DOI:10.5152/forestist.2023.23013
Forestist 2023

ISTANBUL UNIVERSITY CERRAHPASA

Original Article

Uses, Structures, and Biomass of Some Stands of *Bambusa Vulgaris* Schrad, ex J.C. Wendl in the Center Region of Cameroon

Jean Louis Fobane[1,2], Alain Christian Minfegue Bussard[1], Jules Christian Zekeng[3,4,5], Pierre Marie Chimi[2], Marie Marguerite Mbolo[2]

[1]Department of Biological Sciences, Higher Teacher's Training College,University of Yaoundé I, Yaoundé, Cameroun
[2]Department of Plant Biology, University of Yaoundé I Faculty of Science, Yaoundé, Cameroon
[3]Department of Forest Engineering, Advanced Teachers Training School for Technical Education, University of Douala, Douala, Cameroon
[4]Conservation and Sustainable Natural Resources Management Network (CSNRM-Net), Yaoundé, Cameroon
[5]Olivier R. Tambo Africa Research Chairs Initiative (ORTARCHI), School of Natural Resources, Copperbelt University Kitwe, Zambia

ABSTRACT

Our work aims to improve the knowledge of the various ecosystem services rendered by *Bambusa vulgaris*, one of the non-timber forest products with high conservation value. The study was carried out in Ekali I and Ballong II, two localities in the Center Region of Cameroon. A semi-structured questionnaire on the ethnobotany of bamboo species was administered to 150 people selected in the two study localities. The clumping-based sampling design was used to collect structural data for *Bambusa vulgaris*. In addition, its biomass was estimated using allometric models developed using the destructive method. The survey revealed that *Bambusa vulgaris* is used for construction, food, handicrafts, household energy supply, and agriculture and as poles for transporting electric wires. The average culm density of *Bambusa vulgaris* in both localities is 4733.67 culms ha^{-1} with an average number of clumps of 96 ha^{-1}. The Ballong II locality has higher structural parameters than Ekali, with 120 clumps ha^{-1}, an average density of 5720 stems/ha^{-1}, an average diameter of 9.46 cm, and an average height of 12.61 m. The biomass of the *Bambusa vulgaris* stands estimated to average 24.66 ± 21.50 kg ha^{-1}, with a coefficient of variation of 1.19%. Because of the pressure on this species due to its uses and role in climate regulation, it is urgent to think of a robust policy for its development and conservation.

Keywords: *Bambusa vulgaris*, biomass, ecosystem services, ethnobotany

Introduction

Ecosystems are one of the frameworks for all human life and activity. They improve human well-being through the goods and services they provide (Mohamed, 2018). In the forest, the ecosystem services provided included food, water, climate stability, disease regulation, soil formation as a basis for production, and cultural, recreational, and spiritual frameworks. Many of the plant species in the forest are non-timber forest products. These species are used for food, medicine, energy, handicrafts, and architectural purposes (Chabi, 2011). Within the list of these non-timber forest products, bamboo is a species known and promoted to improve the economic and environmental well-being of resource-dependent communities in Asia (Ramananantoandro et al., 2013). In several tropical countries, bamboo is variously used by people as a source of food, fodder, medicines, gums, resins, building materials, etc. (Hasan et al., 2020; Ingram & Tieguhong, 2013). Bamboo contributes to household economies, food security, and environmental preservation (Boon & Ahenkan, 2013). The role that bamboo might play in sustaining local livelihoods has not been documented, despite its daily use for craft and household production, agricultural support, local transmission stations, and many other benefits. The widespread use of bamboo implies that those who cannot produce bamboo buy from producers, leading to a market situation of buying and selling bamboo-related products.

Currently, the same effort is being made in Africa by the International Network for Bamboo and Rattan (INBAR), which is the center of efforts to promote research on production systems, processing, utilization, and socioeconomic impacts, technology transfer (on processing techniques), information exchange, and capacity building in the bamboo sector globally (INBAR, 2018; Ingram et al., 2010). Planted bamboo can reach maturity in three years and then be harvested every two years for up to 120 years (Ingram et al., 2010). This requires a modest investment in the plantation to provide a steady income. Bamboo fibers are reportedly ten times stronger than wood fibers for construction, and bamboo is much lighter and easier to transport than wood (Ingram et al., 2010).

Cite this article as:
Fobane, J. L., Minfegue Bussard, A. C., Zekeng, J. C., Chimi, P. M., & Mbolo, M. M. (2023). Uses, structures and biomass of some stands of bambusa vulgaris schrad, ex J.C. wendl in the center region of Cameroon. [published Early View Article, 2023 December 28] *Forestist*, 10.5152/forestist.2023.23013, DOI: 10.5152/forestist.2023.23013.

Corresponding Author:
Jean Louis Fobane
e-mail:
jlfobane@gmail.com

Received: March 8, 2023
Accepted: July 12, 2023
Publication Date: December 28, 2023

The bamboo resource's social, economic, and ecological impacts at the local and national levels are unknown or have not yet been documented. However, bamboo has long been considered one of the neglected Non-Timber Forest Products (NTFPs) in Central Africa (Ingram et al., 2010), despite being a renewable resource that is easily domesticated, has an annual yield, is readily available to rural communities, and has the potential to accelerate rural development (an aspect long recognized in Asia) (Belcher, 1998; Luo et al., 2020; Pérez et al., 1999).

According to INBAR (2018), the global bamboo market, in which China plays a leading role, currently represents USD 60 billion in annual turnover and constitutes a privileged potential source of income for rural communities (Dje et al., 2017). In this context, it seems appropriate that Cameroon, which holds one of the significant potentials of bamboo in Central Africa (Wonkam, 2019), can intensify its efforts in terms of valorization of this strategic resource, which has become a major economic asset in several Asian countries (Nfornkah et al., 2020). To better understand this species' diversity, Cameroon conducted in 2015 an inventory of the stands of this resource in the Center, Littoral, South, and Southwest Regions. The literature review revealed the existence of six species of bamboo within the country, including four well represented, namely *Bambusa vulgaris, Bambusa vitata, Yushana alpina,* and *Oxytenathera abyssinica*, and two other species are observed in trace form; these are *Dendrocalamus aurea* and *Phyllostachys* species (Nfornkah et al., 2020).

Bamboo is considered a multipurpose species by rural communities (Hasan et al., 2020). This resource is nowadays overexploited and does not guarantee the sustainability of the goods and services it provides. However, it is an exciting plant from an ecological point of view because it can replace wood from the natural forest through the goods and services it provides and its carbon sequestration capacity (Hasan et al., 2020; Odiwe et al., 2012). In this market, the main actors remain poorly described in Cameroon (INBAR, 2011). The study aims to highlight bamboo's goods and services and carbon storage potential for better valorization and conservation. More specifically, it will (i) characterize the socioeconomic profile of the actors of the bamboo sector and the use of bamboo; (ii) describe the structure of bamboo clumps; and (iii) determine the biomass of bamboo culm.

Methods

Study Area

The study sites were located in the Center region of Cameroon, where two localities were selected due to their high level of intensity in the use of bamboo. The locality of Ekali I is located in the sub-division of Mfou, Division of Mefou and Afamba, Center Region of Cameroon (Figure 1). Ekali I is located about 20 km from Yaoundé to Nsimalen airport, on the road to Mbalmayo. The commune of Mfou was elected by the presidential decree of 1974 as the head of the department of Mefou and Afamba. It has a surface cover of 3338 km^2. It is limited to the north by the district of Yaoundé IV, to the south by Mbalmayo, to the east and south-east by the district of Awae-Nkol Afamba, and to the west by Bikok (Mougoue, 1989).

The locality of Ballong II is located in the Batchenga commune, Lékié department, Center Cameroon region (Figure 1). It was created by presidential decree N°94/082 of April 24, 1995. It is 62 km from Yaoundé. Likewise, it has an area of 216 km^2. This municipality is bordered to the west by the arrondissement of Ntui, to the north by the arrondissement of Mbandjock, and to the south by the arrondissement of Obala (CVUC, 2014). It should be noted that the site of Ballong II is located in an old tobacco plantation that was managed at the time by a tobacco company in the city of Batchenga. After the latter's departure, the place became a vast bamboo plantation.

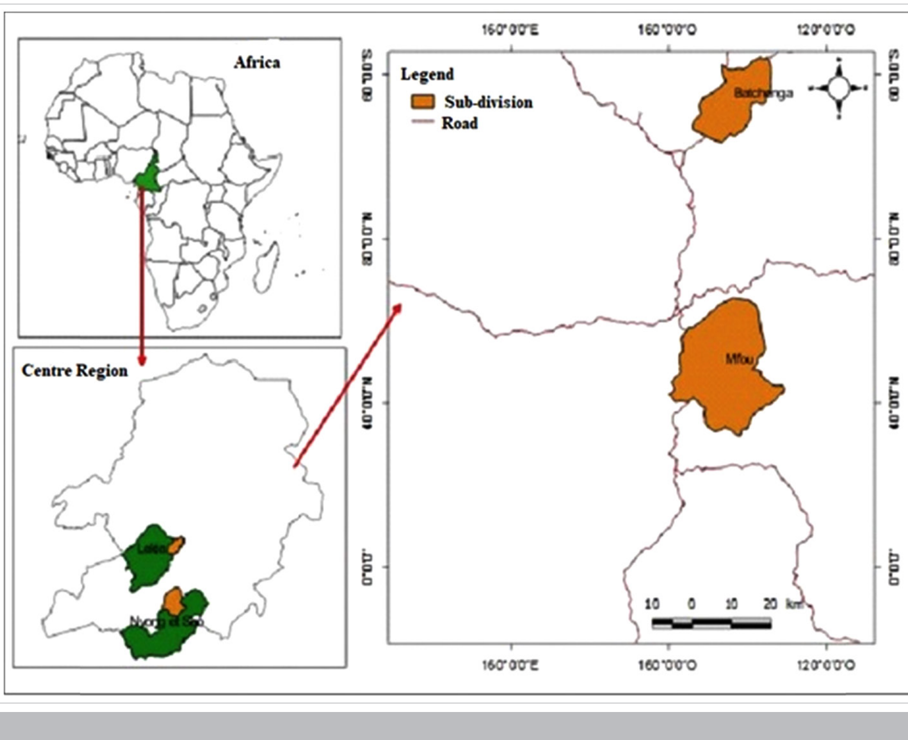

Figure 1.
Map of the study site.

Sampling Design

In each locality selected, a list of bamboo user groups was established. Focus groups were organized with the user groups of Bambama. Snow ball sampling approach was used to identify the user of bamboo and to advise on the identification of the next person or household. Each person or household indicated the nearest bamboo clumps that were further georeferenced for inventory. One hundred fifty people distributed among the two sites were interviewed.

The clumping-based sampling design (INBAR, 2019) was used for collecting bamboo biomass data at the study sites (Figure 2). At the GPS waypoint of the plot, the nearest bamboo clump was determined; then, five distances L1 to L5 of the six nearest bamboo clumps were successively measured (Figure 2). Thus, a total of 6 clumps per location were installed and measured.

Data Collection

Bamboo Socioeconomic Data Collection

The interview guide, semi-structured questionnaire, and diary note used for data collection were structured based on the importance of NTFP and the social and economic values of bamboo-based resources (Rosa et al., 2016; Sohel et al., 2015; Gbesso et al., 2017; Adomou et al., 2012; Endalamaw et al., 2013). The surveys were based solely on surveys of the different actors directly involved in the bamboo sector in the study area. A total of 150 people were surveyed in the two community village sites, distributed among three focus groups of 10–15 people. For each site, 75 people, or households were interviews. The social and economic characteristics, including the gender of the users, age groups, level of education, categories of use of bamboo, etc., for focus groups, interviews, and observations of each person surveyed were noted.

Bamboo Biophysical and Biomass Estimation Data Collection

Within each clump, parameters such as the circumference of each culm at 150 cm from the ground (Figure 2) and the height (*H* in m) of the bamboo culm were measured, and the number of culms per bamboo clump was counted. Allometric equations using data from the destructive method were developed and used to evaluate the biomass of all 12 measured clumps. To do this, 30 bamboo culms were taken from the 12 measured clumps. Each bamboo stubble was cut flush with the ground using the saw cut to facilitate transport. These samples were grouped into different compartments (trunks, leafless branches, and leaves), then packaged in 50 kg bags, and labeled (INBAR, 2018). At the same time, the sheets were also packaged and labeled in A4 envelopes. They were then transported to the Laboratory of Systematic Botany and Ecology of the Higher Teacher's Training College of the University of Yaoundé I, where they were dried in an oven at 105°C until a constant dry weight was obtained. The sum of the dry biomass of the three compartments for each stem gives the total aboveground biomass of the culm. The aboveground biomass data of the bamboo culm as well as the dendrometric parameters (circumference and height) were used to establish allometric equations and estimate the biomass of bamboo. The best model was used to estimate bamboo biomass in the study area.

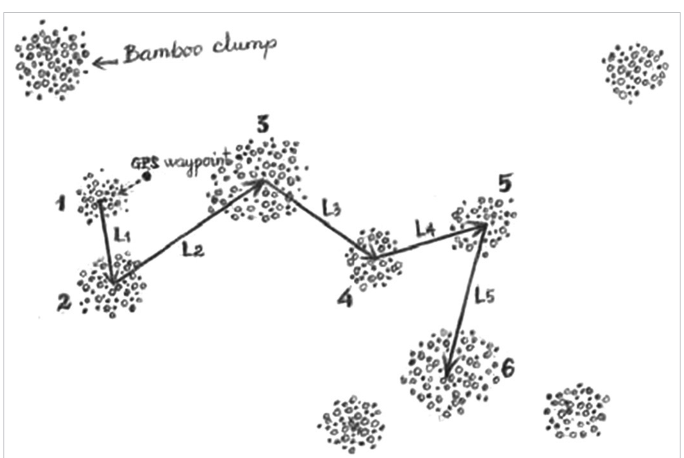

Figure 2.
Cluster sampling for very dense culm bamboo (INBAR, 2019).

Data Analysis

Determination of the Sociodemographic Profile of Respondents and the Use of Bamboo

At the end of the surveys carried out in the localities of Ballong II and Ekali I, socioeconomic data collected in 150 files were processed using the Excel software. Descriptive statistics were performed on the socioeconomic profile of respondents and highlighted the different categories of bamboo use in the localities.

Modeling Allometric Equations for the Prediction of Height and Stem Biomass of Bambusa vulgaris

The diameter and height data of the bamboo were used to establish linear regressions between them. The logarithmic linear model has been considered for this purpose. Furthermore, for predicting the biomass of *B. vulgaris* stems, the diameter (*D*) and the height (*H*), or a combination of "D^2H," were used as predictors. Logarithmic and power models have been tested. The response variable was aboveground bamboo biomass. The selection of predictors for each model shapes for bamboo biomass is consistent with the existing literature (Isagi et al., 1997; Yuen et al., 2017), which confirms the use of the power shape with a predictor as the diameter to estimate the biomass of bamboo according to Li et al. (2016). The variables diameter and height are used to estimate the biomass of certain bamboo species.

However, most bamboo biomass models used diameter as the only predictor because it is both inexpensive and easy to measure. This is why, in the context of this study, different models combining different predictors and models with diameter as the only predictor to be applied when the other predictors are not available have been developed. Therefore, for this study, the various models below were tested:

$$B = a + bxD \ln B = a + bx\ln(D) \quad (1)$$

$$\ln B = a + bx\ln(H) \quad (2)$$

$$\ln B = a + bx\ln(D) + cx\ln(H) \quad (3)$$

where B = biomass in kg; D = tree diameter in cm; H = height of the tree in m; a, b, and c are the coefficients.

The models are compared in pairs based on additional tests carried out for each model, namely: the residual standard error (RSE), the adjusted coefficient of determination (R^2Adj), and the Akaike information criterion (AIC). Thus, this best model was chosen to estimate the total aboveground biomass of bamboo per hectare by the non-destructive method. Biomass data were estimated per hectare.

Estimation of the Structural Parameters and the Biomass of Bamboo Culms

From the average distance between the bamboo tufts, the following structural parameters were evaluated:

- The number of clumps per hectare was determined by the ratio of the surface area per hectare to the average distance between the clumps per hectare by applying the formula below:

$$\frac{10000}{Average\,distance^2}$$

- The density of culms per hectare represented the number of culms per tuft multiplied by the number of tufts per hectare.
- The average diameter and the average height represented the average diameter and height of the culms for a given tuft, respectively.

In addition, the biomass of culms was evaluated using the specific equation defined in this study. Then, the average biomass of a culm per hectare is obtained by multiplying the average biomass by the number of clumps per hectare.

Statistical Analysis

Differences between localities were analyzed according to structural data using the Welch two-sample *t* test and the Kruskal–Wallis test when the data did not meet assumptions of normality. The assumption of normality was tested using the Shapiro–Wilk test (Fox, 2005). All values of $p < .05$ are reported as significant.

Results

Sociodemographic Profile of Actors and Categories of Bamboo Use

Distribution of Respondents by Gender And Age

Socioeconomic surveys in the study area (Ballong II and Ekali I) were carried out on 150 people, of whom 138 were men (92%) and 12 were women (8%). Overall, the analysis of sociodemographic data reveals that 73% of individuals in the age group of 20–30 years old are the most involved in the utilization of bamboo because of the labor required to realize the tasks. This age group is followed by 30–40 years.

The analysis of respondents according to age groups working in the bamboo sector reveals that men constitute almost all people in age groups (10–20), (20–30), and (40–50), and a minority for the age group of (30–40). Among women, the greatest number is recorded between the age groups of 30 and 40 years, which is 33.33%.

Regarding the contribution by locality, we note that men in the age group of 20–30 years represent 41% of all people involved in the utilization of bamboo. Men follow these in the same age group in the locality of Ekali I, with a proportion of 27%. The age group of 30–40 years comes in the second place with 14% of the total respondents. This 14% is made up mainly of men from the locality of Ekali I (7%), followed by those from the locality of Ballong II (4%).

Distribution of Respondents According to a Level of Education

The survey results show that 100% of people involved in the utilization of bamboo have at least the primary level, or 85.33%, and at most the secondary level, or 14.67%. Moreover, men represent 92%, with 77.13% for the primary level and 14.67% for the secondary level.

The locality of Ballong II has the highest percentage (43%) of men who have attended primary school, against 34% for those in the locality of Ekali I. On the other hand, concerning the secondary education level, the percentage of men is higher in the locality of Ekali I (11%) compared to 4% in the locality of Ballong II. In both localities, 8% of women who have only completed primary school are divided into 5% for the locality of Ekali I and 3% for the locality of Ballong II.

Distribution of Respondents According to Categories of Bamboo Use

The survey results reveal that 39% of respondents use bamboo thatch for energy, 31% for commercial, and 27% for artisanal purposes (Figure 3). Uses for cultural and medicinal purposes are a minority in both localities. The proportion of women involved in exploiting bamboo does so primarily for energy purposes (7%), while the remaining 1% do so for commercial purposes (Figure 3).

Moreover, the use of bamboo varies according to the locality (Figure 4). Indeed, in the locality of Ekali I, men prefer to exploit bamboo for artisanal purposes, while in the locality of Ballong II, they prefer to exploit

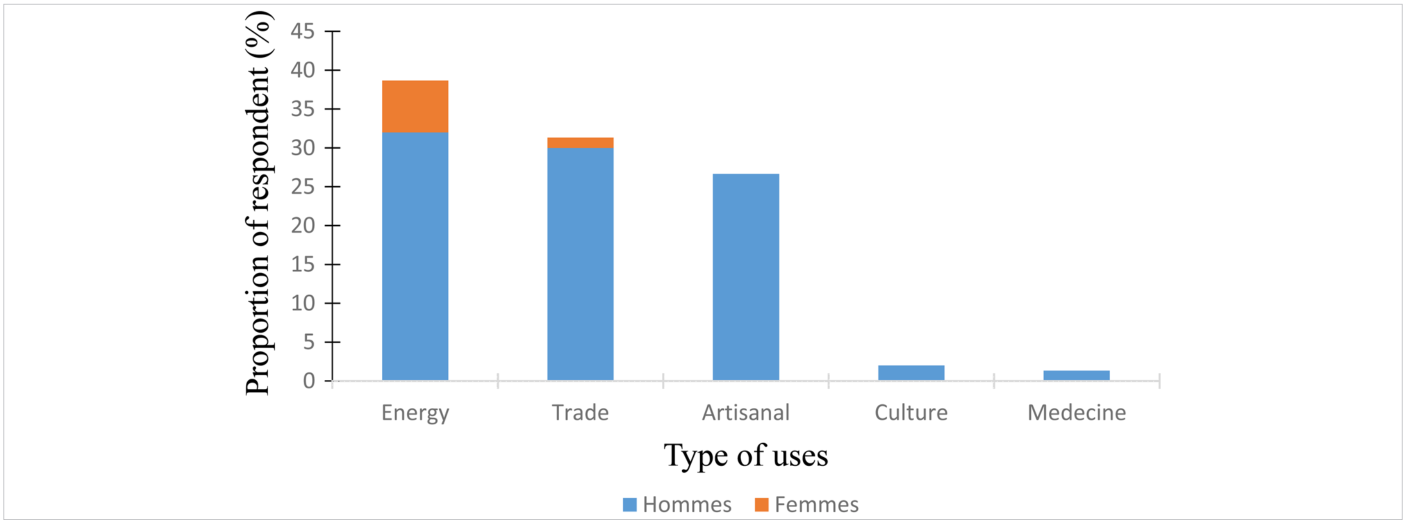

Figure 3.
Distribution of respondents according to types of bamboo used.

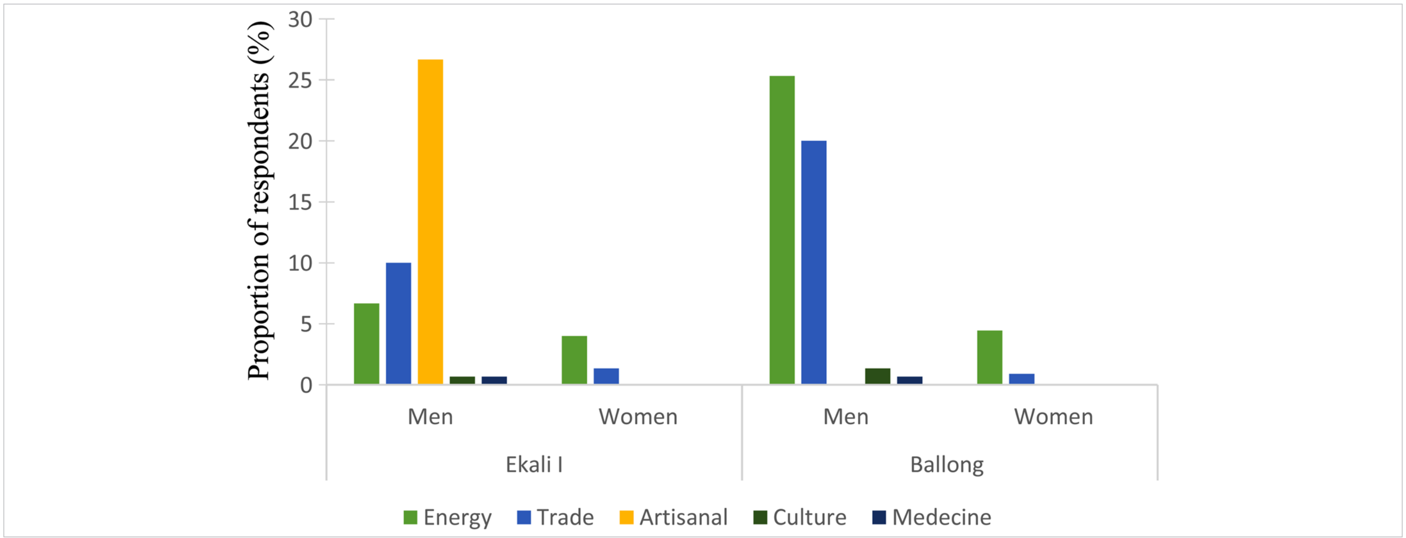

Figure 4.
Distribution of respondents according to types of bamboo used by locality.

bamboo for energy and commercial purposes. For a specific purpose, women have the same preference, namely using bamboo for energy purposes (Figure 4).

Furthermore, the use for artisanal purposes results in several products: beds, interior linings (walls and ceilings), furniture, rafts, flutes, cupboards, goblets, various utensils, and many arts and crafts.

Regression Equations

Diameter–Height Regression Equations of Bambusa vulgaris

Weak relations were observed between the diameter and height of the bamboo. Logarithmic transformation improved the goodness of fit (Table 1). In this study, the chosen model is $H = e^{a+bx\ln D}$.

Allometric Equations for Aboveground Biomass Estimation

The results highlight the logarithmic and non-logarithmic linear relationship between the diameter and bamboo biomass (Figure 5).

Linear allometric equations for estimating the biomass of bamboo with the developed diameter and height as variables are presented in Table 2. The low value of the adjusted coefficient of determination was obtained for the models that only considered the diameter as a predictor variable (R^2Adj = 0.321), compared to that related to the present height where the R^2Adj = 0.528. However, the consideration of two variables in the model improved the quality of the adjustment. Thus, the $B = e^{-2.42+0.58x\ln\left(D^2xH\right)}$ equation was the best allometric equation for the prediction of the aboveground biomass of *B. vulgaris* in the study area if we stick to the values of the additional tests (R^2Adj (0.749), RSE (0.349), and AIC (27)) performed (Table 2).

Stand Structure and Biomass of Bambusa vulgaris

Stand Structure of Bambusa vulgaris

The average density of *B. vulgaris* stands in the two localities is 4733.67 culms ha^{-1} with an average number of culms of 96 per hectare. The average diameter of the culms is 8.11 cm for an average height of 12.11 m (Table 3). Taken separately, the locality of Ballong II, although presenting the best structural parameters, presents a highly significant difference only for the variable number of culms sampled per hectare (p = .037). For the other parameters, no significant difference (p > .20) was observed between the two localities. However, the locality of Ballong II has 120 tufts ha^{-1}, an average density of 5720 stems/ha, an average diameter of 9.46 cm, and an average height of 12.61 m. While the locality of Ekali I has 73 tufts/ha, an average density of 3747 stems ha^{-1}, an average culm diameter of 6.76 cm, and an average height of 11.61 m (Table 3).

Stand Biomass Stock of *Bambusa vulgaris*

Using the equation $B = e^{-2.42+0.58x\ln\left(D^2xH\right)}$, the biomass of *B. vulgaris* stands is estimated on average at 24.66 ± 21.50 kg ha^{-1} with a coefficient of variation of 1.19%. The Shapiro–Wilk normality test shows that the distribution of the biomass of the twelve clumps does not follow a normal law (w = 0.48; p < .001) and is partly due to the distribution within the clumps from the locality of Ballong II. Indeed, the locality of Ballong II presents an average quantity of biomass of 36.02 ± 25.50 kg ha^{-1}, which is significantly higher (p = .016; Kruskal–Wallis test) than the value of 13.31 ± 3.18 kg ha^{-1} obtained in the locality of Ekali I.

Discussion

The socioeconomic surveys carried out in Ekali I and Ballong II on a sample of 150 people made it possible to question 103 men, i.e., 93.63% of the people questioned. Most were between 20 and 30 years old. We find the same characteristics in Ghana (Obiri & Oteng-Amoako, 2007), in Ivory Coast (Dje et al., 2017), and in Bangladesh (Mukul & Rana, 2013). Indeed, the exploitation of bamboo is not the main activity of the respondents. The young people of these study sites own the various farms and exploit bamboo as a complementary activity. A similar attitude toward rural populations has been observed with the populations of Azaguié in Côte d'Ivoire, as described by Bi et al. (2020).

Furthermore, they are more involved in food crop agriculture and fishing. These same observations were made by Bi and Kouakou (2004) for the rattan sector. This means that the utilization of NTFPs, such as bamboo and rattan, is an activity that generates additional income for rural communities. There is no ownership for bamboo stands in the two study sites; the stands are open assess, and no peasant owns a bamboo

Table 1.
Diameter–Height Regression Equations

Models	*a*	*b*	R^2 Adj	RSE	AIC	CF	*p*
$H = a + b \times D$	12.378***	0,05	−0.634	2.03	131.55	-	.818
$\ln(H) = a + b \times \ln(D)$	2.557***	-0.012^{ns}	−0.655	0.167	−18.34	0.013	.048

Note: AIC, Akaike information criterion; CF, correction factor; *D*, culm diameter; *H*, height; R^2Adj, adjusted coefficient of determination; RSE, residual standard error;****p* < 0.001; ** p< 0.01; * p <0.05^{ns}Non-significant.

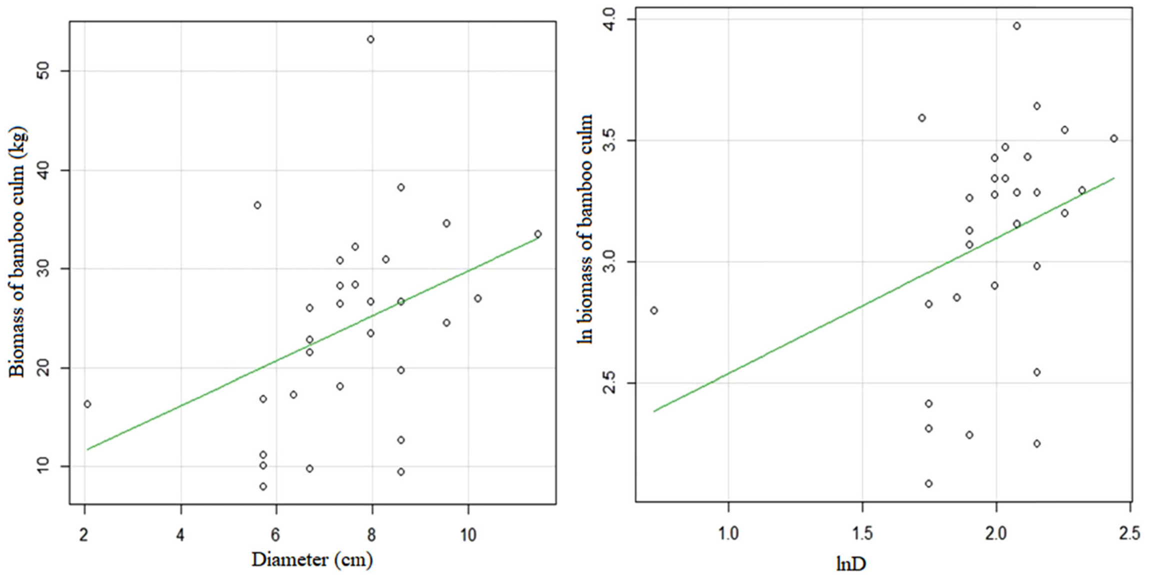

Figure 5.
Relationship between bamboo aboveground biomass and stem diameter with and without logarithmic transformation.

plantation similarly as in China. However, in the locality of Ballong II, most farmers see bamboo as a harmful weed for the development of their crops. Although they recognize the importance of this resource, they nevertheless prefer to get rid of it in their plantations due to its invasiveness by eliminating all surrounding vegetation (Dje et al., 2017).

In the category of uses, 39% of the respondents in the two localities use bamboo as wood energy. In fact, for the respondents, bamboo replaces firewood, which is becoming scarce in the two villages. They believe it is more efficient than firewood because of its brighter flames. In these villages, it is used for more efficient cooking energy; for example, the cooking of large quantities of cassava sticks requires more time in the firewood, but the use of very dry bamboo is more and more used for this purpose. Women in the two localities prefer to use bamboo in the kitchen because they no longer want to spend a lot of time in the kitchen cooking. There is no customary law on bamboo utilization; it is an informal sector with the different actors not grouped into cooperatives or associations to organize the value chain. Anyone from the community can exploit bamboo for any purpose. This harvest is not quantified insofar as everyone cuts the poles according to their needs.

The results reveal that 31% of the respondents are engaged in the bamboo market by selling it to people who want to use it for construction. Bamboo is very important for the scaffolding of houses, given that its

Table 2.
Allometric Equations for Estimating the Aboveground Biomass of Bambusa vulgaris

Equations	*D* (cm)	*a*	*b*	*c*	RSE	R^2 Adj	AIC	CF	*p*
$B = a + b \times D$	2.1–11.5	7.09^{ns}	2.275^{*}	—	9.551	0.321	224	—	.033
$\ln B = a + b \times \ln(D)$	2.1–11.5	1.98^{**}	0.56^{ns}	—	0.448	0.394	41	0.10	.055
$\ln B = a + b \times \ln(H)$	2.1–11.5	-1.22^{ns}	1.70^{***}	—	0.385	0.528	32	0.07	.000
$\ln B = a + b \times \ln(D^2 \times H)$	2.1–11.5	-2.42^{*}	0.58^{*}	1.72^{***}	0.349	0.749	27	0.06	.000

Note: Statistical analyses are significant at 95% confidence interval.AIC = Akaike information criterion; Adj.R^2 = coefficient of determination; *B* = aboveground biomass of the bamboo stem; CF = correction factor; *D* = rod diameter; *H* = total height of the stem; RSE = residual standard error of the model; *a*, *b*, c = coefficients of the model.
***$p < .001$.**$p < .01$.*$p < .05$.^{ns}non-significant $p > .05$.

Table 3.
Structural Parameters of Stands of Bambusa vulgaris

Parameters	Stems/ Clump	The Density of Bamboo Culms ha^{-1}	Average Diameter (cm)	Average Height (m)
Ballong II	47.67 ± 15.00a	5720.00 ± 1800.27a	9.46 ± 7.07a	12.61 ± 0.004a
Ekali I	51.33 ± 11.88a	3747.33 ± 867.03b	6.76 ± 0.85a	11.61 ± 0.01a
Mean	49.50 ± 13.04	4733.67 ± 1695.92	8.11 ± 5.00	12.11 ± 0.01

Note: Different letters indicate a significant difference in the same column following the Kruskal–Wallis test.

resistance replaces wood and iron. This may result in manufacturers making significant savings. This observation was also made by Dje et al. (2017). Definitely, the income generated by exploiting bamboo constitutes an additional contribution to the household's income portfolio. Regarding the management of the resource, they show no interest. The proof is that throughout the year, they can cut the bamboo; they do not imagine that this resource can end. This is probably why no traditional system of long-term management of bamboo resources exists in the study area, and this phenomenon is widespread in Africa (Sunderland, 2001). Farmers believe that bamboo is present all year round because they still use it at domestic levels compared to those with access to urban markets and are aware of sustainability issues.

Allometric models are important for estimating the volume, biomass, and carbon storage of standing plant species (Singnar et al., 2017). In the study, the *D* of bamboo culms as a predictor of biomass and C storage yielded coefficient of determination (R^2) values ranging from 0.321 to 0.394, indicating the low quality of the predictive power of *D*. This could be due to the small sample size. Unlike other studies reporting a high quality of the predictive power of *D* with $R^2 = 0.720–0.836$ (Singnar et al., 2017). The use of *D* to predict the volume and biomass of standing trees and bamboo is common and is faster, less demanding, and more reliable (Amoah et al., 2020; Darabant et al., 2014; Sohel et al., 2015).

However, due to the strong correlation between the diameter and height of standing trees and bamboo (Yen, 2015), including height in addition to diameter as a predictor of biomass improves the utility of the model (Singnar et al., 2017; Yen, 2015). Undeniably, in the study, allometric functions using a power equation based on diameter and height best describe culm biomass. Indeed, the equation $B = e^{-2.42+0.58x\ln\left(D^2xH\right)}$ obtained in the present study gives fits comparable to those of allometric power functions of the stubble biomass of *B. vulgaris* obtained in other regions (Amoah et al., 2020; Darabant et al., 2014). Furthermore, the equation $B = 11.403 + 0.0006\ (D^2H)$ with $r^2 = 0.88$ was obtained in plantations of *B. vulgaris* in degraded tropical forests in Bangladesh.

Our study showed that the density of bamboo stands was 4734 stubble ha^{-1}. In fact, in the Bobiri Forest Reserve in Ghana, where harvesting bamboo for commercial purposes is prohibited, a much higher stubble density is 7171 stubble ha^{-1} (Amoah et al., 2020). Compared to this study, a much lower stubble density of 2933.33 stubble ha^{-1} was obtained in *B. vulgaris* plantations in degraded tropical forests in Bangladesh (Sohel et al., 2015). A density of 3400 to 4722 culms ha^{-1} has also been recorded for Moso bamboo (*Phyllostachys pubescens*) from China (Xu et al., 2018); 3968 culms ha^{-1} (Zhang et al., 2014); and 5222 culms ha^{-1} (Inoue et al., 2018) for the same *Phyllostachys pubescens,* respectively, from China and Japan; and a density of 12,650 culms ha^{-1} to 36900 culms ha^{-1} for *Yushania alpina* Bamboo in Kenya (Muchiri & Muga, 2013). All these elements seem to indicate and confirm the assertion of Liu et al. (2016) and Yen, 2015 that the density of bamboo depends on the size and diameter of the culms, the species, and the differences in the management practices of the silvicultural plantations applied by different countries.

The average aboveground biomass of 24.66 t ha^{-1} obtained in this study for *B. vulgaris* is much lower than the value of 115 t ha^{-1} obtained in the Bobiri forest reserve in Ghana (Amoah et al., 2020). It is also lower than the values of 97.8 t ha^{-1} of *B. vulgaris* obtained in Bangladesh (Sohel et al., 2015) and 53.42 t ha^{-1} of *B. vulgaris* obtained in Uttar Pradesh (Pathak et al., 2015). The biomass value obtained for *B. vulgaris* in the present study is much lower than the estimated biomass results for other species. In Uttar Pradesh, the value of 104.7 t ha^{-1} is recorded for the biomass of *Bambusa balcooa* (Pathak et al., 2015); the value of 126 t ha^{-1} is reported for *Bambusa tuldain* in India (Majumdar et al., 2016); and 41.82 t ha^{-1} for *Bambusa nutan* from Uttar Pradesh (Pathak et al., 2015).

Conclusion

The study on the ecosystem services rendered to the society by *B. vulgaris* was carried out in the localities of Ballong II (Batchenga) and Ekali I (Mfou) in the Center Region of Cameroon. The results of the surveys showed that men are the most significant users of bamboo in these localities followed by young people with primary education. This leads us to believe that they can receive training to popularize this sector of activity, which remains in the informal sector. Concerning the supply services, the populations use it as firewood or cooking wood instead of lignified wood species. Regarding cultural services, bamboo is used to decorate art objects, kitchen utensils, etc. Bamboo, by its rapid growth and maturation after 3 years, as a regulating service, contributes to the fight against global warming through its potential carbon sequestration. The diameter of the bamboo culm accurately predicted the biomass of *B. vulgaris*. However, the allometric models $D^2 \times H$ predicted the biomass of bamboo culms better. All the models developed have a fairly good predictive capacity concerning the small differences observed between the values observed and those predicted. The established allometric models can be used to estimate the biomass of *B. vulgaris* by component under similar environmental conditions. The average stand density of *B. vulgaris* in both localities is 4733.67 culms ha^{-1}, with an average number of clumps of 96 ha^{-1}. The Ballong II locality has higher structural parameters than Ekali, with 120 clumps ha^{-1}, an average density of 5720 stems ha^{-1}, an average diameter of 9.46 cm, and an average height of 12.61 m. The biomass of *Bambusa. vulgaris* stands estimated to average 24.66 ± 21.50 kg ha^{-1}, with a coefficient of variation of 1.19%. Because of the pressure on this species and its role in climate regulation, it is urgent to think of a robust policy for its development and conservation.

This work should be extended to other regions of Cameroon to determine the socioeconomic profile and type of use of the *B. vulgaris* species and its contribution to the improvement of the living conditions of the populations, and to develop regression equations for estimating the biomass of *B. vulgaris*.

Ethics Committee Approval: N/A.

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – J.L.F., A.C.M.B., J.C.Z.; Design – J.L.F., A.C.M.B., J.C.Z; Supervision -- M.M.M. Resources – J.L.F.X., A.C.M.B., J.C.Z.; Data Collection and/or Processing – A.C.M.B., P.M.C.; Analysis and/or Interpretation – A.C.M.B., J.C.Z..; Literature Search – A.C.M.B., P.M.C.; Writing Manuscript – J.L.F., A.C.M.B., J.C.Z.; Critical Review – J.L.F., A.C.M.B., J.C.Z., P.M.C., M.M.M.

Acknowledgments: The authors express their thanks to the populations of the villages in the District of Batchenga for their contribution to the realization of this study. We also thank the head of sectors (district delegation of agriculture, fishing and animal industry, the environment, trade, and the institute of agricultural research for development) for their informative contribution to the preliminary data.

Declaration of Interests: The authors have no conflict of interest to declare.

Funding: The authors declared that this study has received no financial support.

References

- Adomou, A. C., Yedomonhan, H., Djossa, B., Legba, S. I., Oumorou, M., & Akoegninou, A. (2012). Etude Ethnobotanique des plantes médicinales vendues dans le marché d'Abomey-Calavi au Bénin. *International Journal of Biological and Chemical Sciences*, *6*(2), Art. 2. [CrossRef]
- Amoah, M., Assan, F., & Dadzie, P. K. (2020). Aboveground biomass, carbon storage and fuel values of *Bambusa vulgaris*, *Oxynanteria abbyssinica and Bambusa vulgaris* var. Vitata plantations in the Bobiri forest reserve of Ghana. *Journal of Sustainable Forestry*, *39*(2), 113–136. [CrossRef]
- Belcher, B. M. (1998). *A production-to-consumption system approach : Lessons from the bamboo and rattan sectors in Asia*. CIFOR. https://scholar.google.com/scholar_lookup?title=A+production-to-consumption+system+approach%3A+lessons+from+the+bamboo+and+rattan+sectors+in+Asia&author=Belcher%2C+B.M.&publication_year=1998
- Bi, D. P. V. D., Koffi, K. J., & Yao, C. Y. A. (2020). Importance sociale de Bambusa vulgaris Schrad ex. JC Wendl.(Poaceae) dans la Sous-préfecture d'Azaguié, Sud-Est de la Côte d'Ivoire. *Ethnobotany Research and Applications*, *19*, 1–17.
- Bi, I. A. Z., & Kouakou, K. L. (2004). Etude de la filière rotin dans le district d'Abidjan (Sud Cote d'Ivoire). . Biotechnol. Agron. Soc. Environ. *8*(3), 199-209.
- Boon, E., & Ahenkan, A. (2013). Assessing climate change impacts on ecosystem services and livelihoods in Ghana : Case study of communities around Sui Forest reserve. *Journal of Ecosystem and Ecography*, *3*(2). [CrossRef]
- Chabi, R. B. (2011). *Produits forestiers non ligneux végétaux prélevés dans la forêt communautaire d'Igbodja au Bénin : Biodiversité et formes d'usage*. https://www.memoireonline.com/07/15/9215/m_Produits-forestiers-non-ligneux-vegetaux-preleves-dans-la-fort-communautaire-dIgbodja-au-B0.html
- CVUC. (2014). *Commune de Batchenga*. Communes et Villes Unies du Cameroun. https://cvuc-uccc.com/
- Darabant, A., Haruthaithanasan, M., Atkla, W., Phudphong, T., Thanavat, E., & Haruthaithanasan, K. (2014). Bamboo biomass yield and feedstock characteristics of energy plantations in Thailand. *Energy Procedia*, *59*, 134–141. [CrossRef]
- Dje, B. D. P. V., Koffi, J. K., Vroh, B. T. A., Kpangui, K. B., & Yao, C. Y. A. (2017). Exploitation et importance socio-économique du bambou de chine, *Bambusa vulgaris* Schrad. ex J.C. Wendl. (Poaceae) dans la région de l'Agnéby-Tiassa : Cas de la Sous-Préfecture d'Azaguié (Sud-Est de la Côte d'Ivoire). *International Journal of Biological and Chemical Sciences*, *11*(6), Art. 6. [CrossRef]
- Endalamaw, T., Lindner, A., & Pretzsch, J. (2013). Indicators and determinants of small-scale bamboo commercialization in Ethiopia. *Forests*, *4*(3), 710–729. [CrossRef]
- Fox, J. (2005). The R commander: a basic statistics graphical user interface to R. *Journal of Statistical Software*, *14*, 1–42.
- Gbesso, F., Nassi, K. M., Gbesso, G. H. F., & Akoegninou, A. (2017). Utilisation sociale de Borassus aethiopum Mart et de ses habitats dans les Communes de Savè et de Glazoué au Bénin. *International Journal of Biological and Chemical Sciences*, *11*(4), Art. 4. [CrossRef]
- Hasan, S., Shi, W., & Zhu, X. (2020). Impact of land use land cover changes on ecosystem service value: a case study of Guangdong, Hong Kong, and Macao in South China. *PLoS One*, *15*(4), e0231259. [CrossRef]
- INBAR. (2011). *The 2011 import and export market for vegetable materials used primarily for plaiting excluding bamboos and rattans in Asia*. International Bamboo and Rattan Organization. https://www.inbar.int/cn/resources/book/the-2011-import-and-export-market-for-vegetable-materials-used-primarily-for-plaiting-excluding-bamboos-and-rattans-in-asia-2/
- INBAR. (2018). *Revue annuelle de l'INBAR 2018*. International Bamboo and Rattan Organization. https://www.inbar.int/fr/resources/inbar_publications/revue-annuelle-de-linbar-2018-french/
- INBAR. (2019). *A manual for bamboo forest biomass and carbon assessment*. International Bamboo and Rattan Organization. https://www.inbar.int/resources/inbar_publications/a-manual-for-bamboo-forest-biomass-and-carbon-assessment/
- Ingram, V., & Tieguhong, J. C. (2013). Bars to jars : Bamboo value chains in Cameroon. *Ambio*, *42*(3), 320–333. [CrossRef]
- Ingram, V., Tieguhong, J. C., Nkamgnia, E. M., Eyebe, J. P., & Ngawe, M. (2010). *The bamboo production to consumption system in Cameroon. Array—CIFOR knowledge*. Center for International Forestry Research (CIFOR). [CrossRef]
- Isagi, Y., Kawahara, T., Kamo, K., & Ito, H. (1997). Net production and carbon cycling in a bamboo Phyllostachys pubescens stand. *Plant Ecology*, *130*(1), 41–52. [CrossRef]
- Li, L.-E., Lin, Y.-J., & Yen, T.-M. (2016). Using allometric models to predict the aboveground biomass of thorny bamboo (*Bambusa stenostachya*) and estimate its carbon storage. *Taiwan Journal of Forest Science*, *31*(1), 37–47.
- Liu, Z., Mi, B., Jiang, Z., Fei, B., Cai, Z., & Liu, X. (2016). Improved bulk density of bamboo pellets as biomass for energy production. *Renewable Energy*, *86*, 1–7. [CrossRef]
- Luo, B., Ahmed, S., & Long, C. (2020). Bamboos for weaving and relevant traditional knowledge in Sansui, Southwest China. *Journal of Ethnobiology and Ethnomedicine*, *16*(1), 63. [CrossRef]
- Majumdar, K., Choudhary, B. K., & Datta, B. K. (2016). Aboveground woody biomass, carbon stocks potential in selected tropical forest patches of Tripura, Northeast India. *Open Journal of Ecology*, *6*(10), 598–612. [CrossRef]
- Mohamed, L. A. H. (2018). *Economic evaluation of ecosystem services provided by marine protected areas in western Africa : Example national park of the Bench of Arguin in Mauritania* [Phdthesis, Université Montpellier]. https://theses.hal.science/tel-02047962
- Mougoue, B. (1989). Mfou : Une ville satellite de Yaoundé. *Revue de Géographie du Cameroun*, *8*(2), 139–152.
- Muchiri, M. N., & Muga, M. O. (2013). A preliminary yield model for natural Yushania alpina Bamboo in Kenya. *Journal of Natural Sciences Research*, *3*(10), 77–84.
- Mukul, S. A., & Rana, P. (2013). The trade of bamboo (Graminae) and its secondary products in a regional market of southern Bangladesh : Status and socioeconomic significance. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *9*(2), 146–154. [CrossRef]
- Nfornkah, B. N., R. Kaam, T. Martin, Z. Louis, C. D. Cedric, G. W. Forje, T. Armand Delanot, T. Mélanie Rosine, A. Jean Baurel, T. Loic, Z. T. Guy Herman, K. Yves, and D. S. Vartent. 2021. Culm Allometry and Carbon Storage Capacity of Bambusa vulgaris Schrad. ex J.C.WendL. in the Tropical Evergreen Rain Forest of Cameroon. *Journal of Sustainable Forestry 40*(6):622-638. [CrossRef]
- Obiri, B. D., & Oteng-Amoako, A. A. (2007). Towards a sustainable development of the bamboo industry in Ghana. *Ghana Journal of Forestry*, *20*(1). [CrossRef]
- Odiwe, A. I., Adewumi, R. A., Alimi, A. A., & Ogunsanwo, O. (2012). Carbon stock in topsoil, standing floor litter and above ground biomass in Tectona grandis plantation 10-years after establishment in Ile-Ife, Southwestern Nigeria. *International Journal of Biological and Chemical Sciences*, *6*(6), Art. 6. [CrossRef]
- Pathak, P. K., Kumar, H., Kumari, G., & Bilyaminu, H. (2015). Biomass production potential in different species of bamboo in Central Uttar Pradesh. *Ecoscan*, *10*(1), 41–43.
- Pérez, M. R., Maogong, Z., Belcher, B., Chen, X., Maoyi, F., & Jinzhong, X. (1999). The role of bamboo plantations in rural development : The case of Anji County, Zhejiang, China. *World Development*, *27*(1), 101–114. [CrossRef]
- Ramananantoandro, T., Rabemananjara, Z. H., Randrianarimanana, J.-J., & Pommier, R. (2013). Valorisation de la filière bambou dans les zones orientales de Madagascar : Contraintes et opportunités. *Bois & et Forets des Tropiques*, *316*, 79–91. [CrossRef]
- Rosa, R., Pimentel, M., Galan, J. G., Baptista, M., Lopes, V. M., Couto, A., Guerreiro, M., Sampaio, E., Castro, J., Santos, C., Calado, R., & Repolho, T. (2016). Deficit in digestive capabilities of bamboo shark early stages under climate change. *Marine Biology*, *163*(3). [CrossRef]
- Singnar, P., Das, M. C., Sileshi, G. W., Brahma, B., Nath, A. J., & Das, A. K. (2017). Allometric scaling, biomass accumulation and carbon stocks in different aged stands of thin-walled bamboos Schizostachyum dullooa,

Pseudostachyum polymorphum and Melocanna baccifera. *Forest Ecology and Management*, *395*, 81–91. [CrossRef]

- Sohel, Md. S. I., Alamgir, M., Akhter, S., & Rahman, M. (2015). Carbon storage in a bamboo (*Bambusa vulgaris*) plantation in the degraded tropical forests : Implications for policy development. *Land Use Policy*, *49*, 142–151. [CrossRef]
- Sunderland, T. C. H. (2001). *The taxonomy, ecology and utilisation of African rattans (Palmae : Calamoideae)*. University of London, University College London.
- Wonkam, G. B. (2019). *Dégradation des forêts africaines : Le bambou et le rotin à la rescousse—Médiaterre*. https://www.mediaterre.org/afrique-centrale/actu,20191209103240.html
- Xu, M., Ji, H., & Zhuang, S. (2018). Carbon stock of Moso bamboo (*Phyllostachys pubescens*) forests along a latitude gradient in the subtropical region of China. *PLoS One*, *13*(2), e0193024. [CrossRef]
- Yen, T.-M. (2015). Comparing aboveground structure and aboveground carbon storage of an age series of moso bamboo forests subjected to different management strategies. *Journal of Forest Research*, *20*(1), 1–8. [CrossRef]
- Yuen, J. Q., Fung, T., & Ziegler, A. D. (2017). Carbon stocks in bamboo ecosystems worldwide : Estimates and uncertainties. *Forest Ecology and Management*, *393*, 113–138. [CrossRef]
- Zhang, H., Zhuang, S., Sun, B., Ji, H., Li, C., & Zhou, S. (2014). Estimation of biomass and carbon storage of moso bamboo (*Phyllostachys pubescens* Mazel ex Houz.) in southern China using a diameter–age bivariate distribution model. *Forestry: An International Journal of Forest Research*, *87*(5), 674–682. [CrossRef]