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ORIGINAL ARTICLE

Ecosystem services and biomass stock from bamboo stands in central and southern Benin, West Africa

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Abstract Bamboo is a multi-purpose woody grass with international and national interests accentuated by the promotion of green energy. In Asia, bamboo plantations are being successfully promoted and constitute important carbon sinks, while in Africa, they remain unimproved despite their potential service supply. In this study, we assessed ecosystem services (ESs) and biomass stock from bamboo stands in central and southern Benin. First, we interviewed 264 informants across seven sociolinguistic groups from 10 municipalities to analyse ESs importance across gender and multi-linguistic group spaces and determine trade-offs and synergies between services. Second, we used field plots to quantify biomass stocks in selected bamboo stands. Seven ESs (building material, handicraft material, medicine, firewood, support for agriculture, biological control and cultural dance) were mentioned, with provisioning ESs being the most important. ESs were equally mentioned by women and men, except for firewood and medicine which showed slightly different patterns. Handicraft material, firewood and cultural dance were mostly mentioned by *Nago* and *Fon*, whereas biological control and support for agriculture were cited by *Toffin* and *Weme*. Handicraft material, firewood and cultural dance were synergistically mentioned, but negatively associated with citations of biological control and support for agriculture, suggesting trade-offs. The estimated biomass density was remarkably low, ranging from 0.54 to 29.7 t/ha, with an average value of 11.1 t/ha. These results show a need for participative management integrating sociolinguistic groups into decision-making processes while promoting extensive bamboo plantations and bamboo carbon farming.

Keywords Biomass · Cultural valuation · Gender · Local perception · Sociocultural group

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1 Introduction

Ecosystem services (ESs) are the benefits obtained from nature (MEA 2005). Four categories of ESs are identified and include provisioning, regulating, supporting and cultural ESs. The provisioning ESs are the physical goods such as raw materials, fresh water, medicinal resources and foods (e.g. mushrooms, indigenous fruits, edible plants; Mensah et al. 2017a). The regulating ESs include local climate and air quality regulation, global climate

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regulation, erosion control, maintenance of soil fertility, water purification and pollination (De Groot et al. 2002; MEA 2005). The cultural ESs enhance the quality of human life through non-material benefits such as recreation, tourism, spiritual experience, aesthetic experiences and cognitive development. The supporting ESs underpin the basic life-support processes. They also underpin other ESs and include, for example, biodiversity maintenance, genetic diversity and habitats for species.

Wild plant resources, particularly non-timber forest products, are vital commodities that provide a number of services such as low-cost building materials, fuel wood, food supplements, herbal medicines and income (Vodouhê 2011). Plants with nutritional, medicinal and commercial potentials play crucial role in supporting human livelihoods and maintaining the balance between agricultural output and population growth (Barminas et al. 1998). Multi-purpose species such as bamboos contribute to the alleviation of social and environmental problems in the developing world (Quintans 1998). Generally considered as a woody grass, bamboo is used in building (scaffolding), in agriculture (irrigation), for energy (fuel wood) and in paper industry (Laha 2000; Nath et al. 2011). There are insights that bamboo leaves serve as forage for ruminants (Singhal et al. 2011), and contain flavonoids that have potential to prevent cancer, diabetes and heart disease (Laleye et al. 2015). Furthermore, bamboo clumps contribute to soil stabilization due to their dense rooting system (Okioga 2006). Therefore, bamboo is a potential source of ESs, which should be assessed to provide a basis for management actions and conservation measures.

Bamboo raw products are widely used and are seen as important economic assets in poverty alleviation, economic and environmental development (FAO 2005; Xuhe 2003; Van der Lugt and Lobovikov 2008). For instance, Asia is successful in the development of bamboo plantations which cover large areas from lowlands to mountainous ecosystems (Yang et al. 2004). In China, bamboo industries boost national and regional economies through export and domestic manufacturing while employing thousands of people (Lobovikov et al. 2007; Bystriakova et al. 2003). Besides, recent studies emphasized the potential of bamboo stands in storing important amount of atmospheric carbon (Yen and Lee 2011; Qi et al. 2016), giving insights in their contribution to global climate change. In Africa, however, bamboo remains underexploited and unimproved (Schreckenberg 1999; El-Siddig et al. 2006), with research studies on biomass stock in bamboo forests in Africa still lacking.

Consideration of ESs as an anthropogenic concept is a key for management decision as it reflects the benefits from nature, the interactions with humans, and strongly relates them with ecosystem integrity and functions (Mensah 2016; Mensah et al. 2017a). Studies on bamboos in Africa have mostly focused on chemical composition, population structure, mechanical properties and traditional knowledge of use (Dah-Dovonon 2000; Bitariho and McNeilage 2008; Honfo et al. 2015). Due to their socio-economic importance, research should also aim to assess, from a general perspective, ESs obtained from bamboo stands. For example, cultural valuation (education-, demography- and culture-related aspects) of ESs provides basic information on their importance to specific categories of stakeholders (Mensah et al. 2017a) and also helps to identify the trade-off between ESs (Haase et al. 2012).

In southern Benin, bamboo and other forest resources generate social benefits to local people. A recent study in south-eastern Benin revealed cultural and economic importance of bamboo at household level (Honfo et al. 2015). As bamboo stands generally grow fast, it would be useful to estimate their biomass and carbon stocks. Therefore, in this study, we used both social surveys with local populations and inventory field plots in southern and central Benin to (1) assess ESs obtained from bamboos and determine the most important ESs as perceived by local populations; (2) analyse ESs importance across gender and multi-linguistic group space; (3) determine trade-offs and synergies between ESs; and (4) quantify the biomass and carbon potential in selected bamboo stands.

2 Materials and methods

2.1 Study area

This study was carried out in the central and southern regions of the republic of Benin, West Africa (Fig. 1). The southern Benin lies between 6°30′ and 7°N and is characterized by a sub-equatorial climate with annual rainfall varying from 900 to 1500 mm. The average annual temperature is 26.5 °C, and the annual relative humidity is 75%. The vegetation in southern Benin is composed of fragmented patches of dense forests, dry semi-deciduous forests, sacred groves and Guinean savannahs (Alohou et al. 2017). The central region lies between 7° and 10°N, with an average annual rainfall of 1100 mm and average annual temperature of 27 °C. The annual relative humidity is 60%. The vegetation in this area is composed of semi-deciduous forests, gallery forests, savannahs and bushlands. Recent investigations in the regions revealed the presence of natural and planted bamboo stands, which provide vital benefits to local communities (Honfo et al. 2015; Tovissodé et al. 2015). For instance, in south-eastern Benin, bamboo culms are used as poles for cultural rituals and in traditional fishing systems (Honfo et al. 2015).

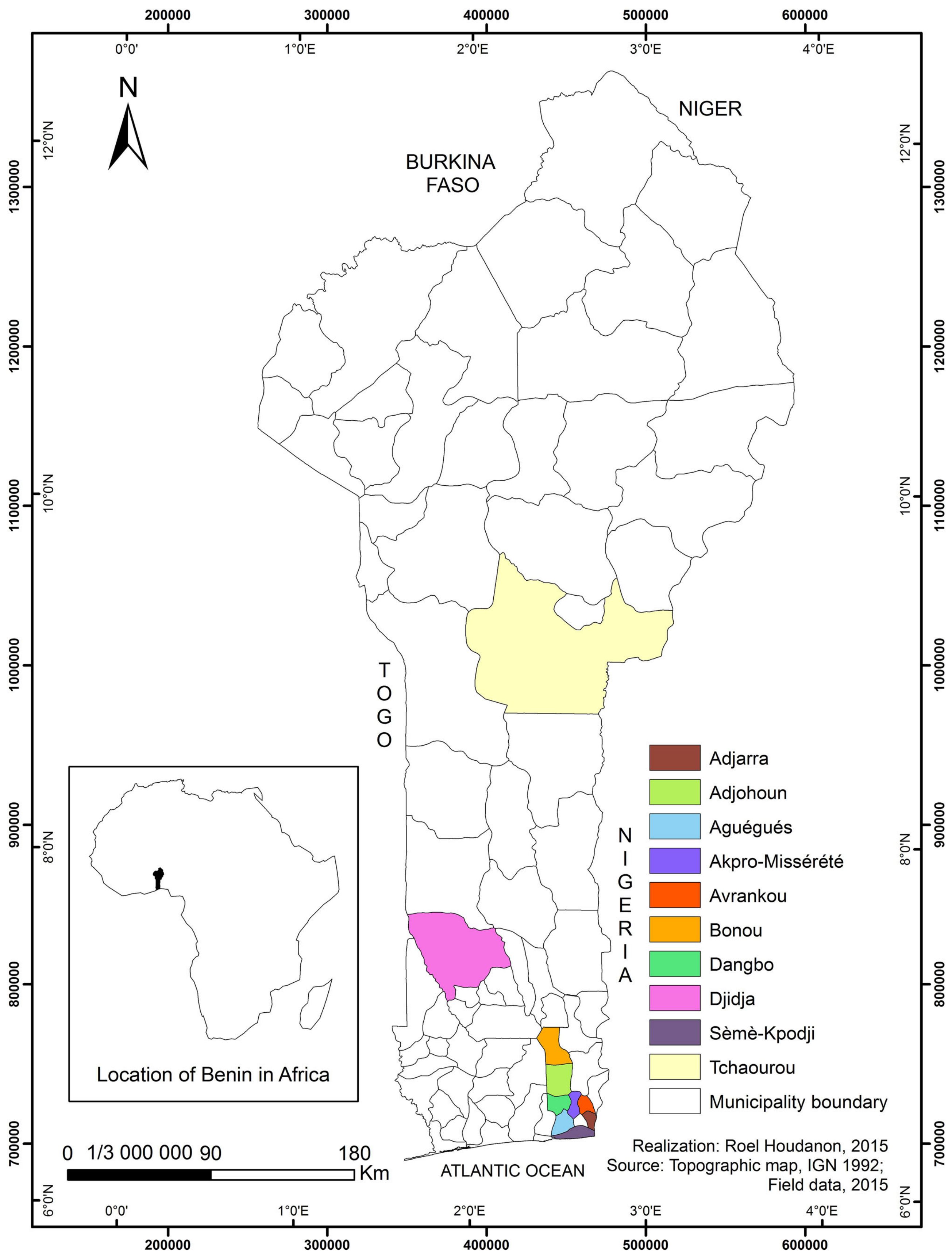

Fig. 1 Location of the study area in Benin

A preliminary exploration was conducted in the southern and central regions for identification of rural communities using bamboo as sources of benefits. A total of 10 municipalities (Fig. 1) were explored: eight in the southern Benin region (Adjarra, Adjohoun, Aguegue, Akpro-Misserete, Avrankou, Bonou, Dangbo and Sèmè-Podji) and two in the central Benin region (Djidja and Tchaourou).

2.2 Sampling and data collection

To assess ESs and biomass stock, we used social surveys and inventory plots, respectively. The social surveys are not directly related to the biomass assessment, as information on biomass density could not be obtained from the interviewees. Nevertheless, the inventoried bamboo stands for biomass assessment were identified during the focus group discussions.

In each municipality, a pilot survey was conducted with 50 randomly selected people to estimate the proportion p of people using bamboo as ES providing units. The proportion p was then used to calculate the sample size for each municipality by applying the following formula:

$$n = p(1-p)/e^2 \times U^2_{1-\frac{\alpha}{2}}, \quad (1)$$

where n is the estimated sample size, U the value of the normal random variable (1.96 for $\alpha = 0.05$), e the error margin assumed to be 5%, and p the proportion of people using bamboo. The reason for using this sampling method is that it mostly targets households/informants of interest, and not the entire community (Mensah et al. 2017a). In total, 264 people (Table 1) were randomly selected for the social surveys. As an outcome, seven major sociocultural groups were covered: *Toli* (77 respondents), *Weme* (75 respondents), *Toffin* (28 respondents), *Goun* (16 respondents), *Nago* (32 respondents), *Fon* (19 respondents) and *Fulani* (17 respondents).

Information on ESs was collected through focus group discussions and individual interviews. Prior to these, the concept of ES was explained to the participants. The focus group discussions were held to help enumerate various ESs obtained from bamboo stands. The focus group discussions took place during the dry season when major agricultural activities were reduced, to facilitate the participation of the local populations. Each focus group discussion was conducted with 5–7 participants aged 30–70 years. During individual interviews, informants were requested to mention the services obtained from bamboo stands. New ESs quoted by the informants were added to the list.

The focus group discussions also helped identify surrounding bamboo stands for biomass estimation. Eight bamboo stands were identified for diameter measurement and further estimation of stand density biomass and carbon. For each stand, a 0.25-ha square plot was laid out. In total, eight inventory plots were laid out, and culms of bamboo species were counted and diameter at breast height (DBH) was measured.

Table 1 Repartition of the sample size according to the sociocultural groups and the gender category

Sociocultural groups	Number of interviewees (women/men)	Total
Fon	8/11	19
Goun	9/7	16
Nago	13/19	32
Fulani	5/12	17
Toffin	10/18	28
Toli	26/51	77
Weme	35/40	75
Total		264

2.3 Assessing ESs from bamboo stands

The number of times a service was mentioned (frequency of citation) by the respondents was used to assess ES importance. Because of the differences in sample size within sociocultural groups and gender categories, we calculated the mean frequency of citation for each sociocultural group and gender category by weighting the frequency of citation by the number of informants within each group. ESs with the highest mean frequency of citation were considered as the most important. The frequency of citation of each ES was assessed globally for all sociocultural groups (including gender categories). To analyse ESs importance across gender and multi-linguistic group space, the frequency of citation of each ES was further assessed for each sociocultural group and gender category separately. A principal component analysis (PCA) based on the frequencies of citation was used to assess the correlations between ESs and provide insights into trade-offs and synergies. The first two principal components were selected according to the latent root criterion (Hair et al. 2009). The principal component analysis was performed using package FactoMineR in the R statistical software (version 3.1.2, https://www.R-project.org/).

2.4 Assessing biomass and carbon stock in bamboo stands

To quantify the biomass and carbon potential in bamboo stands, we calculated the total biomass for individual bamboo culms using the allometric equation developed by Qi et al. (2016) for the Moso bamboo in South Anhui Province, China.

$$B = 0.24 \times \mathrm{DBH}^{1.87}, \quad (2)$$

where B is the total biomass and DBH is the diameter at 1.3 m, in mm. The equation is based on destructive sampling and measurement of the main biomass components (leaves, branches, culms, pachymorph rhizomes and pachymorph rhizome roots). Using the culm diameter data collected from bamboo stand, biomass was estimated at stem level and further at stand level by summing up individual culm biomass values in the following formula:

$$B_i = \left(\sum_{j=1}^{n} B_j\right) / S_{\mathrm{p}}, \quad (3)$$

where B_i is the total biomass (kg/ha) of the ith plot, B_j, the total biomass of the jth individual in the ith plot, and S_{p}, the plot size (in ha). The biomass values were converted into carbon (C) stock by applying a conversion factor of 0.5 as in Zhou and Jiang (2004), Chen et al. (2009) and Yen and Lee (2011).

3 Results

3.1 Ecosystem services from bamboo stands

In total, seven ESs were mentioned by seven sociocultural groups across the study areas. Out of these ESs, four provisioning services were identified: building material, handicraft material, medicine and firewood; two were supporting services: support for agriculture and biological control; and one cultural service (cultural dance) was mentioned (Fig. 2). The support for agricultural activities as mentioned by interviewees was mainly for crop production, animal production and fisheries. Based on the frequency of citation, the most important/relevant ESs were the provisioning ESs, while the less important were the cultural ESs.

All ESs were mentioned by both women and men. There were no clearly distinguishable patterns between men and women perceptions towards the importance of these ESs ($t = -0.013$; p value = 0.989), except for firewood and medicine where slight demarcations were observed (Fig. 3). Accordingly, firewood was more valued by women, while medicinal resources were more valued by men.

Out of the seven ESs, four (mostly provisioning ESs; building material, handicraft material, medicinal resources, firewood) were cited by all sociocultural groups (Fig. 4). The cultural service (cultural dance) was cited by six sociocultural groups, while biological control was only mentioned by three sociocultural groups. The results of the PCA revealed two significant axes explaining 69.48% of

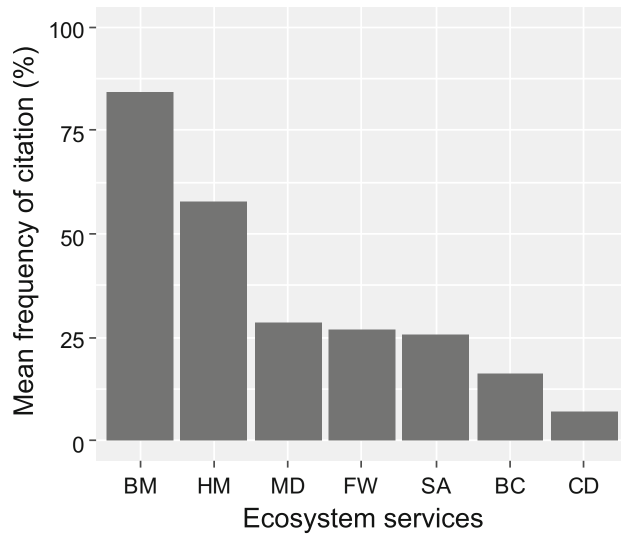

Fig. 2 Mean frequency of citation of ESs obtained from bamboo stands. *Note BM* building material; *HM* handicraft material; *MD* medicine; *FW* firewood; *SA* support for agriculture; *BC* biological control; *CD* cultural dance

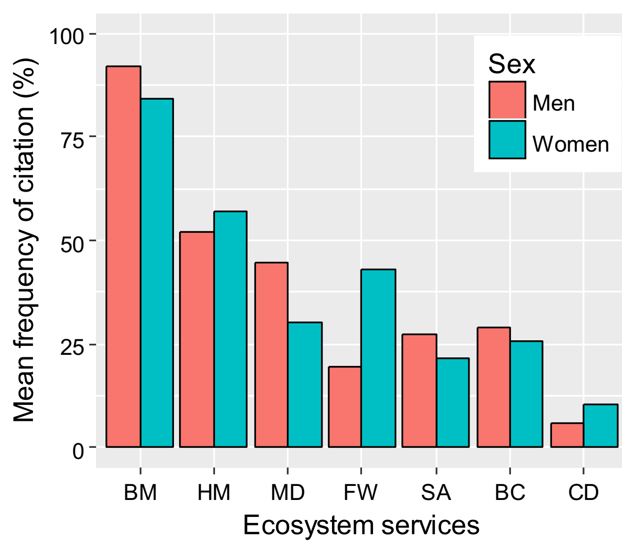

Fig. 3 Mean frequency of citation for each ES according to gender. *Note BM* building material; *HM* handicraft material; *MD* medicine; *FW* firewood; *SA* support for agriculture; *BC* biological control; *CD* cultural dance

the total variance of the mean frequency of citation (Table 2). The first axis (39%) was significantly and positively correlated with handicraft material ($r = 0.93$), firewood ($r = 0.80$) and cultural dance ($r = 0.67$), and negatively associated with biological control ($r = -0.47$) and support for agriculture ($r = -0.63$) (Table 2). Furthermore, handicraft material, firewood and cultural dance were mostly cited by *Nago* and *Fon*, while biological control and support for agriculture were mainly cited by *Toffin* and *Weme* (Figs. 4, 5). The second axis was

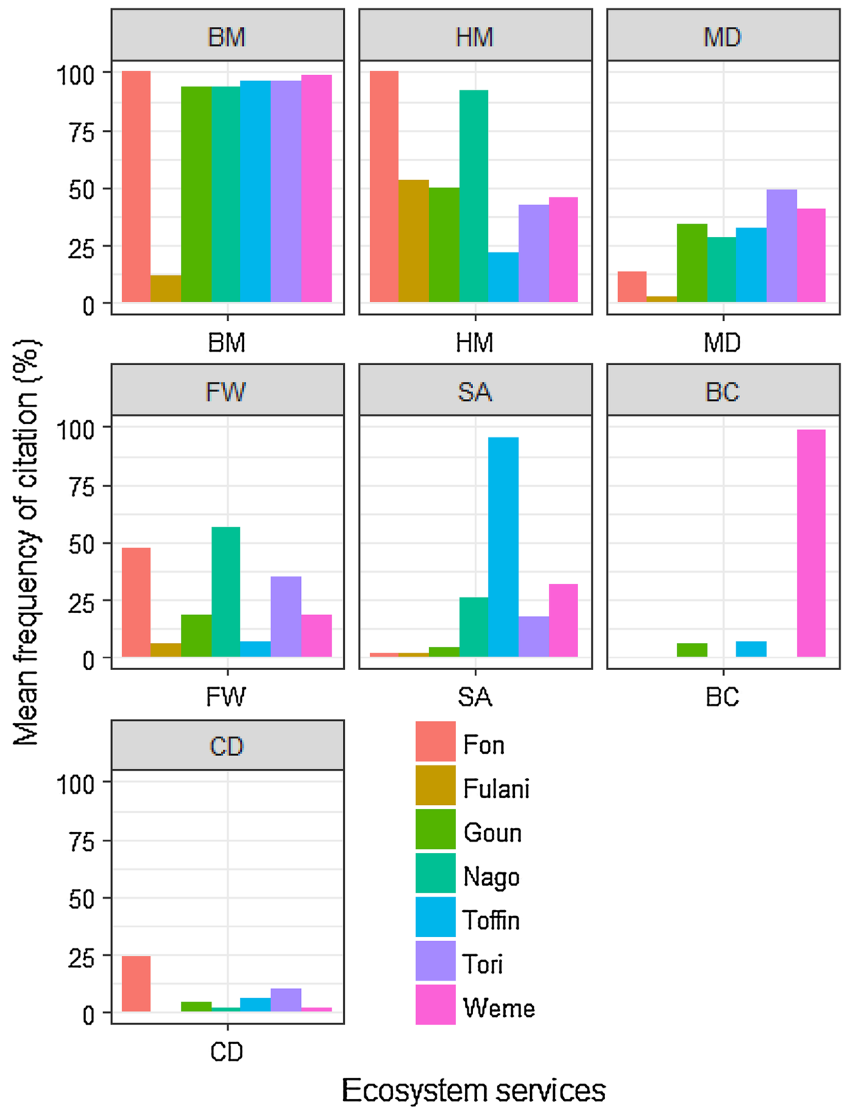

Fig. 4 Mean frequency of citation of ESs across sociocultural groups. *Note BM* building material; *HM* handicraft material; *MD* medicine; *FW* firewood; *SA* support for agriculture; *BC* biological control; *CD* cultural dance

Table 2 Significance of correlation coefficients between principal components and ESs

	Dim. 1	Dim. 2	Dim. 3
Eigen value	2.76	2.11	0.97
Percentage of variance	39.39	30.09	13.87
Cumulative percentage of variance	39.39	69.48	83.36
Correlations			
Building material	0.08	0.97	− 0.07
Handicraft material	0.93	0.02	0.22
Firewood	0.80	0.47	0.11
Medicine	− 0.43	0.79	0.12
Cultural dance	0.67	0.33	− 0.35
Biological control	− 0.47	0.30	0.71
Support for agriculture	− 0.63	0.33	− 0.52

positively correlated with building materials ($r = 0.97$) and medicine ($r = 0.79$). Apart from *Fulani*, all sociocultural groups used bamboo as building materials, while the use of bamboo as medicinal resources was mostly cited by *Toli* and *Weme* (Figs. 4, 5).

3.2 Bamboo biomass and carbon stock

The estimated bamboo biomass density in southern Benin ranged from 0.54 to 29.7 t/ha, with an average value of 11.1 t/ha. The corresponding carbon density value was 5.5 t/ha. The distribution of biomass values across diameter classes (Fig. 6) followed a bell-shaped pattern, with the highest contribution from 70 to 80 mm diameter class.

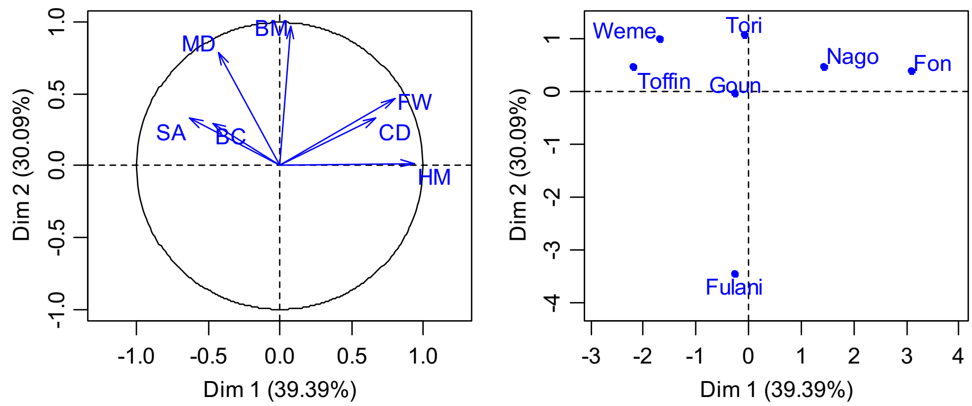

Fig. 5 Results of the PCA showing the relationships between ESs and sociocultural groups. *Note BM* building material; *HM* handicraft material; *MD* medicine; *FW* firewood; *SA* support for agriculture; *BC* biological control; *CD* cultural dance

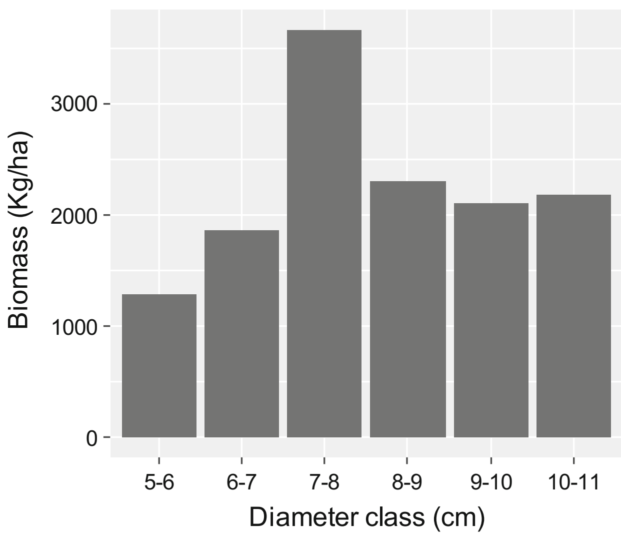

Fig. 6 Distribution of biomass storage of the studied bamboo species across diameter classes

4 Discussion

4.1 Ecosystem services from bamboo stands in gendered and sociocultural perspectives

Understanding cultural perceptions of ESs is important for conservation purposes and local development planning. In our study, (1) seven ESs were mentioned by both men and women; (2) provisioning ESs were the most cited and by all sociocultural groups; (3) citation of ESs varied with specific sociocultural group and slightly between gender; and (4) synergistic and trade-offs relationships were found between ESs.

Most ESs were mentioned by studied sociocultural groups, suggesting crosscutting information, knowledge and use of the benefits from bamboo stands. More interestingly, provisioning ESs were the most cited by the respondents. This result concurs with the general idea that local people highly appreciate material benefits from nature. The appreciation of provisioning ESs by rural inhabitants may be attributed to their close connection to the natural ecosystems (Martín-López et al. 2012; Mensah et al. 2017a), which also seems to be in line with the availability hypothesis (Albuquerque et al. 2006).

ESs such as building material, handicraft material and firewood were the most mentioned; these services are obtained from bamboo culms. Thus, most important/relevant ESs provided by bamboos are the provisioning services. This finding accords with past studies that reported diverse use of bamboo culms in Africa and other parts of the world (Benton et al. 2011; Honfo et al. 2015). For instance, Chihongo et al. (2000) and Bystriakova et al. (2003) documented the use of bamboo in furniture making, house construction as well as for firewood. The physical characteristics of bamboo species such as length and strength could partly support the preferences and use as antenna pole and building material. According to Nath et al. (2011), houses built from bamboo raw materials present acceptable comfort and are resistant to heat and humidity. In the study areas, respondents reported the use of bamboo for local constructions (humans and livestock housing). Bamboo also serves in the construction of fences and local bridges. According to Jusu and Cuni Sanchez (2014), plant use by local communities is subject to its availability and abundance, availability of alternative species as well as local preferences. These factors are also likely to affect the appreciation of the services provided by bamboos. There are further insights that bamboo culms are used in fishing activities, especially as fencing structures in traditional in-lake fish breeding systems known as "acadja" (Niyonkuru and Lalèyè 2010). The leaves also serve as mulch in agriculture and as forage for livestock (Honfo et al. 2015).

There were no clear differences in the citation of ESs between men and women, except for firewood and medicine. Firewood was more valued by women, and medicine by men. From a gender perspective, the positive attitude of women towards firewood and of men towards medicine may be related to the roles men and women have in the household. As pointed out by Mensah et al. (2017a), local populations, especially women, are closely involved in the collection of timber for firewood. On the other hand, the positive attitude of men towards use of bamboo as medicine may be explained by the importance of bamboo leaves in treating men-related disorders. For instance, Laleye et al. (2015) reported the use of *Oxytenanthera abyssinica* (A.Rich.) Munro—largely found in South Benin—in the treatment of men-related disorders.

There were variable citation patterns among studied sociocultural groups, suggesting intercultural differences in the citation of ESs, consistently with previous studies (Assogbadjo et al. 2008; Vodouhê et al. 2009; Houehanou et al. 2011). The differences in the mean frequency of citation among sociocultural groups could be due to the influence of traditional knowledge as regards the use of bamboo, which varies with sociocultural aspects (Honfo et al. 2015). The positive attitudes towards the use of bamboo as wood energy, materials for building and fish trap materials by *Fon*, *Toffin*, *Toli* and *Weme* sociocultural groups could be explained by the characteristics of the living environment of these populations, especially the increased reduction in plant cover (due to the uncontrolled exploitation of trees for charcoal production) (Agbomahenan et al. 2009). In addition, populations of *Toffin*, *Toli* and *Weme* sociocultural groups living in wet lands and lacustrine areas build their houses from bamboo culms. Similar practices and use of bamboos as materials (for house fences, or to support wooden houses, and construction of local bridges) were reported in Analanjirofo, Madagascar (Capo-chichi 2008).

Our study further revealed some associations between ESs; for instance, there were synergetic attitudes towards bamboo as handicraft material, firewood and cultural dance, which probably resulted in the observed decrease in the frequency of citation of supporting ESs such as biological control and support for agriculture. Thus, the study indicated that handicraft material, firewood and cultural dance were supplied at the expense of other ESs such as biological control and support for agriculture, suggesting trade-offs.

4.2 Bamboo biomass and carbon stock in southern and central Benin in comparison with other regions

Increased attention has been given to bamboos as they have many advantages (rapid growth, high production and versatility; Fu 2001; Embaye et al. 2005; Chen et al. 2009) over other woody plants. Yet, few studies focused on bamboos' contribution to the global carbon cycle and their potential for accumulation and storage of carbon (Yen and Lee 2011; Song et al. 2013), especially in Africa. Studies that addressed such aspects showed that bamboo species and stands have remarkable carbon storage potential. For instance, Lou et al. (2010) found that aboveground carbon stock in 9–10-years-old Moso bamboo (*Phyllostachy pubescens*) plantations in China ranged from 25 to 32 t/ha. *Phyllostachy pubescens* and *Phyllostachys bambusoides* bamboo species in natural forests in Japan showed aboveground carbon stock of 78.6 and 52.3 t/ha, respectively (Isagi et al. 1994, 1997). Zhou and Jiang (2004) found that total carbon storage capacity in typical Moso bamboo ecosystem, including the soil, was 106.36 t/ha, of which the aboveground vegetation stored 34.3 t/ha. Similarly, the total carbon storage in *Phyllostachys bambusoides* stands in Japan was 165.1 t/ha, of which 31.7% was from the aboveground compartment and 68.3% from the belowground pool (Isagi et al. 1994). Tripathi and Singh (1996) also reported carbon stock in *Dendrocalamus strictus* stands in Indian dry tropics amounting to 75.4 t/ha, of which 23–28% came from vegetation, 2% from litter, and 70–75% from the soil. These studies showed high potential of carbon storage in bamboo forests. In our study, the estimated biomass density in southern Benin ranged from 0.54 to 29.7 t/ha, with a carbon stock value estimated at 5.5 t/ha. These estimated values were remarkably low compared to those mentioned by the studies above. This result can be attributable to the predominance of small-sized bamboo culms (usually DBH < 8 cm) in the studied bamboo stands. Bamboo culms with larger size accumulate more biomass than those with smaller size simply because woody biomass generally increases with increasing diameter and height (Mensah et al. 2016, 2017b). The predominance of small-sized culms observed here may be attributed to the reduced bamboo stand density resulting from human pressure on bamboo forests and individuals of larger diameter, as recently reported in southern Benin (Tovissodé et al. 2015). The lower values of bamboo biomass stock are also indicative of the increased benefits that local populations derive from bamboo stands.

5 Conclusion

In this study, ESs and biomass stock were assessed in bamboo stands in southern and central Benin. The studied municipalities vary considerably in their sociocultural groups, structure and functioning, which supported the intercultural variation in the perceived importance of these ESs. The results further showed that bamboo stands were socially valued for their physical goods (culms) used as firewood, timber for construction and crafting; they are also a source of medicinal resources, support cultural activities and dance. The estimated value of biomass stock was remarkably low and indicative of the increased benefits and services local people derived from the bamboo stands. Given the potential of bamboo stands to store atmospheric carbon, and their contribution to global climate change, there is urgent need for management interventions that promote extensive bamboo production for alternative wood source and bamboo carbon farming.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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