood for them.

(ii) *Incorporation of multidisciplinary approach to management process:* In order for mangroves to be managed effectively, Hanneke et al. (2012) found that critical framework or enabling conditions must be

established which include a clear and accepted understanding of ownership and use rights and a solid legal infrastructure that supports and incorporates mangrove management strategies into a wider planning and policy framework. They noted that such frameworks will involve all relevant agencies and stakeholders and extend across all adjacent zones and communities. The sustainable management of the Bimbia-Mabeta mangroves ecosystem needs be integrated into a broader spatial framework of coastal zone management which incorporates the multidisciplinary (holistic), participatory and integrated stakeholders' approaches in the management process. It is a participatory system whereby planning, management and implementation of conservation, sustainable multiple utilization and restoration of the mangroves ecosystem can be achieved through stakeholders dialogue, negotiations, consensus and compromise due to divergent views or interests.

(iii) *Building organizational and functional capacity of fishers and other mangrove exploiters*: They equally need to organize the fishermen or other mangrove exploiters into co-operative or associations or socio-professional groups that provides a conducive environment, common participatory and synergistic framework to facilitate the co-management of the adjacent mangroves forest and also for sustainable resource use innovations to operate.

(iv) *Carryout community-based tree planting schemes for mangrove restoration*: The government and civil society organizations need to be stimulus to carry out a campaign mobilizing other stakeholders groups on planting (afforestation) and replanting (reforestation) of mangroves trees (mangroves restoration) at severely degraded sites with the effective involvement and participation of stakeholders. Their level of involvement will be commensurate with their different stakes in the resource.

(v) *Creation of effective partnerships to support participatory mangrove management*: Successful and sustainable mangrove management will depend upon the creation of effective partnerships and promoting participatory activities between the different users and beneficiaries in the chain of delivery of mangrove ecosystem services. The financial support through the REDD+/climate change mechanism towards conservation efforts to developing countries should be reinforced to encourage local communities having mangrove stands to sustainably manage and protect their mangrove forest geared towards preventing global climate change.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# Species composition, habitat association, altitudinal variation and distribution of small mammals in Chato Protected Area, Western Ethiopia

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Species composition, habitat association and altitudinal distribution of rodents and shrews were assessed in Chato Protected Area, Ethiopia, between July, 2015 and March, 2016. The area was stratified into five habitats based on dominant vegetation types and altitudinal zonation. The habitats were *Carissa spinarum* - *Justicia schimperiana*, *Maytenus gracilipes*, *Podocarpus falcatus* - *Pyschotria orophila* dominated habitats, riverine and plantation. A total of 254 small mammals comprising five rodent and one shrew species were live trapped from 1862 trap nights. The recorded rodent species were: *Stenocephalemys albipes* (40.95%), *Lophuromys flavopunctatus* (23.6%), *Arvicanthis* sp. (16.9%), *Mus mahomet* (13%), *Mastomys natalensis* (4.35%) and a shrew sp. (1.2%). Two of these rodent species (*S. albipes* and *L. flavopunctatus*) were the most abundant species that comprised 64.56% of the total; while *Crocidura* sp. was the least abundant distributed along the centre of the forest. *M. gracilipes* was dominant at 1,789 to 1,975 m, and was the most diverse habitat and comprised 19.39% of the trap success. *P. falcatus*- *P. orophila* was dominant from 1,975 to 2,230 m, and was diverse habitat that comprised 22.7% of the trap success. The plantation supported the least number of rodents.

**Key words:** Altitudinal variation, Chato Protected Area, distribution, habitat, small mammals.

## INTRODUCTION

Rodents belong to mammalian order Rodentia, which consists of about 1750 species world-wide. They account for 28% of the total mammalian fauna in Eastern Africa (Kingdon, 1989). In Africa, rodents are the most ubiquitous and numerous among the mammals. The

soricomorph fauna (shrews) were slightly diverse with 140 species (Hutterer and Yalden, 1990).

In Ethiopia, the diverse macro and micro-climatic conditions have contributed to the formation of different ecosystems leading to diversity of life forms of both

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animals and plants (Senbeta, 2006). It is known that there occur 284 species of mammals of which 39.4% are small mammals (Yalden and Largen, 1992). However, recent data indicate the number has risen to over 300 (Bekele and Yalden, 2013).

Rodents are not uniformly distributed in all habitat types (Shenkute et al., 2006). The distribution of rodents and shrews depends on various factors, largely on the seasonal availability of food and water. In addition, vegetation structure and cover affect the micro-climate and protect small mammals against predators (Hansson, 1999). Their distribution and abundance is influenced by vegetation structure and composition, which reflect the habitat condition (Gebresilassie et al., 2004). Bekele (1996b) has revealed the distribution patterns of 10 species of rodents across different vegetation zones including human habitats in the Menagesha State Forest.

Small mammals consume invertebrates, leaves, fruits and seeds, and play extremely important role as dispersal and pollination agents in different habitats. Thus changes in their abundance and distribution can affect the dynamics of other species as well (Solari et al., 2002). In addition to seed dispersal, rodents and shrews are known to have ecological, economical, social and cultural values (Avenant, 2011). They play an important role in natural communities and they are the main food items for many predators including humans (Davies, 2002).

Small mammals are the most diverse group of mammals in Ethiopia. According to Yalden and Largen (1992), rodents comprise 25% of the Ethiopian mammal fauna, and around 50% of total endemic species. This is due to the diversified topography of the country.

Western lowlands of Ethiopia are under-explored for faunal diversity due to inaccessibility and remoteness of the area. Accelerated human interactions in search of arable land and resettlement have been adversely affecting the natural habitats of this area (Chekol et al., 2012). As a result, the biodiversity resources along with their habitats were rapidly disappearing in the country (Senbeta and Denich, 2006). Therefore, there is a need for further biodiversity assessments focused on the different habitats present in the area, with a particular emphasis on small mammals. The current study aims to investigate the diversity, abundance, habitat associations and distribution of rodents and insectivores in Chato Protected Area, Ethiopia.

## MATERIALS AND METHODS

### Study area

Chato Protected Area (CPA) is located in the Horo Guduru Wollega Zone of Oromia Region, Ethiopia. It was part of National Forest Priority Areas (NFPAs) and was known by the name, Chato-Sangi-Dangab Forest. The forest lies approximately between 9° 38' to 9°

48' N latitude and 36° 58' to 37° 20'E longitude along the borders of Jardega Jarte, Abe Dongoro and Horo Districts, 30 km north-west of Shambu which is located at about 314 km west of Addis Ababa. Chato Protected Area was located along altitudinal ranges between 1532 and 2537 masl and covers a total area of 42,000 ha. Plantations of *Eucalyptus* tree, *Juniperus procera* and *Cupressus lusitanica* comprise 18,000 ha of CPA, which correspond to 42.8% of its area (Figure 1).

For this study, we considered five habitat types. Thus, the native forests were categorized into three plant communities (Abdena, 2010), according to their structural composition and use (Table 1). The remaining two habitats correspond to forest plantations and riparian vegetation.

### Methods

A representative grid for each vegetation type was established based on possible representation of different habitats as well as easy accessibility. For both live and snap traps during wet (the last week of July and the first two weeks of August) and dry (March) seasons, the same sampling grids were used. Bats were not considered in this study.

Snap trapping grids were established at 200 m away from live trapping grids in each area. Traps of both live and snap trapping grids were separated and placed at 10 m intervals. Each sampling site of live trap constituted an area of 4900 m<sup>2</sup> (70 × 70 m). For body measurements (head and body length, tail length, hind foot and ear length) and further studies, 15 snap-traps were used during both wet and dry seasons.

A total of 49 Sherman live traps were used in randomly selected grids of each habitat during both seasons. The traps were baited with peanut butter and checked twice a day, early in the morning hours (6:00 - 8:00h) and late in the afternoon hours (17:00-18:00h). Traps were covered by hay and plant leaves during the dry season. Traps were re-baited as necessary for three consecutive nights.

Trapping and handling of captured rodents and shrews followed the procedures of Gurnell and Flowerdew (1990). A number was assigned to each toe and no two individual animals on the same grid were given the same mark even if they belong to the same species. Following the toe clipping method, a toe per foot was clipped to mark the individuals captured. Known captured animals were identified to their genus level, while others coded for identification in the Zoological Natural History Museum (ZNHM) of Addis Ababa University except *Crocidura* species which was not snap trapped.

Population number of rodents in each trapping sessions and grids was estimated by capture mark recapture (CMR) method. Shannon-Weaver Diversity Index was used for calculating the rodent species diversity in different habitat types. As;  $H = -\sum_{i=1}^s (p_i \ln p_i)$ , where:  $P_i$  is the relative proportion of species  $i$  in habitat and  $\ln$  is the natural logarithm.

Abundance of small mammals in each habitat was assessed by trap success during the wet and dry seasons. The percentage of trapped individuals was expressed as,  $\text{Trap success} = \frac{N}{Nt \times Nn} \times 100$ , where  $N$  is the number of individuals captured,  $Nt$  is the number of traps and  $Nn$  is trap nights. Comparisons of species richness, distribution and habitat association of species in the study area were made by using Chi-square test and SPSS Version 21.0 statistical program.

## RESULTS

From a total of 1862 trap nights, 254 individuals

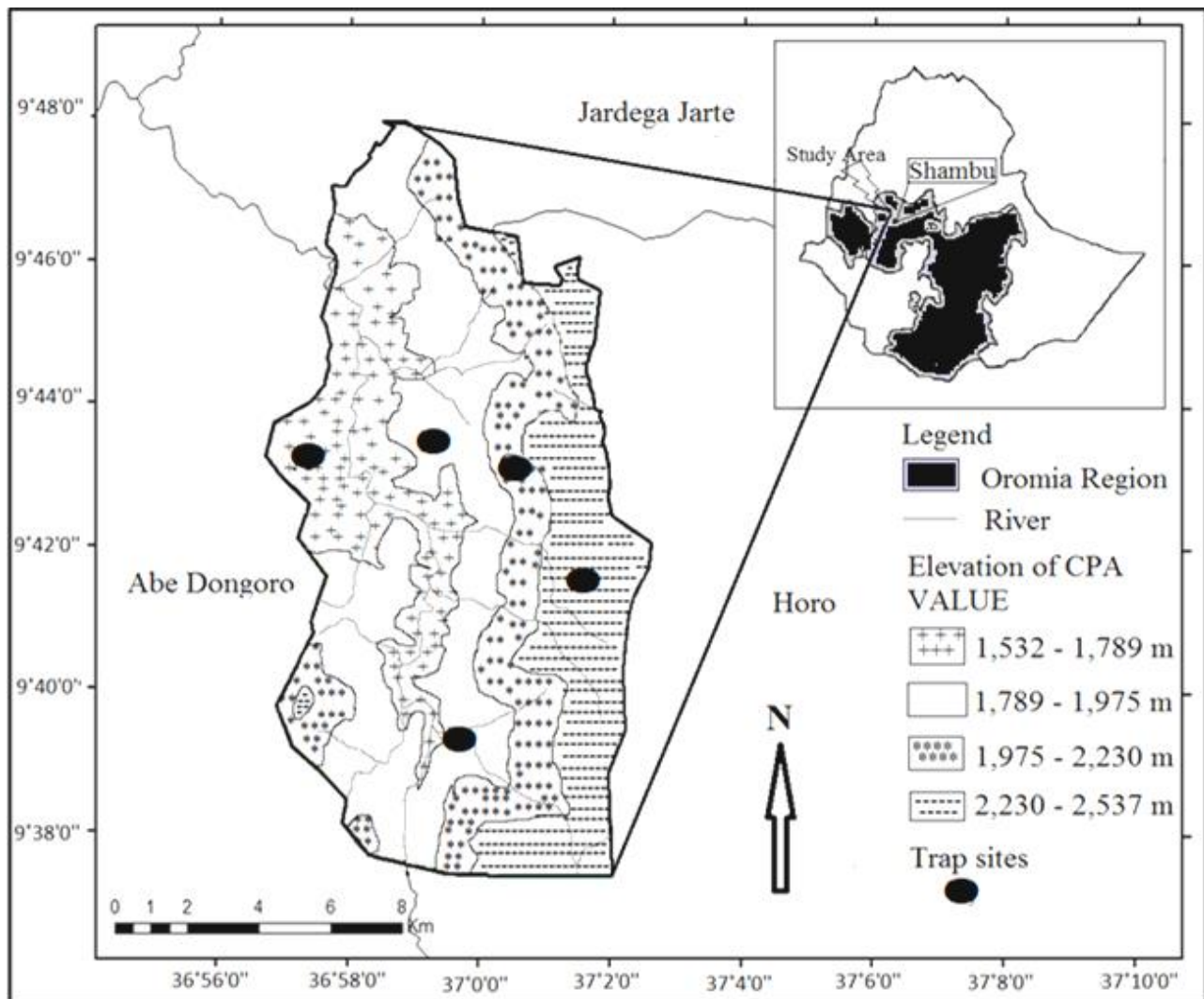


Figure 1. Location of the study area/Chato Protected Area, Ethiopia.

representing 5 rodent species and a shrew species were captured during both dry and wet seasons. These were: *Stenocephalemys albipes*, *Lophuromys flavopunctatus*, *Arvicanthis* sp., *Mus mahomet*, *Mastomys natalensis* and a *Crocidura* species. The total trap success was 13.64%. All of the species were recorded from *Maytenus gracilipes* dominated habitat between 1,789 -1,975 m asl.

*Stenocephalemys albipes* and *L. flavopunctatus* were trapped from all habitat types and *Arvicanthis* sp. was absent from a plantation habitat. *S. albipes* was the most abundant of all trapped animals that accounted the highest abundance (40.95%). A *Crocidura* sp. was the least abundant species of the study area while *L. flavopunctatus*, *Arvicanthis* sp. and *M. mahomet*, accounted 23.6, 16.9 and 13%, respectively. *Mastomys natalensis* was one of the least abundant (4.35%) rodents

of the area. *Crocidura* sp. was trapped only from two habitats (*Maytenus gracilipes* and *P. orophila* - *P. falcatus* dominated habitats) during the wet season, accounting 1.2% of all trapped animals. The total number of animals captured and percentage abundance of rodents and shrews were presented in Table 2.

All species were relatively more abundant during the wet season than the dry season. They showed an increment in number in all habitats except *L. flavopunctatus* in *M. gracilipes* dominated habitat and *S. albipes* in plantation habitat. *Crocidura* sp. was trapped only during the wet season from *M. gracilipes* and *P. orophila* - *P. falcatus* dominated habitats. The species richness of the habitats during the dry and wet seasons was statistically not significant ( $\chi^2 = 0.00$ ,  $df=5$  and  $p > 0.05$ ) (Table 2).

**Table 1.** Trapping sites at variable vegetation composition and altitudinal ranges in Chato Protected Area.

Habitat/ altitude	Dominant vegetation	Topography	Human activity
C.J. (1,532 up to 1,789 m)	Tree: <i>Carissa spinarum</i> , <i>Justicia schimperiana</i> ; Shrubs: <i>Clausena anistata</i> , <i>Ekebergia capensis</i> , <i>Diospyros abyssinica</i> , and <i>Maesa lanceolata</i> ; Herbs: <i>Hyposetes forskaoi</i> , <i>Setaria megaphylla</i> , <i>Kalancheo petitiana</i> , <i>Cyathula cylinderica</i> and <i>Achyranthes aspera</i> .	Steep	Low or no logging trees
M.G. (1,789 up to 1,975 m)	Trees: <i>Maytenus gracilipes</i> ; Shrubs: <i>Prunus africana</i> , <i>Ficus thonnigii</i> , <i>Ochna holstii</i> , <i>Myrsine africana</i> , <i>Dracaena afromontana</i> ; Herbs: <i>Cyperus fischerianus</i> , <i>Commelina foliacea</i> , and <i>Oplismenus hirtellus</i> .	Steep	Logging trees No other activities
P.P. (1,975 up to 2,230 m)	Trees: <i>Pyschotria orophila</i> , <i>Podocarpus falcatus</i> , <i>Landolphia buchananii</i> , and <i>Olea capensis</i> ; Shrubs: <i>Calpurnia aurea</i> , <i>Ocimum lamiifolium</i> , <i>Rubus steudneri</i> , and <i>solanum giganteum</i> , with few herbaceous plants	Slightly Steep	Logging trees Frequently grazed by domestic animals
Pl. (Above 2,230 m)	Plantation: Conifers ( <i>Juniperus procera</i> ), <i>Cupressus lucitanica</i> and <i>Eucalyptus</i> tree; Natural vegetation, and shrubs and grasses	Slightly steep	Logging and planting trees grazed by domestic animals
Rv. (1,714 up to 2,200 m)	Trees like <i>Podocarpus falcatus</i> , Shrubs:- <i>Ochna holstii</i> , <i>Olea welwitschii</i> , and some herbaceous plants	Steep	Logging trees grazed by domestic animals

C.J. = *Carissa spinarum* - *Justicia schimperiana* dominated, M.G. = *Maytenus gracilipes* dominated, P.P. = *Pyschotria orophila* - *Podocarpus falcatus* dominated, Rv. = riverine and Pl. = plantation.

**Table 2.** Seasonal species composition, distribution and abundance of live trapped small mammals from different habitats during both wet and dry seasons.

Species	Seasonal distribution of rodents at different vegetation zones										Total	% Abundance
	C.J.		M.G.		P.P.		Rv.		Pl.			
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet		
S.a.	9	12	7	15	18	22	2	8	7	4	104	40.95
L.f.	-	1	10	9	9	14	4	8	2	3	60	23.6
A. sp.	4	9	10	11	4	4	1	-	-	-	43	16.9
M.m.	3	3	3	7	6	10	-	-	-	1	33	13
M.n.	2	3	2	1	-	-	1	2	-	-	11	4.35
C.sp.	-	-	-	1	-	2	-	-	-	-	3	1.2
Total	18	28	32	44	37	52	8	18	9	8	254	100

- = not recorded, S.a. = *S. albipes*, L.f. = *L. flavopunctatus*, A.sp = *Arvicanthis* sp., M.m= *M. mahomet*, M.n. = *M. natalensis* and C.sp.= *Crocidura* sp. C.J. = *C. spinarum* and *J. schimperiana* dominated, M.G. = *M. gracilipes* dominated, P.P. = *P. orophila* and *P. falcatus* dominated, Rv. = riverine and Pl. = plantation.

The abundance of rodents varied between habitats. The highest abundance for *S. albipes*, 38.46% and *L. flavopunctatus*, 38.33% was in *P. orophila* - *P. falcatus* dominated habitat. The lowest abundance for *S. albipes*, 9.61% and *L. flavopunctatus*, 1.67% was in riverine and *C. spinarum* - *J. schimperiana* dominated habitats, respectively (Table 3).

Trap success and diversity index of five habitats with their altitudinal variation were given in Table 4. *M.*

*gracilipes* dominated habitats, between 1,789 and 1,975 m altitudinal variation was more diverse than others with  $H' = 1.51$  and trap success of 19.39%. The highest trap success was observed in *P. orophila* - *P. falcatus* dominated habitat (22.7%). This was the second most diverse habitat with diversity index of 1.32.

From the trapped animals, females comprised 54.3% and males 45.7%. The overall sex ratio of captured rodents from male to female of the study area was

**Table 3.** Species diversity, habitat preference and abundance in different habitats.

Species	Species abundance index per habitat				
	C.J.	M.G.	P.P.	Rv.	Pl.
<i>S. albipes</i>	20.19	21.15	38.46	9.61	10.57
<i>L. flavopunctatus</i> .	1.67	31.67	38.33	20	8.33
<i>Arvicanthis</i> sp.	30.23	48.83	18.60	2.32	0
<i>M. mahomet</i>	18.18	30.30	48.48	0	3.03
<i>M. natalensis</i>	45.45	27.27	0	27.27	0
<i>Crocidura</i> sp.	0	33.33	66.67	0	0
Abundance	18.10	30.0	35.04	10.20	6.7

C.J. = *C. spinarum* -*J. schimperiana* dominated, M.G. = *M. gracilipes* dominated, P.P. = *P. orophila* - *P. falcatus* dominated, Rv. = riverine and Pl. = plantation.

**Table 4.** Trap success and diversity indices of rodents and shrews in different habitats at various altitudes.

Altitude (m)	Habitats	No. of species	Trap nights	Total catch	(H') Shannon's diversity index	Trap success (%)
1,532-1,789	C.J.	5	294	46	1.30	15.65
1,789-1,975	M.G.	6	392	76	1.51	19.39
1,975-2,230	P.P.	5	392	89	1.32	22.7
1714-2200	Rv.	4	392	26	1.1	6.6
Above 2,230	Pl.	3	392	17	0.8	4.3

C.J. = *C. spinarum* -*J. schimperiana* dominated, M.G. = *M. gracilipes* dominated, P.P. = *P. orophila* - *P. falcatus* dominated, Rv. = riverine and Pl. = plantation.

1:1.19. The variation was statistically non significant. The structure of rodents and shrews of Chato Protected Area based on age and sex varied between species. From the total captured rodents and shrews, 142 individuals (55.9 %) were adults, 95 individuals (37.4%) were sub-adults and 17 individuals (6.70%) were young. In *S. albipes*, *L. flavopunctatus* and *Arvicanthis* sp., the number of adult individuals were higher than the number of sub-adults and young. The age structure of these rodents was statistically not significant ( $\chi^2=0.00$ ,  $df=2$  and  $p > 0.05$ ).

## DISCUSSION

Five species of rodents and one species of shrew were trapped from different vegetation types along altitudes of 1,532 to 2,537 m asl. This may not represent the whole species of the habitat due to heterogeneity and inaccessibility of some areas, but it gives update accounts of rodents and shrews recently present in the forest.

In terms of diversity, *P. orophila* - *P. falcatus* dominated habitat was the next more diverse ( $H'=1.32$ ) habitat than others. The lowest species composition and abundance were recorded in the plantation habitat due to barren

ground cover. Similar result was obtained from the study of Bekele (1996a) where young *J. procera* and *C. lusitanica* plantations supported fewer species and individuals because of bare ground, no cover and no berries.

The interference of human and other domestic animals was also another disturbing factor for rodents and shrews. Similar report by Bayessa (2010) indicated that modified habitats including plantation forest and cultivation influenced rodent distribution due to availability and quality of food, shelter and rainfall.

*S. albipes* and *L. flavopunctatus* were the two most distributed rodent species of the area. Their highest record was from *P. orophila*-*P. falcatus* dominated habitat followed by *M. gracilipes* dominated habitat. In the report of Bekele (1996a) in the Menagesha State Forest, *S. albipes* was found to be ubiquitous in the forest and was distributed up to 3300 m asl. *L. flavopunctatus* is one of the most common rodents in the moist areas of East Africa (Clausnitzer and Kityo, 2001), with very wide range of altitude from 500 to 4200 masl (Mulungu et al., 2008). This might be attributed to the diverse feeding habit of the species (Hanney, 1964).

*Arvicanthis* sp. was the third dominant and widely distributed rodent of the study area. Datiko et al. (2007)



also confirmed its wide occurrence in Ethiopia. The highest record of *Arvicanthis* species was from *M. gracilipes* and *C. spinarum* - *J. schimperia* dominated habitats. It was frequently trapped from lower areas of riverine habitat and totally absent from plantation habitat. The altitudinal distribution of this rodent was similar to that of Bekele's (1996a).

*M. natalensis* is distributed throughout sub-Saharan Africa (Kingdon, 1974). It is also widely distributed over most places in Ethiopia (Yalden et al., 1976). In Chebera Churchura National Park (CCNP), *M. natalensis* was the most abundant species constituting 29.0% of the total number of captures (Datiko and Bekele, 2013). Even though, in CPA, *M. natalensis* was the least abundant, it was trapped from *C. spinarum* - *J. schimperia*, *M. gracilipes* dominated habitats and riverine habitats only. *Crocidura* sp. was restricted to *M. gracilipes* and *P. orophila* - *P. falcatus* habitats (1,789-2,230 m).

Mean trap success of the current study area was 13.73%, which is high compared to Bekele (1996a) on Menagesha Forest (9.1%), Kassa and Bekele (2008) on Wando Genet (12.7%). There are also other places that have higher trap success in Ethiopia, Tsegaye (1999) on Entoto Natural Park (62.8%).

Total number of captures varied between seasons and the highest number of individuals was trapped during the wet season. The abundance of rodents was based on their reproduction time which can be affected by availability of food, shelter and moisture. The time of reproduction also varied from species to species. Similarly, Datiko et al. (2007) and Geleta (2010) stressed quality of food resource and shelter within habitats playing crucial role on the onset of breeding in many small mammal species.

In the present study, out of the total number of captured individuals, adults comprised the largest number (55.9%). This result goes in line with the study of Shanker (2001) who reported that adults and sub-adults have relatively larger home ranges than young individuals of the same species. As a result, the total number of capture for each age group varied. In most places of CPA, the abundance of female rodents was more than that of males. Similar findings were reported by Bekele (1996a), Datiko et al. (2007) and Datiko and Bekele (2013) in different parts of the country.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# Assessing the spatial distribution of bamboo species using remote sensing in Cameroon

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Bamboo resource assessment has witnessed great interest in the world with very little attention in the Congo Basin forests. This study was initiated to assess bamboo species distribution in Cameroon with respect to Agroecological Zones (AEZ), using remote sensing. Forty-eight sheets of Landsat 8/Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments' images were mosaiced with the Envi 5.3 software. The bamboo index (BI) was calculated and used to identify wild bamboo-growing regions in Cameroon. Maps of bamboo growing regions helped in ground truthing. GPS coordinates were used to validate the bamboo presence with an accuracy of 78%. The result showed that bamboo spatial area statistics was 794.60, 451 308.36, 241 295.87, 302 989.41 and 219 094.67 ha in Sudano-Sahel, Guinea Savannah, Western Highlands, Monomodal rainfall forests and Bimodal rainfall forest, respectively with a total of 1 215 482.91 ha. *Bambusa vulgaris* Schrad. ex J.C.Wendl.; *Oxytenanthera abyssinica* (A. Rich.) Munro; *Phyllostachys* sp.; *Yushania alpina* K. Schum; *Ochlandra travancorica* (Bedd.) Gamble; *Dendrocalamus strictus* (Roxb.) Nees; *Phyllostachys atrovaginata* C. S. Chao & H.Y.Chou; *Phyllostachys aurea* Rivière & C. Rivière, were found in Cameroon. *O. abyssinica* was dominant in Agroecological zones 1 and 2; *P. aurea* in Agroecological zones 3; and *B. vulgaris* in respectively Agroecological zones 4 and 5. These results can orientate policies and planning towards a sustainable bamboo sector development and mitigating the effects of climate change in Cameroon.

**Key words:** Spatial distribution, remote sensing, agroecological zone, climate change mitigation.

## INTRODUCTION

Bamboo belongs to the true grass family Poaceae and subfamily of Bambusoideae. There are 128 genera and 1718 bamboo species naturally distributed in tropical and

subtropical belts of Africa, Asia, Central and South America (Maria et al., 2016; Canavan et al., 2017). It is one of the fastest growing plants in the world (Kaushal et



al., 2018) and, some species can also successfully grow in the temperate regions of Europe and North America (Durai and Trinh, 2019; Nfornekah et al., 2020). The knowledge of bamboo distribution has been greatly enhanced by space technology. The use of remote sensing in mapping and monitoring of the spatial extent of bamboos growing in different regions of the world is a high-priority requirement for planners and resources managers. The conventional method of surveying and estimating the growing stock is time-consuming and costly. However, the development in space technology, particularly the repetitive satellite remote sensing (RS) across various spatial and temporal scales, offers the most economic means of assessing, planning, managing and monitoring the forest resources, including bamboo (Goswami et al., 2010; Zhao et al., 2018).

Bamboo is difficult to identify using remote sensing when compared to other land cover classes. This is due to the fact that: (1) many bamboos are distributed in patches influenced by their local climate conditions or anthropic interventions; thus, requiring high resolution imagery to identify them (Ghosh and Joshi, 2014); (2) some bamboo forms the understory layer of forested zones or mixed with other canopy (Reid et al., 2004; Doležal et al., 2009); (3) bamboo are among the fastest growing plants on Earth and frequently changing, thus increasing the challenge in collecting samples (Mertens et al., 2008; McMichael et al., 2013) and (4) bamboo has similar spectral properties with other vegetation classes, thus limiting the accuracy of spectrum use in separating bamboo from other vegetation types (Singh, 1987; de Carvalho et al., 2013).

Studies have been able to differentiate bamboo from other land use classes with data from remote sensing. Han et al. (2014) use SPOT-5 image data for bamboo mapping. A high spatial resolution, an object-based image analysis method and texture measures obtained from grey level co-occurrence matrices was used to map Moso bamboos in China. Ghosh and Joshi (2014) use the World View 2 imagery, which provide 2 m multi-spectral and 0.5 m panchromatic spatial resolution in lower Gangetic plains in West Bengal, India. The images used were obtained at the beginning of monsoons season, void of clouds. Li et al. (2016) use 4 Landsat images, and prove the importance of temporal information in bamboo mapping in China. Zhao et al. (2018) use multi-temporal Landsat imagery at 30 m spatial resolution, to identify bamboo hotspots of highland (*Yushania alpina*) and lowland (*Oxytenanthera abyssinica*) bamboos in Ethiopia, Kenya and Uganda. Du et al. (2018) use multisource remote sensing data to map the global bamboo forest distribution and gave an

appropriate area of bamboo forests globally at national or regional scale. INBAR (2018) use the United State Survey Landsat 8 Surface Reflectance images in the based-regional bamboo resource assessment of Madagascar's bamboo.

Bamboo has vigorous growth, with completion of the growth cycle between 120 and 150 days. This makes bamboo a powerful carbon sink as its sequestration carbon. Yuen et al. (2017) report that, bamboo biomass from 70 species (22 genera) estimated gave plausible ranges for above-ground carbon (AGC) biomass (16-128 Mg C/ha), below-ground carbon (BGC) biomass (8- 64 Mg C/ha), soil organic carbon (SOC; 70-200 Mg C/ha), and total ecosystem carbon (94-392 Mg C/ha). They further illustrate that, the total ecosystem carbon range is below that for most types of forests such as the rubber plantations and tree orchards, but greater than agroforests, oil palm, various types of swidden fallows, grasslands, shrublands, and pastures. In a similar dynamic, Nath et al. (2015) find that the mean carbon storage and sequestration rate in woody bamboos range from 30–121 Mg ha<sup>-1</sup> and 6-13 Mg ha<sup>-1</sup> yr<sup>-1</sup> respectively. With this great ability, bamboo can best be positioned in mitigating the effects of climate change within the context of REDD+ (Terefe et al., 2019).

In the context of this study, Landsat 8/OLI-TIRS (Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments) was used for mapping bamboo species distribution in Cameroon. The method of Goswami et al. (2010) was exploited because (1) it covers large surfaces beyond regional level (47 565 000 ha for Cameroon) (Talukdar, 2001), (2) did without temporal data (Ghosh and Joshi 2014) and (3) was less time consuming and cost effective.

Remote sensing shows China's bamboo resources covering about 6.5 million hectares of forests comprising 40 genera and 800 species (INBAR, 2019a). In East African countries, similar studies estimated bamboo resources in: Ethiopia as: 1 438 705 ha of highland and lowland bamboo resources; Kenya: 131 040 ha of bamboo; and Uganda: 54 587 ha (Zhao et al., 2018). Tanzania has about 127 000 ha of bamboo (Xiaoli, 2006); and Madagascar with about 1 123 694 ha of bamboo resources (INBAR, 2018). This knowledge on the bamboo stocks facilitate and support government actions on their environmental and socio-economic development orientations. In the Central African sub region (Central African forest Commission (COMIFAC)) countries amongst which Cameroon is a member, bamboo stocks are undetermined. A survey in literature for spatial or remote sense-based bamboo resources assessment yields no results; therefore, leaving a wide knowledge

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gap in the Congo Basin. This study has as objectives to map and identify bamboo species distribution in Cameroon with respect to the different AEZs. These results will facilitate policy and planning orientation towards a sustainable bamboo sector development and fight against effects of climate change in Cameroon in particular and Congo Basin as a whole.

## MATERIALS AND METHODS

### Study area

Cameroon is located between Latitude 2° N to 13° N and Longitude 8° 25' E and 16° 20' E in the Central African sub region. It opens to the Atlantic Ocean in the West with a total coastline of 402 km. It is bounded to the west by Nigeria, North-east by Chad, South by Gabon, Congo and Equatorial Guinea and to the East by Central African Republic. It has a total surface area of 47 565 000 ha (MINFOF, 2018).

The country is highly ecologically diverse and the diversity has earned Cameroon the title of "Africa in miniature". MINEPAT (2015) has broadly divided the country into five agroecological zones (Figure 1): agroecological Zone 1 (AEZ 1): Sudano-Sahel (19.8% of the country) where a more or less arid climate prevails; AEZ 2: The high Guinean savannah (19.8% of the country); AEZ 3: Western highlands (8.2%); AEZ4: Monomodal rainfall forest (12.3%) consisting of dense forests with a humid equatorial climate, covering the South West (4.3%), the Coast (3.4%), part of the South (3.7%) and a tiny portion of the Centre (0.7%); and AEZ5: Bimodal rainfall forest (39.9% of the country), composed of humid tropical forests, with a particularly dense hydrographic network, extending over the East (20.7%), the Centre (12.3%) and the South (6.4%). The climate and relief of the different agroecological zones of Cameroon vary between the Agroecological Zones (rainfall: 500-11000 mm; temperature: 21-28°C, elevation: 0.2-4050m) (Toukam et al., 2009). Three major soil types are common across Cameroon; ferrallitic soil covering Southern Regions (67%), volcanic soil covering Western Regions and ferruginous soils covering the Northern Regions (Yerima, 2005; Jiotsa et al., 2015; CIRAD, 2020). Vegetation of Cameroon is characterized by both forest and grassland. The forest covers AEZ 4 and AEZ 5 (Letouzey 1985). These zones are covered mainly with the equatorial forest, with the presence of mangroves mainly along the coast of Cameroon. The grassland covers the AEZ 3, 2 and 1 (Dobgima, 2014).

Bamboo is part of the true grass family (Poaceae), and makes up the largest and most productive member of the grass family. Bamboos are fast growing plants. They have three growing habits: cluster or clumping or Sympodia; running or spreading or Monopodia and a mixture of clumping and running called Amphipodia (Nath et al., 2015; Terefe et al., 2019). Basically, running bamboos are invasive and spread rapidly, while clumping bamboos generally stay confined to a single area. Bamboo has the ability to grow in regions that range from the sub-Saharan deserts of Africa, to the cold mountain terrain of the Himalayas. The sizes of bamboo species vary greatly. The smallest varieties grow to a height of 11 inches, while giant timber bamboo can reach heights of over 100 feet (<http://www.completebamboo.com/bamboo>).

This study was carried out between September and November, 2019. Data was collected in different phases: literature reviewed to gather secondary data and suitable remote sensing method to realise this study. Best imageries were selected, acquired, treated to obtain the bamboo index, and initial bamboo maps. Ground truthing was done with the help of a pocket GPS. Bamboo coordinates were superimposed to validate the final bamboo distributions in Cameroon. Figure 2 summarises the image

acquisition, treatment and validation for bamboo distribution in Cameroon. Landsat 8 is the most recently launched Landsat satellite in 2013 and carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments. Landsat 8/OLI-TIRS satellite images were chosen for this study. These images were those of November and December 2018 with a resolution of 30 m. These images were downloaded free of charge from [www.glovis.usgs.gov](http://www.glovis.usgs.gov) in GEOTIFF format. Zhao et al. (2018) evaluated the accuracies for bamboo mapped using single season imagery and found that the images acquired in September to February are the most informative in identifying bamboos. Images acquired within this interval are less cloudy and shadow less, and they cover the dying back process of vegetation, which is really important for differentiating vegetation classes, especially in identifying lowland bamboos. For reasons of complete coverage of the national territory, 48 sheets of these Landsat 8 OLI-TIRS satellite images were downloaded. Layer stacking consisted of unzipping the tapes and assembling them into a multispectral file. Geo-referencing and radiometric correction allows reposition of the 1m pixel offsets, to make radiometric and geometric corrections (cloud, atmospheric particles etc.). Mosaicking allows for 48 image scenes to be put together, using the Envi 5.3 software in order to have a continuous landscape of the study area.

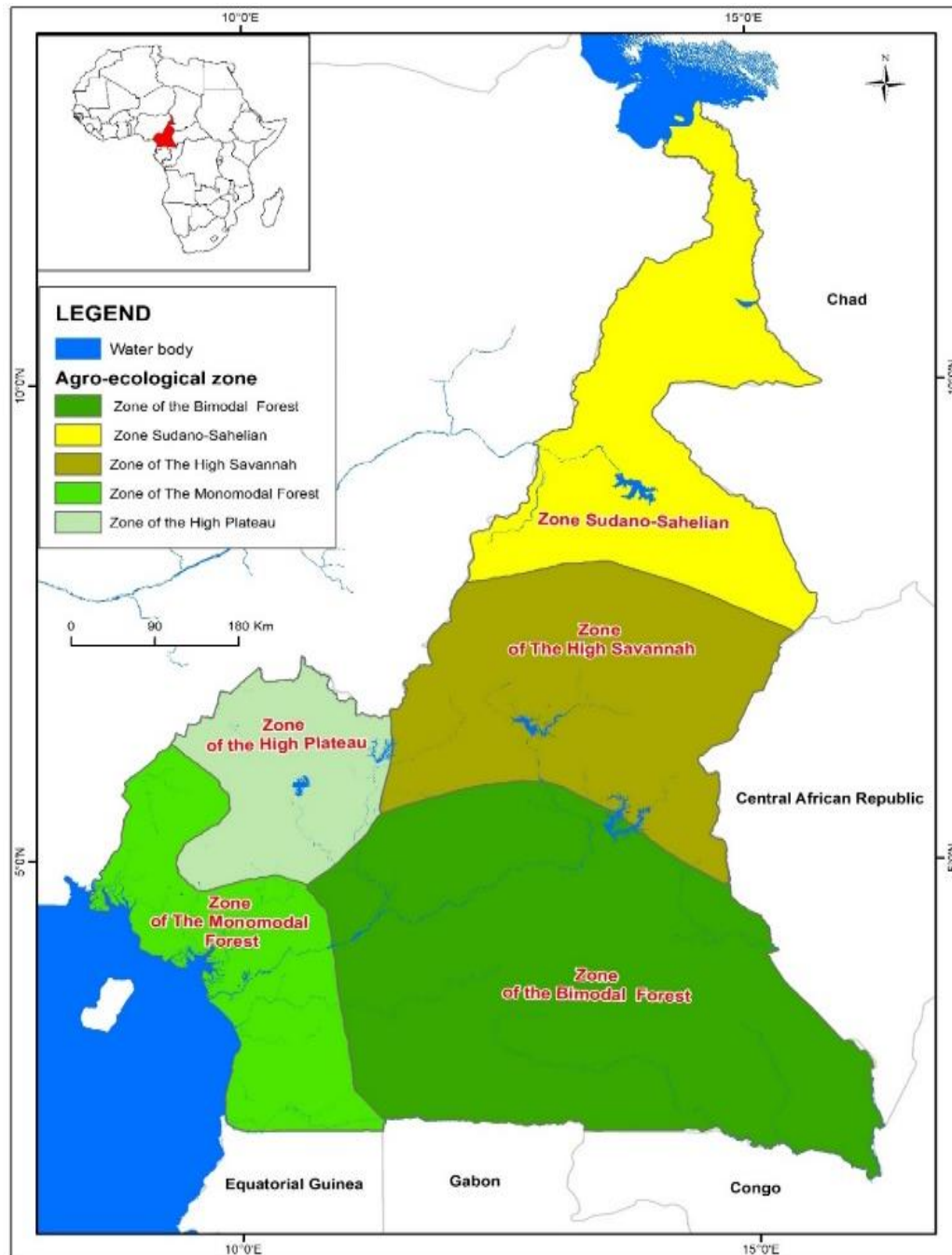
For index calculations, plant reflectance spectrum is determined by its leaf characteristics. This is controlled by certain factors and the main ones are the photosynthetic pigments and water absorptions. Different mathematical combinations (indices) of the multi-spectral bands are found to be sensitive indicators of the present conditions of specific types of green vegetation (Goswami et al, 2010). In this study context, one index (Bamboo Index) was developed and used to identify wild bamboo-growing areas in Cameroon. Preliminary maps of the bamboo growing regions were printed prior to field survey (ground truthing). Ground truthing was carried out with the help of these maps and local assistance. Bamboo growing areas were located based on the preliminary maps prepared through remote sensing prior to field survey. Resource persons contacted in the various localities gave information and led the different teams to the presence of bamboo in the area. The pocket GPS was used to track and record way points on data sheets. The different steps in ground truthing were: arrives in a target locality, acquires administrative and traditional authorisation; recruit local assistance; and identify bamboo sites. Bamboo specimen vouchers were collected for identity confirmation at the National Herbarium of Cameroon. Figure 3 shows the map of ground truthing in the national territory.

### Final validation

The validation consisted in making a comparison between the GPS field coordinates and the calculated bamboo indices. Knowledge-based bamboo species distribution groves in literature aided to upgrade or complement bamboo species identified and their distribution in this study in Cameroon.

### Data analysis

Landsat 8 OLI-TIRS imageries were acquired and treated with Envi 5.3 software; and QGIS 3.2. software was used to dress the maps. GPS coordinates from ground truthing permitted to control the bamboo distributions and validation in the various agroecological zones. The following stages were executed: Bamboo indices were developed for the whole country to identify wild bamboo-growing areas of the 5 different AEZs in Cameroon. For example, Figure 4 represents the wild-growing bamboo area in AEZs 1 (Sudano-Sahelian).

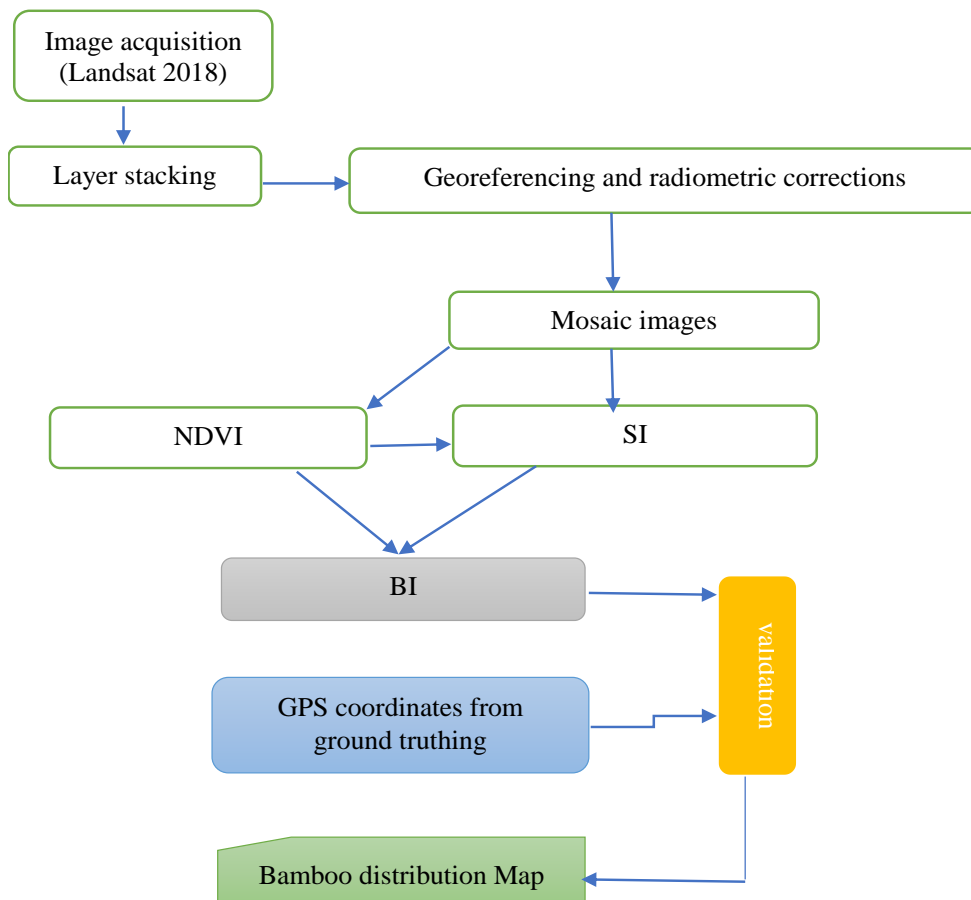


**Figure 1.** Map indicating the agroecological zones (AEZs) of Cameroon. Source: Laboratory of Geomatics.

Bamboo-growing areas (magenta) were spectrally differentiated using a combination of red, near Infrared (NIR) and green (Short Wave Infrared (SWIR)) bands: band 2 - blue (0.45-0.51 μm); band 3 - green (0.53-0.59 μm); band 4 - Red (0.64 - 0.67 μm) 30 m; band 5 - Near-Infrared (0.85 - 0.88 μm) 30 m; band 6 - SWIR 1(1.57 - 1.65 μm); band 7 - SWIR 2 (2.11 - 2.29 μm) 30 m; and band 8 - Panchromatic (0.50-0.68 μm)) 30 m, for Operational Land Imager (OLI). For Thermal Infrared Sensor (TIRS),the two spectral bands were band 10 TIRS 1 (10.6 - 11.19 μm) 100 m and band 11 TIRS 2

(11.5 - 12.51 μm) 100 m (<https://www.usgs.gov/land-resources/nli/landsat/landsat-8>). An improved technique is adopted using a measure of Standardised Vegetation Index (NDVI) and water stress index (SI) as a measure of leaf water content (Goswami et al., 2010). Jensen (1996) and Lillesand and Kiefer (2000) define these indices as:

$$\text{Normalized Difference Vegetation Index (NDVI): } NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$



**Figure 2.** Image acquisition, treatment and validation for bamboo distribution in Cameroon. Legend: NDVI (Normalized Difference Vegetation Index), SI (water stress index) and BI (Bamboo index)

Water stress Index (SI):  $SI = \frac{NIR-SWIR}{NIR+SWIR}$  (2)

Bamboo Index (BI):  $BI = \frac{NDVI-SI}{NDVI+SI}$  (3)

Where: NIR is near infrared; RED is red and SWIR is green.

The demarcation of bamboo areas using water stress index (SI) was possible because of the leaf water content of plants. Leaf water content of bamboo is less than that of other plant species. The index value difference of bamboo leaves with other land-use classes is less. To increase this difference, a normalized (double) difference bamboo index (BI) was prepared using NDVI and SI in a bamboo vegetation. The resultant imagery was then used to identify bamboo areas based on the index values. Accuracy evaluation was done with the help of GPS coordinates collected from ground truthing.

## RESULTS

### Bamboo spatial area statistics

The estimated total area of bamboo distribution in

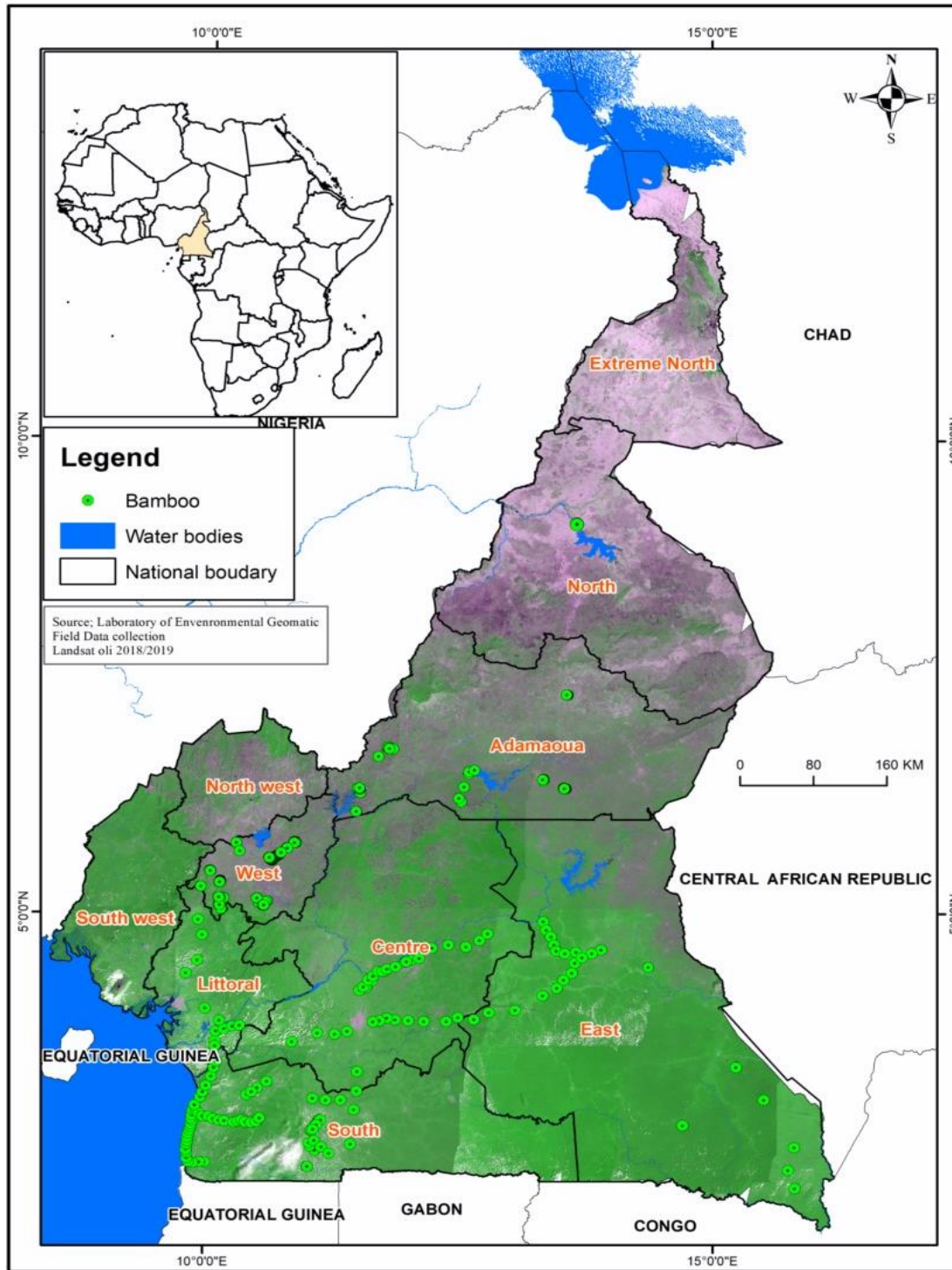
Cameroon for this study was 1,215,482.91 ha (Figure 5). There is unequal distribution of bamboo in the different AEZs (Table 1). Cartographic distribution of the bamboo groves in the different AEZs is illustrated on the map (Figure 5).

### Distribution of bamboo groves in the different AEZs in Cameroon

#### Sudano-Sahelian or AEZ 1

The distribution of bamboos in the AEZ 1 was the least amongst the 5 AEZs with an estimated area of 794.60 ha representing 0.1% of bamboo in Cameroon. Bamboo here is mostly planted at the banks of River Benue; and the species found were both *Bambusa vulgaris* and *Oxytenanthera abyssinica*. These bamboos are planted in the Sub Divisions of Lagdo, Garoua 2, Garoua 3 and Pitoa in the North Region. Bamboo indices indicated the presence of bamboo in the North Eastern part of the



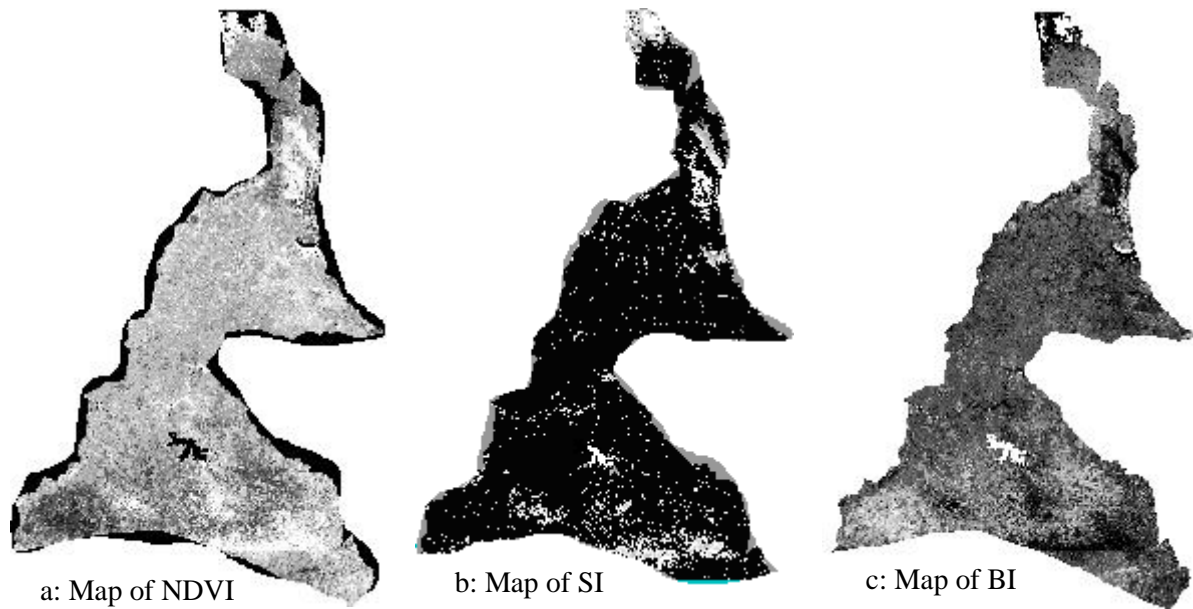


**Figure 3.** Map of ground truthing in the national territory.  
Source: Laboratory of Geomatics.

Waza National Park along River logon (in the Logon and Chari Division); and in Kaele (Mayo Kani Division) from the Far North Region of Cameroon (not ground truth during survey).

**High guinea savannah or AEZ 2**

The bamboo index indicated the largest bamboo distribution in the AEZ 2 with (451,308.36 ha)



**Figure 4.** Bamboo index (BI) for AEZ1 of Cameroon.

Source: Laboratory of Geomatics.

Legend: NDVI (Normalized Difference Vegetation Index), SI (water stress index) and BI (Bamboo index).

representing 37% of the total bamboo in Cameroon. The dominant bamboo species *O. abyssinica* was recorded in this zone. *O. abyssinica* is drought-resistant, so it occurs on the vast savannah woodlands, along the river valleys and spreads around the North Western and North Eastern parts of the Adamaoua plateau. The *O. abyssinica* was also widely distributed in the South Western part of the AEZ 2, especially on the Beyala hill, Ngaoundal, Tibati, Banyo and Bankim (Njoum-njoh). They thrive well in mean rainfall of 1200 mm, mean annual temperature of 23°C and altitudinal range of 500 - 1500 (m.a.s.l.). Two bamboo species were conspicuous in this zone: *B. vulgaris* and *O. abyssinica*.

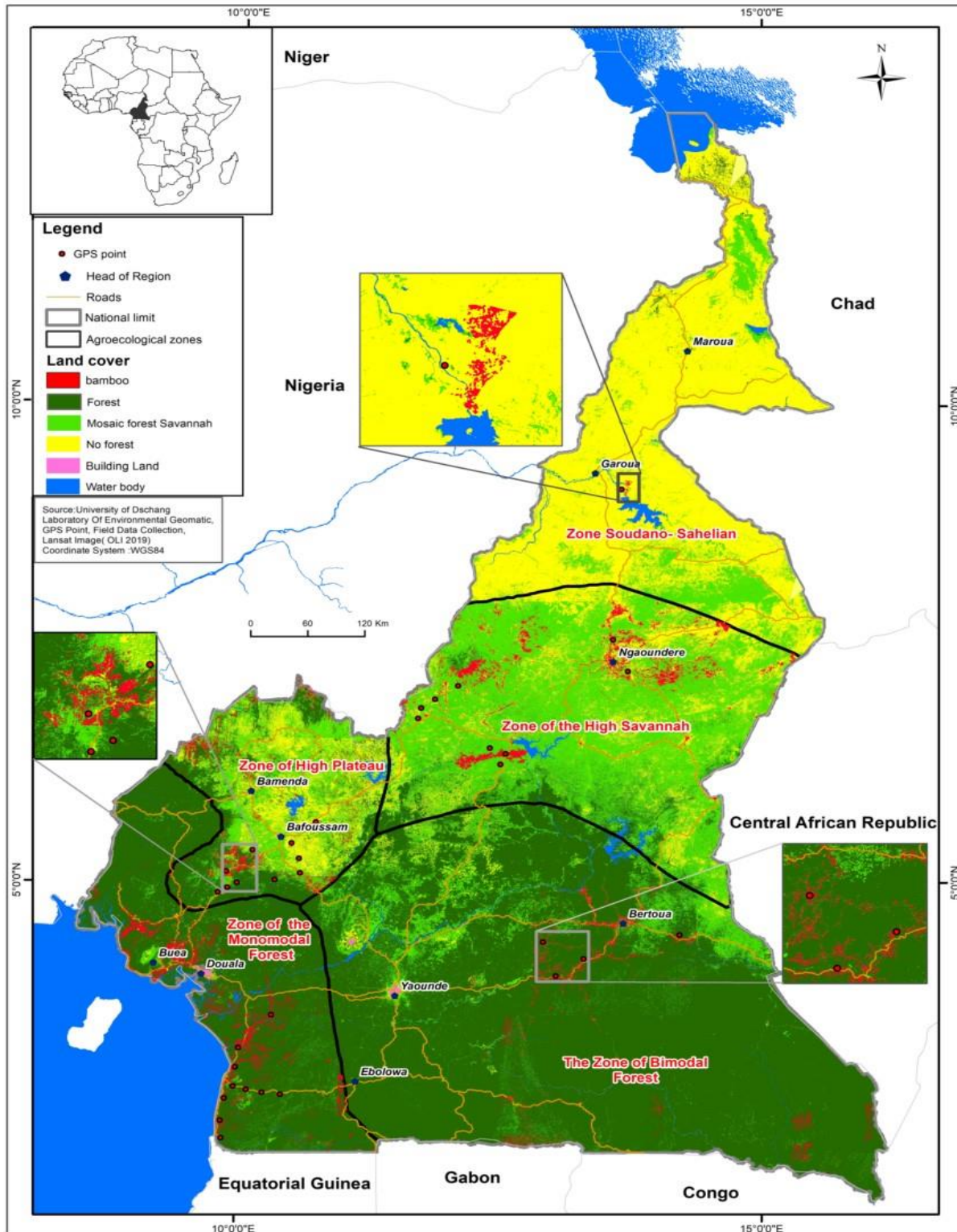
### Western highlands or AEZ 3

This AEZ 3 has bamboo covering 241,295.87 ha representing 20% of the total bamboo in Cameroon. The bamboo species conspicuously found here were: *Phyllostachys* sp., *B. vulgaris*, *Ochlandra travancorica* (Bedd.) Gamble, and *Phyllostachys aurea*. *Ochlandra travancorica* (Bedd.) Gamble was found in life fence/hedge or garden. *Phyllostachys aurea* was the dominant bamboo species in AEZ 3 identified in several Divisions like: Noun, Nde; Bamboutos and Haut-Nkam; on the East of western highlands. *B. vulgaris* groves were also found in abundance in Menoua (Foreke Dschang and Fomopea) Division (South western highland). These were planted on the Foreke escarpment to protect against erosion and landslides. BI indicated the presence

of bamboo in Menchum, Bui and Ndonga-Mantong Divisions in the North West Region of Cameroon, part of the AEZ 3 (not ground truth during survey). The climate here had a mean rainfall of 2000 mm; mean annual temperature of 21°C and elevational range of 1500 to 2500 (m.a.s.l.).

### Monomodal rainfall forest or AEZ 4

The Monomodal rainfall forest or AEZ (South West, Littoral, part of Centre and South Regions) has a dominant bamboo species *B. vulgaris*. Bamboo index indicated this AEZ as the second largest in bamboo surface area coverage with an estimated area of 302,989.41 ha representing 25% of bamboo in Cameroon. This study found that on the West and South East of the AEZ 4 road sides, bamboo groves and isolated stands of *B. vulgaris* were mapped on the Campo – Kribi road; Kribi – Bipindi -Lolodorf- Eseka road; Kribi – Akom 2- Ebolowa road; Akom 2 -Bipindi road; Kribi – Edea road; Edea -Yabassi -Loum road; Edea-Pouma- Boumnebyie road and Loum-Ebonje. *B. vulgaris* was also found in communities of Mouanko; Mbanga; Djombe; Penja; Manjo; Nkongsamba; and Melong. Other Bamboo species were identified: in Kribi (*Dendrocalamus strictus* (Roxb.) Nees) and *Phyllostachys* sp. and Akak-Campo (*Ochlandra travancorica* (Bedd.) Gamble). BI also largely indicated the presence of bamboo in the coastal areas in the South West Region of Cameroon, which is part of the AEZ 4 (not ground truth during survey). In



**Figure 5.** Mapping of bamboo-groves using BI in the different agroecological zones in Cameroon. Source: Laboratory of Geomatics.

total, 4 bamboo species were conspicuously found here. AEZ 4 experiences a mean annual rainfall of 3000 mm;

mean annual temperature of 26°C and elevational range of -2 to 4000 m.a.s.l.



**Table 1.** Area cover map of different AEZs in Cameroon.

Agroecological Zone	Area (ha)	%
Bimodal Forest (AEZ5)	219 094.67	18.03
Monomodal Forest (AEZ4)	302 989.41	24.93
High Plateau (AEZ3)	241 295.87	19.85
Guinea Savannah (AEZ2)	451 308.36	37.13
Sudano-Sahelian (AEZ1)	794.60	0.07
<b>Total</b>	<b>1215482.91</b>	<b>100.00</b>

**Table 2.** Accuracy rates based on different agroecological zones in Cameroon.

Agroecological zone	Precision %
Bimodal Forest (AEZ5)	89.43
Monomodal Forest (AEZ4)	93.65
High Plateau (AEZ3)	91.05
Guinea Savannah (AEZ2)	62.12
Sudano-Sahel (AEZ1)	53.02
<b>Accuracy for the study</b>	<b>77.854</b>

### **Bimodal rainfall forest or AEZ 5**

The bimodal rainfall forest has a bamboo distribution coverage estimated at 219 094.67 ha representing 18% of the total bamboo in Cameroon. *B. vulgaris* was the dominant species. *B. vulgaris* groves were found distributed in areas like Bibey (Mbeli locality); Nanga-Eboko (Mfomalen); Nkoteng (Nzili locality); Ebolowa (localities of Nkoueloun, Niabizam, Akom 2 and Bidou); Eseka (Bat-Bat and Sombadjeck); Mandjou (Kouba and Ngamboula); Abong Mbang (field survey); Lomie and; Djembe and Lobeke. The *O. travancorica* species was identified in Bertoua. In the main towns of AEZ 5, the bamboo species *Phyllostachys* sp. was largely used in life fencing/ hedges and or garden bamboos. The climate here recorded annual mean rainfall of 1600 mm; mean annual temperature of 25°C and elevation of 400 to 1000 (m.a.s.l.).

### **Accuracy rate of bamboo images**

The accuracy rate of bamboo surveyed in AEZs 1 and 2 were 53 and 62% respectively, while AEZ 4 recorded excellent precision of 94%. Then, the mean accuracy rate was 78% (Table 2).

## **DISCUSSION**

### **Bamboo spatial area statistics**

Cameroon in the Central African sub Region, through this

study will be the first country to have estimates of their bamboo stocks spatially, placing this study as a baseline for the other nations within this block. The results of this study showed Cameroon as the second in terms of surface area covered (1,215,482.91 ha) with bamboos in Africa after Ethiopia with 1,438,705 ha and thirdly by Madagascar with 1 123 694 ha of bamboo resources (INBAR, 2018; Zhao et al., 2018). Ghana has 300 000 ha of bamboo (Kwame et al., 2020). However, in terms of the number of bamboo species, Madagascar is the first with 33 bamboo species (Kigomo, 1988; Gurmessa et al., 2016). China has over 6.5 million ha of bamboo surface cover currently (INBAR, 2019b).

### **Distribution of bamboo groves in the different AEZs in Cameroon**

This result made us to understand that different bamboo species are adapted to different ecological zones and their presence seemly affected by altitudes in Cameroon. The different bamboo species abundance in different AEZs may have altitudinal influence in Cameroon (Paudyal et al., 2019; Deo Kumar et al., 2013; Yuen et al., 2017; Terefe et al., 2019). *B. vulgaris* species is found in all AEZs probably because of their wide range in altitudes (300-1500 m.a.s.l) that favours its growth and development, and can be naturalised easily (Paudyal et al., 2019; Deo Kumar et al., 2013). *O. abyssinica* is abundant in the AEZs 1 and 2 probably because it is drought tolerant specie (Inada and Hall, 2008; Deo Kumar et al., 2013, Yohannes, 2019) and lowland specie (Yohannes, 2019), which is synonymous to the climate



and altitude of the AEZ 1 and 2. *Phyllostachys* sp. thrives best at altitudinal range of 1200-1400 m.a.s.l. which fits exactly with the altitude of the zone of dominance in AEZ 3 and *Yushiana alpina* are more adapted to hilly or a certain level of altitude above 2200 m.a.s.l. and the Kilum-Ijem Mt. is above 3000 m.a.s.l. (Grimshaw, 1999; Ingram et al., 2010; Deo Kumar et al. 2013).

This distribution is very crucial and is targeted for Cameroon. The Government of Cameroon (GoC) and INBAR are developing bamboo policy and complementary legislations for a sustainable development of the bamboo sector (Neba et al., 2020). This study will inform policy makers (GoC), planners (INBAR) and development partners on the number of hectares of bamboo existing already in Cameroon, their distributions and the dominant species. This could orientate bamboo development policies, strategies (under elaboration) and bamboo plan (MINOF, 2018; Muh et al., 2018), in the respective ecological zones with respect to more adapted bamboo species. For example, the present known bamboo stocks could be expanded by planting bamboo in marginal and degraded lands of the Guinea savannah and Sudano-Sahelian zones (AEZ 1 and 2) to mitigating the effects of climate change (FAO and INBAR, 2018; INBAR, 2019a); mangroves of the Coastal or Littorals (AEZ 4) of Cameroon, especially aquatic biodiversity conservation (Wetlands International, 2008), bioenergy feedstocks: biofuel, fodder for cattle in AEZs 1, 2 and 3 (Nellie et al., 2012; UNEP, 2019); agricultural production (bamboo agroforestry) (MINADER 2015), industrial transformation of bamboo into best utilities: paper pulp, furniture, construction etc. (AEZ 3, 4 and 5) (INBAR, 2019b). Local population benefits the exploitation of the bamboo rudimentarily and use for social needs in Cameroon (Ingram et al., 2010). This result supports the reference of Goyal et al. (2012) that bamboo is a 'poor man's timber' and is used by many rural populations in daily life.

The images showed the presence of bamboo in part of AEZ1 (Far North); AEZ 3 (North West), and AEZ 4 (South West) regions; that ground truthing did not take place due to insecurity. Complementary data was collected from literature to describe bamboo distribution in the North West region (NW), part of AEZ 3. In Bui (Mt. Kilum Ijum of Oku); *Y. alpina* is the dominant bamboo species at an altitude above 2000 m (Ingram et al. 2010). *B. vulgaris* has also naturalised in the NW. *B. vulgaris* as reported in Bamenda, Bali Nyonga, Bafut, Wum, with their main harvesting sites being Bafut, Bambui and Bamenda (Lauber, 1990; Maisels and Forboseh, 1999; Cheek et al., 2000; Ingram et al., 2010).

In the South West Region, part of AEZ 4, Ingram et al. (2010) report *B. vulgaris* as the dominant species in the Man O war, Lissoka, Idenao, Mundemba and Korup etc. The presence of bamboo groves and isolated stands are reported on Ekok-Mamfe road; Mamfe – Otu road; Buea, Muea, Molyko, Bokwango, Bonananjo, Bonakanda and Bokwai; Bimbia, Tiko, Mutengene, Limbe and Idenau;

Kumba, Takamanda, Mamfe (Dione et al., 2000; Ingram et al. 2010). Mt Kupe; Bimbia Bonadikombo, Manyu and Meme Divisions extensively along the Kumba-Mamfe stretch, in Buea, Limbe, Lebialem and Mundemba; Bachuo'ntai and Eyumojock-Manyu Division, Buea, Limbe; Ejagham, Ossing, Kembong, Besong-Abang (Cheek et al., 2004; Mdaihi et al., 2002; Tabot, 2006; Nkwatoh, 2005).

### Accuracy rate of bamboo images

A number of studies (Singh, 1987; de Carvalho et al., 2013; Zhao et al., 2018) have reported that some bamboo species (*O. abyssinica*) has affinity to shrublands and grasslands. This creates confusion in differentiating bamboo from the shrublands and grasslands leading to overestimation of bamboo in such zones. This should likely be the reasons behind the low accuracy rate in AEZ 2 and AEZ 1. The precision was low confirming the phenological confusion between the bamboo and shrubs/grasses. Bamboo is probably over estimated in these zones. Another reason would be that during the dry season, this specie, *O. abyssinica*, lose their leaves by shedding. *O. abyssinica* losing their leaves during this period may negatively affect bamboo index power from discriminating and differentiating different plant leaves from those of bamboo, thus increasing BI error margin. This rate of confusion can be overcome with thorough ground truthing, repeated temporal and spatial treatment of images and validations of the bamboo images. On the other hand, there is a high tendency that bamboo is underestimated in AEZs 4 and 5. This is because of the canopy shade in the tropical rainforest area (Reid et al., 2004; Doležal et al., 2009), and more so, the phenological confusion of *Y. alpina* and *B. vulgaris* to forest tree canopy (Zhao et al., 2018). The accuracies in AEZs 3, 4 and 5 were high and may be due to the fact that *B. vulgaris*, *Phyllostachys* sp. and *Y. alpina* do not shade leaves in the dry season thus, their leaves were clearly discriminated from other foliage type by index treatment (BI). Knowledge-based results of other bamboo studies would be of help for studies beyond national or regional level.

### Conclusion

Spatial distribution mapping of bamboo is necessary for resource evaluation, conservation of biodiversity, and ecological management. This study estimated the total bamboo surface area cover in Cameroon as 794.60, 451 308.36, 241 295.87, 302 989.41 and 219 094.67 ha in Sudano-Sahel, High Guinea Savannah, Western Highlands, Monomodal rainfall forests and Bimodal rainfall forest respectively; giving a total of 1 215 482.91 ha. From knowledge-based identification of bamboo

species per AEZ, *O. abyssinica* dominated the bamboo species in the AEZ 1 and 2; *P. aurea* dominated AEZ 3; *B. vulgaris* dominated AEZ 4 and 5. The different bamboo species identified during this study included *B. vulgaris*, *O. abyssinica*, *Phyllostachys* sp., *Y. alpina*, *O. travancorica*, *D. strictus*, *P. atrovaginata*, and *P. aurea*. This baseline study in the Congo Basin can be exploited by other researchers and policy makers to orientate policies towards the development of bamboo resources in the Cameroon and Congo Basin.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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