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# Bamboo diversity and carbon stocks of dominant species in different agro-ecological zones in Cameroon

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**Bamboo is of ecological and socio-economic importance in the world. However, knowledge on its potential in climate change mitigation remains superficial in Cameroon. The present study identified bamboo diversity and estimated carbon stocks of the dominant species in Cameroon. Ground truth method and local informants were used for a bamboo species survey in five Agro-ecological zones (AEZs). Twenty-two circular plots of 100 m² each were utilized for biomass and density data collection in AEZ 2, AEZ 3 and AEZ 4. Destructive method was used to collect 5% of culms per plot sampled for bamboo biomass estimation. Culm density and carbon stocks for each bamboo species were extrapolated to hectares. A total of 8 bamboo species were recorded in the inventory. Three dominant bamboo species were identified (*Bambusa vulgaris, Oxytenanthera abyssinica* and *Phyllostachys aurea*) in different AEZs. For the three dominant bamboo species, biomass of culm was greater (76-84%), than those of branches (13-19%) and leaves (4-9%). Culm density varied significantly across the different bamboo species, that is, 2296, 4374 and 38017 culm/ha respectively for *B. vulgaris*, *O. abyssinica* and *P. aurea*. Carbon stocks varied from 13.13 tC ha$^{-1}$ (*O. abyssinica*); 29.62 tC ha$^{-1}$ (*B. vulgaris*) and 67.78 tC ha$^{-1}$ (*P. aurea*), with significant variations ($P < 0.05$) across the different bamboo species. The fast growth rate of bamboo underpins its potential for climate change mitigation and could influence decisions and strategy for the fight against climate change in Cameroon.**

**Key words:** Agro-ecological zone, climate change mitigation, culm density, REDD+ strategy, Cameroon.

## INTRODUCTION

The bamboo plant is a perennial woody-stemmed grass which belongs to the Bambusoideae sub-family, Graminae (Poaceae) family. It can be classified into monopodial (running), sympodial (clumping) and

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amphipodia (Arun et al., 2015). It is fast growing, widespread, and renewable (Lodovikov et al., 2007; Terefe et al., 2019). It easily adapts to an extreme and diverse range of climates and soil conditions (Xu et al., 2018). According to International world checklist Bamboos and Rattans (Maria et al., 2016), 1642 bamboo species have been identified in the world. Bamboo covers approximately 37 million hectares of forests across the tropical and subtropical world: Africa, Asia and Central and South America which is about 3.2% of the world's total forest area (FAO and INBAR, 2018). In Africa, there is an estimated 43 species of bamboo covering about 1.5 million hectares (Gurmessa et al., 2016). Madagascar alone counts 43 species including 32 native African species (INBAR, 2018). In Cameroon, the preliminary inventory done by Ingram et al. (2010) recorded a diversity of 5 bamboo species.

Bamboo plays an important role in ecosystem services, biodiversity conservation and socio-economic development (Ingram et al., 2010; Yuen et al., 2016, 2017; Terefe et al., 2019). In the context of climate change mitigation, it is recognized as an important carbon sink (Gurmessa et al., 2016; Li et al., 2016; Yuen et al., 2016; Xu et al., 2018; Xayalath et al., 2019). In Cameroon, bamboo is considered as a Non-Timber Forest Product (NTFP) by decision n° 0209/D/MINFOF/CAB of 26 April 2019 of the Government of Cameroon. It has an important socio-economic value of Cameroonians (Ingram et al., 2010). Ecologically, it is used to preserve river banks, and to restore some degraded lands due to its extensive fibrous rhizome and root systems that can decrease surface soil erosion, lower the risk of shallow landslides, and stabilize river banks (Song et al., 2011). However, bamboo forests in Cameroon are today under threat by deforestation and degradation, because they have been historically criminalized as invasive species and increasingly discouraged, leaving it with no guarantee to continue its socio-economic and ecological function (Ingram et al., 2010; Yuen et al., 2017).

Global climate change has inspired and instilled an increasing interest of scientific and policy stakeholders in the study of global carbon storage in order to look for a way to mitigate the trends of increasing $CO_2$ concentration in the atmosphere. One important thing about bamboo here is that some major species are introduced and can be accepted in the context of degraded forests restoration in Cameroon, thus constituting one major carbon sinks in the Congo Basin forests. Nevertheless, knowledge on bamboo in Cameroon is still very limited and studies on carbon stocks potential of bamboo are few. Many authors have mentioned bamboo as a solution to climate change mitigation owing to its fast growing nature and high capacity to sequestrate and store carbon (Jyoti et al., 2009; Nath et al., 2012, 2015; Zhuang et al., 2015; Li et al., 2016; Yuen et al., 2017). Considering that Cameroon is involved in many initiatives related to landscape restoration and natural resource management, such as REDD+ mechanism, Afr100 and Nationally Determined Contribution (NDC) with the commitment to reduce emissions (32% by horizon 2035) as a contribution to the global effort of COP 21, it is important to measure the contribution of all potential carbon pools in order to orientate a climate change mitigation strategy. Within this context, bamboo forest ecosystem was a candidate for this study. This study was initiated to (1) investigate the number of bamboo species in Cameroon; (2) characterise the most common bamboo species in Cameroon, (3) estimate bamboo carbon storage capacity with the different agro-ecological zones in Cameroon.

## MATERIALS AND METHODS

### Study area

This study was carried out across the national territory of Cameroon which covers a total surface area of 475 000 $km^2$. Cameroon is located between latitudes 2° and 13° N and longitudes 8° 30' and 16° 10' E. It is divided into 5 AEZs. A summary of the climate and relief of these 5 AEZs is presented in Table 1. Four major types of soil are common across Cameroon; ferralitic soil essentially in the southern part of Cameroon, representing 67% of the soils in the country, volcanic soils within the Cameroon volcanic belt, ferruginous soil covering almost all of the Northern Regions (Adamawa, North and Far North) of the country and hydromorphic soils found especially in wetlands. The hydrographical network is dense in Cameroon (e.g. Sanaga, Benue, Wouri, Moungo, Kadey etc). More than 47% of Cameroon's national territory is forested (de Wasseige et al., 2009). The forest is mainly closed tropical broad-leaved rainforest with three predominant types: lowland evergreen, lowland semi-deciduous, and montane. The closed forests are concentrated in the south and along the coast. Concerning vegetation, Cameroon is characterized by both forest and grassland. From the southern part of Cameroon to the northern part, we can find humid forest, transition forest, savannah, etc. (Ingram et al., 2010). Climate of Cameroon is summarized in Table 1.

Cameroon's population was estimated at 19.4 million as of 1 January 2010, a projection derived from the Population and Housing Census of November 2005. This is based on an estimated annual growth rate of 2.6%. A little over half (50.5%) of the population is female, and 43.6% of the population is less than 15 years old (Ingram et al., 2010). The principal activities of the population are subsistence agriculture through slash and burn, gathering and marketing of NTFPs, hunting and fishing. Bamboo is one of the NTFPs exploited in Cameroon. They are exploited for socio-economic purposes as per listed uses: furniture; fencing and hedges; construction materials; utensils, baskets and containers; hunting implements; crop supports (climbers: bean, yams, tomatoes), musical instruments; ornamental and decorative planting; fuelwood paper and food etc (Ingram et al., 2010).

### Selection of sample sites

This was done with the aid of literature reviews (Ingram et al., 2010; Ingram and Tieguhong, 2013; Ingram, 2017) on bamboo in Cameroon. Literature helped to identify the geographic location of bamboo production, processing and consumption zones in Cameroon. Local bamboo experts (informants) were identified within the bamboo primary stakeholders in the different AEZs of

**Table 1.** Precipitation, altitude, and temperature range in the different AEZ of Cameroon.

| AEZs | Rainfall (mm) | Altitude (m.a.s.l.) | Mean annual temperature (range) |
|---|---|---|---|
| Sudano- Sahelian zone | 500-900 | 250-500 | 28°C (7.7) |
| Sudano-Guinean high savannah zone | 1500-1800 | 500-1500 | 23°C (6.4) |
| Western Highlands zone | 1800-2400 | 1500-2500 | 21°C (2.2) |
| Monomodal rainfall forest zone | 2000-11000 | 0-500 | 26°C (2.8) |
| Bimodal rainfall forest zone | 1500-2000 | 400-1000 | 25°C (2.4) |

Source: Toukam et al. (2009).

Cameroon. These informants were knowledgeable of bamboo production and different bamboo groves in order to lead field technical research teams for data collection. Five technical data collection teams were deployed to the different AEZs for ground truthing (field verification to ascertain truth) and data collection. Here the geographical coordinates of the bamboo groves were recorded (Figure 1). Bamboo specimen vouchers were collected to identity confirmation in the National Herbarium Obili at Yaounde. These data permitted us to complement and confirm the major bamboo species present in the AEZs in Cameroon. This survey in the 5 AEZs and literature permitted this study to count the number of bamboo species in the lineage of Bambuseae in Cameroon.

However, it is important to note that our study on bamboo carbon stocks estimation laid emphasis on *Oxytenanthera abyssinica* (A. Rich.) Munro; *Phyllostachys aurea* Riviére & C. Riviére., and *Bambusa vulgaris* Schrad. ex J.C.Wendl. in three AEZs where they were found in great quantities in Cameroon and was in AEZ 2, 3 and 4 respectively.

## Data collection

### *Ecological factors*

The three bamboo species were from three different ecological zones (Agroecological zones): *O. abyssinica* from (AEZ 2), *P. aurea* from AEZ 3 and *B. vulgaris* from AEZ 4. Since the environment upon which the plants grow affect the plants, the ecological factors of the plots were collected and presented in Table 2 (AEZ 2), Table 3 (AEZ 3) and Table 4 (AEZ 4).

### *Carbon stocks assessment*

Bamboo density and biomass data were collected in a forest of bamboo, meeting the definition of a forest as defined by FAO (2010). The size and shape of the sample plots were consistent across the sample plot system. The circular plot of 100 m² was laid out for running bamboo (*P. aurea*) when the density of bamboo was 60-120 culms plot$^{-1}$ and for clumping bamboo (*B. vulgaris* and *O. abyssinica*) when 1.5-2 clumps plot$^{-1}$(Huy and Trinh, 2019).

Bamboo culm density and biomass data were collected in a total of 22 circular plot of 100 m² (5.64 m radius): eight plots of *O. abyssinica*; 6 plots of *P. aurea* and 8 plots of *B. vulgaris*. Bamboo culm densities and biomass plots designed for clumping bamboo (*O. abyssinica*; and *B. vulgaris*) were as follows: at a GPS waypoint placed by convenience in the plot on arrival, the nearest bamboo clump was determined; from there five distances of six nearest bamboo clumps sequentially were measured (Huy and Trinh, 2019). From the average distance between the bamboo clumps, the number of bamboo clumps per hectare was calculated. The number of culms ($N_{culms}$) per clump was also counted.

Bamboo biomass estimation was done using the destructive approach because, allometric equations developed for these species elsewhere did not have the same environmental factors (e.g. edaphic factor, climatic variables, etc.). According to this context and in each circular plot, 5 % of bamboo with respect to age group was felled for sampling; for each clump present (sympodial bamboo *B. vulgaris* or *O. abyssinica*) and for *P. aurea* (running bamboo) in the plot. In all, 5 % of all total culms in circular plots were sampled. It is important to note that for each plot sampled, three age classes were considered. The age class was divided into 1 year, 2 year and ≥ 3 year old culms (Devi et al., 2018). Bamboo morphology and color change aided in identifying different age groups (Huy et al., 2013; Li et al., 2016). For each culm sampled, in addition to specimen collection for bamboo species identity confirmation, dendrometric variables were the height, the diameter at 1.50 cm (Huy and Trinh, 2019) and age class. For sympodial bamboo, additional data like girth (m) and number of culms ($N_{culm}$) were also collected. Then, the harvested bamboo was sorted out into components (e.g. culms, branches and leaves), weighed with an electronic suspension scale (capacity 300 kg) separately for total fresh biomass of the bamboo. Subsamples of the different bamboo components: culm (at 3 positions on the culm: root collar, middle and top); branches and leaves with approximately 100-300 g (using electronic scale of precision 0.1 g) were collected for each bamboo sampled. These subsamples were oven dried at 105°C until constant weight, in the laboratory of Rural Engineering of the University of Dschang, Cameroon; in order to obtain the biomass ratio.

## Data analysis

Data analysis was done using R software version 3.4.1. Descriptive analysis was done for measurement variables and bamboo biomass of components.

## Bamboo density estimation

The estimation of the number of clumps and culms per hectare of sympodial bamboo *B. vulgaris* and *O. abyssinica* was done using respectively the following formulae (Huy andTrinh, 2019):

$$\mathrm{N_{clumps}\ ha^{-1} = N_{clump} \times \frac{10^4}{plot\ area\ (m^2)}} \quad (1)$$

$$\mathrm{N_{i\ culms}\ ha^{-1} = N_{i\ culm} \times N_{clump}\ ha^{-1}} \quad (2)$$

For running bamboo (*P. aurea*), the number of culms was determined using the formulae:

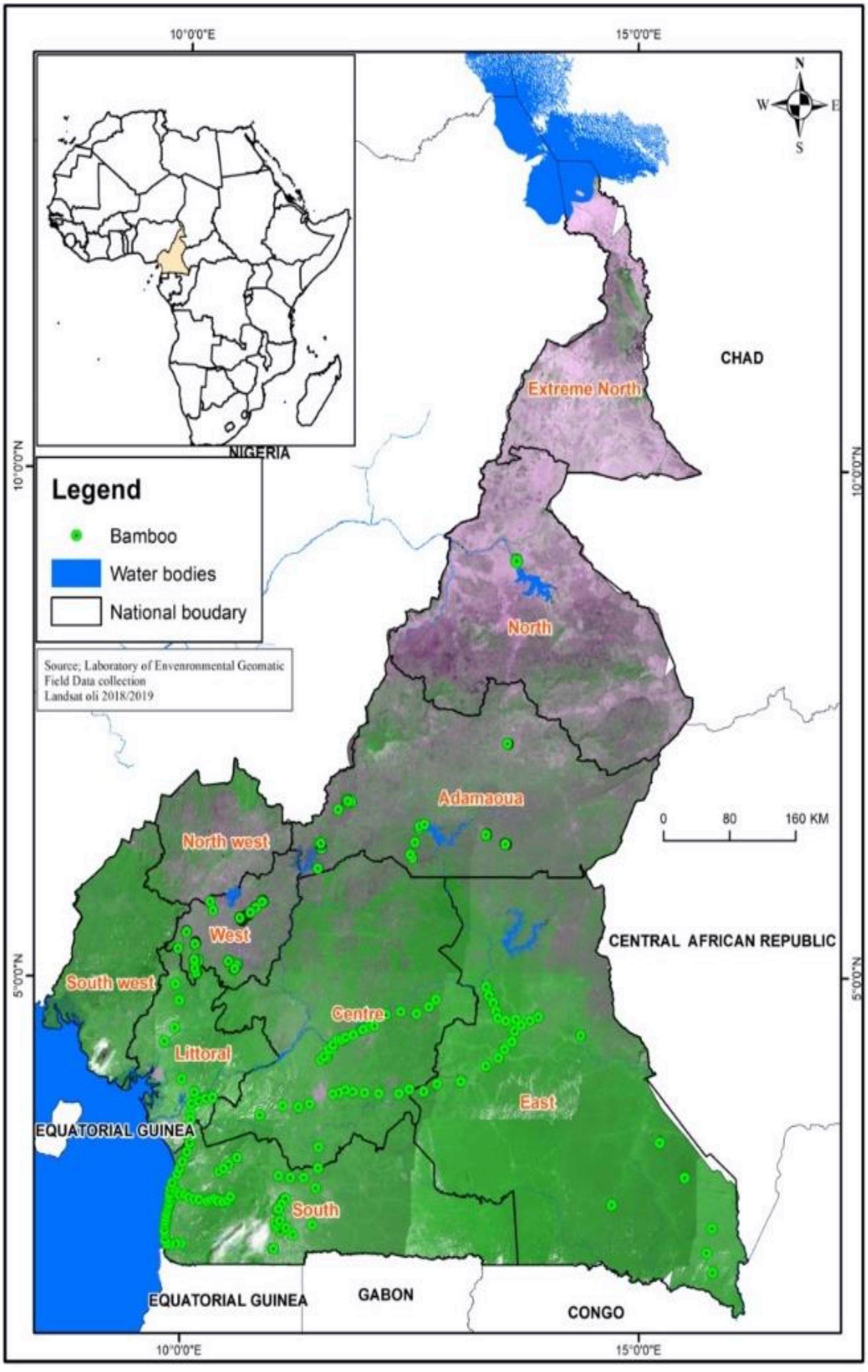


**Figure 1.** Map of ground truthing in the national territory of Cameroon.

**Table 2.** Summary of ecological factors affecting *Oxytenanthera abyssinica* in AEZ 2.

| Factors/variable | Value |
|---|---|
| Mean annual rainfall (mm) | 1200 |
| Mean annual temperature (°C) | 23 |
| Source : Toukam et al. (2009); Institut de Recherche Agricole pour le Développement (I.R.A.D.) (2005) | |
| | |
| Bedrock | Metamorphic rocks |
| Soil colour | Red |
| Soil type | Ferruginous soils |
| Source: Yerima and Van Ranst (2005); CIRAD, 2000). | |
| | |
| Altitude range (m.a.s.l.) | 778 to 1038 |
| Soil layer depth range (cm) | 25 to 40 |
| Slope gradient range (°) | 10 to 20 |
| Source: Sample plots | |

**Table 3.** Summary of ecological factors affecting *Phyllostachys aurea* in AEZ 3.

| Factors/variable | Value |
|---|---|
| Mean annual rainfall (mm) | 2000 |
| Mean annual temperature (°C) | 21 |
| Source : Toukam et al. (2009) ; IRAD (2005) | |
| | |
| Bedrock | Igneous rocks |
| Soil colour | Red, grey, dark |
| Soil type | Volcanic soils (clay, rocky) |
| Source : Yerima and Van Ranst (2005); Jiotsa et al. (2015) | |
| | |
| Altitude range (m.a.s.l.) | 1124 to 1349 |
| Soil layer depth range (cm) | 5 to 70 |
| Slope gradient range | 10 to 40 |
| $H_{culm}$ (m) | 9.9 to 11.2 |
| Source: Sample plots | |

$$\mathrm{N_{culms}}\ ha^{-1} = \mathrm{N_{culm}} \times \frac{10^4}{\text{plot area } (\mathrm{m}^2)} \quad (3)$$

**Bamboo biomass and carbon stocks estimation**

Total dry-weight of each component (for each culm bamboo sampled) was determined using the following formulae (Gurmessa et al., 2016):

$$\mathrm{TDW} = \frac{SDW}{SFW} \times \mathrm{TFW} \quad (4)$$

Where; TDW= total component dry weight; SDW= subsample dry weight; SFW= subsample fresh weight; and TFW=total component fresh weight.

Culm bamboo above ground biomass ($AGB_{bamboo}$) corresponds to the sum of the total dry bamboo biomass of the culm ($AGB_{cl}$, kg), branches ($AGB_{br}$, kg) and leaves ($AGB_{le}$, kg):

$$AGB_{bamboo} = AGB_{cl} + AGB_{br} + AGB_{le} \quad (5)$$

For sympodial bamboo, aboveground clump biomass ($AGB_{clump}$) was estimated by the formulae:

$$AGB_{clump} = AGB_{bamboo} \times \mathrm{N_{i\ culm}} \quad (6)$$

For culm and/or clump aboveground biomass estimation for each plot, the extrapolation at the hectare was done using the following extrapolation factor,

$$\text{(EF); EF=}\ \mathrm{AGB}\ (\mathrm{t\ ha^{-1}}) = \frac{10^4}{\text{plot area } (\mathrm{m}^2)} \quad (7)$$

AGB corresponds to the bamboo aboveground biomass (culm or clump) in 100 m².

**Table 4.** Summary of ecological factors affecting *Bambusa vulgaris* in AEZ 4.

| Factors/variable | Value |
|---|---|
| Mean annual rainfall (mm) | 3000 |
| Mean annual temperature °C) | 26 |
| Source: Toukam et al. (2009); IRAD (2005) | |
| Bedrock | Metamorphic, Igneous rocks |
| Soil colour | Greyish dark, brown red to dark, dark |
| Soil type | Ferralitic soils (Silty, hydromorphic and Sandy) and Volcanic soils (rich in organic matter) |
| Source: Yerima and Van Ranst (2005); Jiotsa et al. (2015) | |
| Altitude range (m.a.s.l.) | -7 to 755 |
| Soil layer depth range (cm) | 5 to 60 |
| Slope gradient range (°) | 2 to 8 |
| $H_{culm}$ (m) | 12.3 to 19.3 |
| Source: Sample plots | |

According to Jyoti et al. (2009), Huy and Trinh (2019) and Huy et al. (2019), the carbon content in bamboo represents 47% of it biomass. Like that, bamboo carbon stocks at the hectare were estimated by the following formulae:

$$\text{Carbon stock (t C ha}^{-1}\text{)} = \text{biomasses (t ha}^{-1}\text{)} \times 47\% \quad (8)$$

With respect to the fact that 1 tC = $3.67tCO_{2eq}$, the following formulae was used for bamboo $CO_2$ stocks.

$$\text{Stock } CO_2\ (tCO_2eq.ha^{-1}) = \text{Carbon stock (t Cha}^{-1}\text{)} \times 3.67 \quad (9)$$

#### Comparative carbon analysis

For the comparison of culm density, biomass and carbon stocks amongst 3 bamboo species, firstly, the Shapiro-Wilk normality test was used to test data for normality test. ANOVA and Turkeys tests (parametric test) were used for data which follow a normal distribution and the non-parametric tests (Kruskal-Wallis and Wilcoxon) used for data do not follow a normal distribution; were performed to test for significant difference amongst these bamboos. In this study, Kruskal-Wallis and Wilcoxon tests were used for bamboo culm density comparison and ANOVA and Turkey tests were used to compare biomass of the different bamboo species.

## RESULTS

### Bamboo species in Cameroon

Bamboo species inventoried nationwide permit the identification of eight (8) bamboo species in the lineage of Bambuseae (tropical woody). These bamboo species were: *Bambusa vulgaris* Schrad. ex J. C. Wendl., *Oxytenanthera abyssinica* (A. Rich.) Munro, *Bambusa sp. longinternode, Phyllostachys aurea* Riviére & C. Riviére., *Phyllostachys* sp., *Ochlandra travancorica* (Bedd.) Gamble, *Phyllostachys atrovaginata* C. S. Chao & H. Y. Chou and *Dendrocalamus strictus* (Roxb.) Nees. Out of these bamboo species in Cameroon, only *Oxytenanthera abyssinica* (A. Rich.) Munro is endemic in Africa. *B. vulgaris* was found represented in all the different AEZs. They were in great quantities (abundant) as the dominant bamboo species in AEZ4 and AEZ5. Some bamboo species like *Dendrocalamus strictus* and *Ochlandra travancorica.* were less common in Cameroon. Bamboo species like *Phyllostachys aurea* and *Dendrocalamus strictus* were found in AEZ3 and AEZ4, respectively (Table 4).

Literature however, provided the following bamboo species in Cameroon: *Dendrocalamus aurea* (MINFOF 2018), *Puelia atractocarpa* and O*reobambos buchwaldi* (Bystriakova et al., 2002; Ohrnberger and Goerrings 1988); *Yushania alpina* (Ingram et al., 2010), making a total of 12 bamboos of the lineage of Bambuseae. Data from the National Herbarium, Yaounde identifies 11 bamboos to species level and 4 species to sp. level; giving a total of 15 bamboo species in Cameroon.

### Characteristics variables of the three bamboo species

According to our observation in the field, three bamboo species appeared dominant in Cameroon (study area). Their characteristics are presented in Table 5. Considering the fact that *P. aurea* is not a sympodial species, data like girth (m) and $N_{culms}$ were not available for this bamboo species. *B. vulgaris* had the largest diameter with main diameter of 7.62±1.21 and the highest height with mean 15.95±2.96. For girth, *B. vulgaris* was still the largest with mean value of 20.75±9.76. Therefore, *B. vulgaris* > *O. abyssinica* > *P. aurea* in diameter. Comparing height, *B. vulgaris* > *P. aurea* > *O. abyssinica.* For girth of clump and number of culms per clump: *B. vulgaris* > *P. aurea.* $N_{culms.clump}^{-1}$:

**Table 5.** Bamboo species identified in different AEZs with respect to their abundance in Cameroon (“+” refer to the abundance of bamboo species with respect to other bamboo species in this area. Absence of “+” refer to the absence of bamboo species observed in this AEZ).

| Bamboo species | Status | Area observed in Cameroon | Abundance in different agroecological zone | | | | |
|---|---|---|---|---|---|---|---|
| | | | AEZ1 | AEZ2 | AEZ3 | AEZ4 | AEZ5 |
| *Bambusa vulgaris* Schrad.ex. J.C.Wendl. | Introduced | South, Littoral, Centre, West, East and Adamoua | + | + | ++ | ++++ | ++++ |
| *Bambusa longinternode* | | Centre; West | | | + | | + |
| *Dendrocalamus strictus* (Roxb.)Nees | Introduced | Kribi | | | | + | |
| *Ochlandra travancorica* (Bedd.) Gamble | Introduced | Kribi, Campo, Bafang | | | + | + | |
| *Oxytenanthera abyssinica* (A. Rich.) Munro | Native | Beyala, Tibati, Banyo, Bankim, North. etc. | + | ++++ | | | |
| *Phyllostachys aurea* Riviére & C. Riviére, | Introduced | Bafang, Baleck, Babou, Koupara, West Cameroon | | | ++++ | | |
| *Phyllostachys atrovaginata* C. S. Chao & H. Y. Chou | Introduced | Bertoua, Tonga, | | | + | + | |
| *Phyllostachys sp.* | Introduced | Bafang, Bertoua, Menuoa etc. | | | + | | + |

### Characteristic of biomass components (leaves, branches, culms and total AGB culm bamboo) of these three bamboo species

Summary of bamboo biomass of the three most abundant bamboo species in Cameroon is given in Table 6. Biomass of bamboo culm was higher than those of branches and leaves. Average biomass of bamboo leaves for the three bamboo species was: *B. vulgaris* > *P. aurea* > *O. abyssinica*. Those of branches and culm follow the gradient *B. vulgaris* > *O. abyssinica* > *P. aurea.* Concerning the percentage of biomass for the different bamboo components, aboveground biomass for bamboo was 84, 13 and 4% respectively for culms, branches and leaves of *B. vulgaris*. For *O. abyssinica*, it was 77, 19 and 4% respectively; and for *P. aurea,* bamboo biomass was 76, 14 and 9% respectively for the three components.

### Culm density and carbon stocks of the three bamboo species on study

Since *P. aurea* is running bamboo, the $N_{clump}$ $ha^{-1}$ was not estimated. The arithmetic average with standard deviation and statistical analysis of density, biomass, carbon stocks and $CO_2$ stocks are summarized in Table 7. The results showed that average culm per hectare varied significantly with respect to the bamboo species (Kruskal-Wallis test, p<0.000). However, Wilcoxon test showed that this difference was not significant between culm number per ha of *B. vulgaris* and *O. abyssinica*. The high value of culm per ha was found for *P. aurea* which was significantly different from those of these two bamboo species (Figure 2A). The contrary was observed with average culm bamboo biomass (kg) which varied significantly with respect to the bamboo species (Figure 2B) where that of *P. aurea* was low and significantly different from those of *B. vulgaris* and *O. abyssinica* (Kruskal-Wallis and Wilcoxon tests, p <0.000). ANOVA test (p <0.000) showed a significant difference between the three bamboo species with respect to carbon stocks and $CO_{2eq}$ (Figure 2C, D). Comparing the carbon stocks or $CO_2$ stocks of these bamboo species two by two, Turkey test showed a significant difference (p <0.000). Globally, average carbon stocks of the three (3) bamboo species significantly followed the gradient of: *P. aurea* (67.78 tC $ha^{-1}$) >*B. vulgaris* (29.62 tC $ha^{-1}$) > *O. abyssinica* (13.13 tC $ha^{-1}$) Table 8.

## DISCUSSION

### Bamboo species and characterization

The diversity of bamboo showed that, many species were small sized bamboo except of the pan-tropical species (*Bambusa* sp.) which are medium. Cameroon still need to have big sized bamboos and this will probably be introduced species. The medium and big sized bamboo shall be very important for industrial transformation into other utilities. Cameroon has 12 bamboo species and other studies reports Madagascar, Ethiopia and Ghana with 33, 25 and 8 bamboo species respectively (INBAR 2018, Mulatu et al., 2016; Amare and Shiferaw, 2020; Kwame et al., 2020).

Bamboo has 10 000 documented uses (INBAR, 2019)

**Table 6.** Summary of bamboo dendrometric parameters in the selected AEZs.

| AEZs | Bamboo species | Predictive variables | Minimum | Maximum | Mean | Stand. dev. |
|---|---|---|---|---|---|---|
| | | Diameter (cm) | 4.33 | 10.66 | 7.62 | 1.21 |
| | | Height (m) | 9.55 | 22.34 | 15.97 | 2.96 |
| AEZ 4 | *B. vulgaris* | Age (year) | 1 | ≥ 3 | - | - |
| | | $Girth_{clump}$ (m) | 7.18 | 40.00 | 20.75 | 9.76 |
| | | $N_{culm\ clump}{}^{-1}$ | 20 | 255 | 107 | 67 |
| | | Diameter (cm) | 2.01 | 6.61 | 3.93 | 0.66 |
| | | Height (m) | 2.00 | 11.02 | 8.40 | 0.36 |
| AEZ 2 | *O. abyssinica* | Age (year) | 1 | ≥ 3 | - | - |
| | | $Girth_{clump}$ (m) | 2.18 | 8.33 | 3.64 | 1.19 |
| | | $N_{culm\ clump}{}^{-1}$ | 9 | 61 | 23 | 11 |
| | | Diameter (cm) | 1.69 | 4.39 | 3.40 | 0.51 |
| | | Height (m) | 7.70 | 13.70 | 10.67 | 1.34 |
| AEZ 3 | | Age (year) | 1 | ≥ 3 | - | - |
| | *P. aurea* | $Girth_{clump}$ (m) | - | - | - | - |
| | | $N_{culms\ clump}{}^{-1}$ | - | - | - | - |

**Table 7.** Summary of the biomass of bamboo culms (kg) of the three (03) bamboo species.

| Parameter | AEZ 4 | | | AEZ 2 | | | AEZ 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***B. vulgaris*** | | | ***O. abyssinica*** | | | ***P. aurea*** | | |
| | leaves | branches | culms | leaves | branches | culms | leaves | branches | culms |
| Minimum | 0.08 | 0.18 | 1.69 | 0.00 | 0.01 | 1.01 | 0.01 | 0.04 | 0.4 |
| Maximum | 4.07 | 14.57 | 55.03 | 1.29 | 7.62 | 18.44 | 0.95 | 0.99 | 6.02 |
| Mean | 0.82 | 2.65 | 17.61 | 0.22 | 1.14 | 4.67 | 0.36 | 0.54 | 2.9 |
| Stand. Dev. | 0.84 | 2.34 | 10.58 | 0.34 | 1.18 | 2.98 | 0.25 | 0.21 | 1.12 |

**Table 8.** Carbon stocks of the three bamboo species most abundant in Cameroon.

| Descriptive statistic | AEZ 4 | AEZ 2 | AEZ 3 |
|---|---|---|---|
| | ***B. vulgaris*** | ***O. abyssinica*** | ***P. aurea*** |
| $N_{culms.}$ $ha^{-1}$ | $2296±631^{a}$ | $4374±2604^{a}$ | $38017±4510^{b}$ |
| $N_{clumps.}$ $ha^{-1}$ | $20±3^{a}$ | $184±83^{a}$ | - |
| Average $AGB_{culm}$ (kg) | $29.80±6.96^{b}$ | $6.39±3.44^{a}$ | $3.79±0.54^{a}$ |
| $AGB_{clump}$ bamboo (t $ha^{-1}$) | 63.02±4.10 | 27.97±14.63 | 144.21±21.58 |
| $AGB_{clump}$ bamboo (t C $ha^{-1}$) | $29.62±1.93^{b}$ | $13.13±6.88^{a}$ | $67.78±10.14^{c}$ |
| $AGB_{clump}$ bamboo (t $CO_{2eq\ ha}{}^{-1}$) | 108.70±7.07 | 48.19±25.24 | 248.75±37.22 |

Statistical analyses (parametric and non-parametric tests) are significant at 95% confidence interval.

and every part of the plant can be utilised. This knowledge on the number, diversity in species and characteristics (diameter, height, culm density and clump density per hectare) of bamboo are very important to inform policy makers and planners in the bamboo sector of the resources available, their ecological conditions and location. This information shall have an impact on the bamboo choices to be promoted for different transformation sectors. For the case of Cameroon, *O. abyssinica* (lowland bamboo) is best adapted to the semi-arid zones with mean annual rainfall of ≤1200 mm and temperature of ≤ 23°C (Guinea savannah and Sudano-

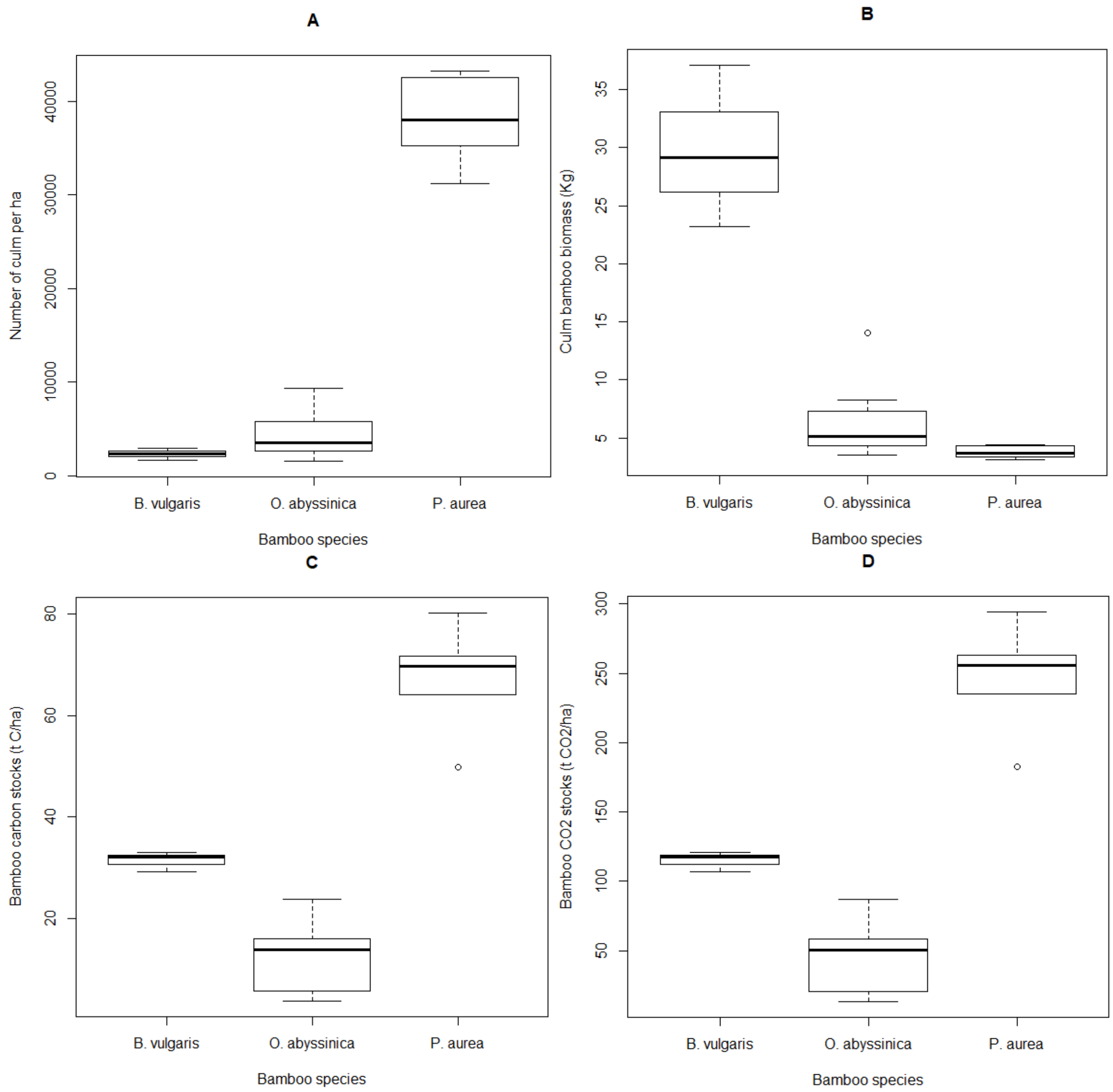


**Figure 2.** Culm density and carbon stocks per hectare of the three most abundant bamboo species in Cameroon.

Sahel zones). The planting of *O. abyssinica* can be promoted in degraded landscapes, marginal lands, plantations and even intercropped in agroforestry systems (Arun et al., 2015) in Guinea Savannah and Sudano-Sahel zones to mitigate climate change (FAO and INBAR, 2018; Terefe et al., 2019; Yuen et al., 2017), serve as bioenergy (fodder, animal feed, hay, firewood, Charcoal, pellet, biogas etc.) for both animals and the local population. Bamboo can be processed in various ways to become an important source of biomass energy for cooking, heating and electricity, and has important co-benefits for farmers (INBAR, 2019a). *B. vulgaris* strives perfectly well in tropical zones with high temperatures and rainfall. In fact, *B. vulgaris* recorded in all the agro-ecological zones of Cameroon, therefore, its plantations could be promoted to serve as feed stocks for industrial transformation of bamboo throughout the country. *P. aurea* and *Y. alpina* are western highlands species (volcanic soils) in Cameroon. The western highlands local population are known for using bamboo for handicrafts, culture, housing, beehive keeping, fishing, drying rags, crop staking (Neba et al., 2020; Ingram et al., 2010; Tchamba et al., 2020).

### Bamboo carbon stocks in Cameroon

Average $AGB_{culm}$ (kg) was significantly different with respect to the three bamboo species. *B. vulgaris* was the bamboo species with the highest significant $AGB_{culm}$

biomass compared to the two other bamboo species. In fact, we observed that similar to trees (Yuen et al., 2016), the $AGB_{culm}$ increased with increase in culm diameter. For this reason, therefore, the diameter follows the gradient: *B. vulgaris* > *O. abyssinica* > *P. aurea*. The same gradient was found for total culm aboveground biomass. Nevertheless, concerning aboveground biomass proportions of the bamboo components, it was approximately similar for the three bamboo species. This has also been reported by several authors who studied these three bamboo species and other bamboo species in the world (Gurmessa et al., 2016; Li et al., 2016; Nath et al., 2012; Yuen et al., 2017; Zhuang et al., 2015). With respect to literature review, bamboo carbon stocks found in the world vary in function of bamboo species (Jyoti et al., 2009; Nath et al., 2012; Patricio and Dumago, 2014; Yuen et al., 2016, 2017). This observation was confirmed in the context of this study where the average carbon stocks of three bamboo species varied in relation to the bamboo species: 13.13; 29.62 and 67.78 t C. $ha^{-1}$ respectively for *O. abyssinica, B. vulgaris* and *P. aurea*. In fact, the review of bamboo aboveground carbon (AGC) for seventy bamboo species by Yuen et al. (2017) showed a range of 16 to 128 Mg C $ha^{-1}$ for the different bamboo species. Many things could explain the variation of carbon stocks between bamboo species. Despite the faster growing rate of bamboo than other trees, these differences may be explained by the fact that, different bamboo species seem to have a different capacity in terms of carbon stocks. The density of culm/ha seems also to explain the significant difference of carbon stocks found between these bamboo species. For example, though *P. aurea* has a low $AGB_{culm}$ (kg) when compared to *B. Vulgaris* and *O. abyssinica*, its abundance per hectare may have a significant influence on its carbon stocks potential making it the bamboo species with the highest carbon stocks per hectare. Its abundance per hectare was 9 and 17 times greater than that of *B. vulgaris* and *O. abyssinica* respectively. In addition, ecological conditions (clump crowding, and culm position within a clump) and bamboo morphology (sympodial or running) may also influence the carbon storage potential (Xayalath et al., 2019; Yuen et al., 2017).

### Importance of bamboo in restoration of forests and mitigation of climate change

Degradation and deforestation have a direct impact on forest cover. The reduction in forest cover aggravates climate change and global warming because the forest is one of the largest carbon sinks and plays an important role in the global carbon cycle and photosynthesis. Plants grow by $CO_2$ fixation through photosynthetic processes and decrease the concentration of $CO_2$ gases from the atmosphere. Therefore, reforestation with fast growing plants like bamboos (*P. aurea*) (Arun et al., 2015; Terefe et al., 2019; Yuen et al., 2017) could be recommended in the national strategy, to fight against climate change. To attain the climate change mitigation objective and the fact that *P. aurea* has the highest carbon storage capacity in Cameroon; this bamboo species is a solution to combat global warming effect. This bamboo species could be recommended in the context of the Bonn Challenge landscape restoration, and Africa 100 000 ha landscape restoration initiatives. The REDD+ mechanism in reducing emissions from deforestation and forest degradation in conserving forest carbon stocks, sustainably managing of forests, and enhancing forest carbon stocks is an initiative to bamboo for its high carbon storage capacity in Cameroon.Yuen et al. (2017) carried out a study on the carbon storage capacity of 70 bamboo species demonstrating that the total bamboo ecosystem carbon storage capacity is lower than that of most types of forests, as it is on a par with that of rubber plantations and tree orchards, but greater than agroforests, oil palm, various types of swidden fallows, grasslands, shrublands, and pastures. This means that bamboo can successfully substitute degraded lands (e.g. agroforestry systems, oil palm plantations, various types of swidden fallows, grasslands, shrublands, and pastures; especially in the Guinea Savannah and Sudano Sahel Regions) and marginal lands, and contribute significantly towards mitigating climate change in Cameroon. It is also feared that bamboo's rapid growth could modify the original or local biodiversity of an area.

## Conclusion

The results of this study on bamboo species, complemented with the literature review confirmed the diversity of 15 bamboo species and data from National Herbarium, Yaounde Cameroon; among which are three native African species. However, three of these bamboo species were more abundant and each in a specific AEZ. Concerning their capacity to mitigate climate change, we found that carbon stocks varied significantly ($p < 0.5$) with respect to the different bamboo species. *P. aurea* was the bamboo species with the highest value of carbon stocks (67.78 tC $ha^{-1}$) and *O. abyssinica* with the least carbon stocks (13.13 tC $ha^{-1}$).

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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