Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 2, No. 5, p. 50-60, 2012
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Comparing the distribution, harvesting and regeneration of *Beta vulgaris* in the Owabi wildlife sanctuary and the adjacent agricultural farmlands in the Atwima District of Ghana

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Received: 02 April 2012
Revised: 15 May 2012
Accepted: 16 May 2012

Key words: Bamboo culms, harvesting, conservation, regeneration, shoot production.

Abstract

Deforestation of tropical forests through timber harvest has been described as one of the major causes of global warming and carbon emission. Bamboo conservation presents an alternative strategy for ameliorating the effect of forest tree loss in the tropics. The purpose of this study was to compare the distribution, harvesting and regeneration of *B. vulgaris* in harvested and non-harvested sites. It also aimed at assessing the effect of seasonal changes on the regeneration levels of *B. vulgaris* in harvested and non-harvested sites. The two sites were located in the Owabi wildlife sanctuary and the adjacent agricultural farmlands in the Atwima district of Ghana where *B. vulgaris* is in abundance. Using adaptive sampling method, 25 and 35 plots measuring 50x50m were installed in the sanctuary and on the agricultural farmlands, respectively. The population and regenerative capacity of bamboo culms in each site were determined by counting the number of shoots, young, mature, dead and harvested culms in each clump in the sampled plots. The results showed that two out of three (67.9%) of the culms on the farmlands were harvested with the number of harvested culms averaged 64.0±14.12% per clump, while mature and dead culms in the sanctuary averaged 32.0±13.96% and 26.5±20.28%, respectively. Site (harvested versus non-harvested) did not have a significant effect on the regeneration of juvenile culms, while the effects of seasonal changes and the interaction between the sites and seasonal changes were significant, with the bamboo on the farmlands responding more positively to regeneration of juvenile culms (11.7%) than those in the sanctuary (3.6%). The average ratio of juvenile culm production to the number of mature culms per clump before rainy season was 3:10 compared with 8:10 at the end of the rainy season, suggesting that the presence of mature culms could potentially stimulate the regeneration of juvenile culms. Despite the ability of mature culms to stimulate culm regeneration, the contribution of non-harvested site to regeneration was far less compared to that of harvested site. It seems reasonable to conclude that optimum regeneration of culms could be achieved if older culms are harvested.

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Introduction

The current rate of deforestation in Africa has been described as alarming. Between 2000 and 2005, the rate of deforestation in Africa was estimated at 4 million hectares, representing about one-third of the area deforested globally (FAO, 2009). With the quest for urbanisation, large-scale agriculture and industrial development, coupled with the high demand for energy in the form of fuelwood, the forest situation in Africa is expected to exacerbate (FAO, 2009). This situation could potentially lead to soil erosion, loss of soil fertility and large scale desertification.

Conservation of bamboo resources presents an alternative strategy for ameliorating the negative consequences of forest loss. Apart from playing an important economic role in the rural and urban settings (Bitariho and Mosango, 2005; Hakim *et al.,* 2002; Embaye, 2000; Sharma, 1980), bamboo plays an indispensable role in the environmental restoration (Obiri and Oteng-Amoako, 2007; Embaye, 2000), biodiversity preservation, soil conservation and waste purification (Bitariho and Mosango, 2005; Embaye *et al.,* 2005; Embaye, 2000; Zhou, 1999; Singh and Singh, 1999). The high growth rate of bamboo is closely associated with high nutrient consumption, thus making bamboo a suitable candidate for vegetation filter purposes, a biological means of purification, whereby most of the pollutants in the waste are used for biomass production through the plant-growth process (Embaye, 2000).

Bamboo can be found on agricultural lands (*ex situ*) and in forest reserves or protected areas (*in situ*). Bamboos, when found on agricultural lands, compete with other agricultural land uses for space. Regeneration of culms may therefore be hampered by anthropogenic disturbances such as clear cutting and burning of culms to make way for agriculture. Additionally, uncontrolled harvest of bamboo poses a threat to regeneration of bamboo on agricultural lands. Therefore the *in situ* bamboo conservation which occurs in forest reserves and or protected areas presents a more sustainable means of conserving bamboo.

The productivity ability of bamboo in the protected areas and forest reserves is therefore critical to the sustainability and conservation of bamboo and hence merit attention. The study of the effect of culm harvest on the regenerative capacity of bamboo culms has produced mixed results. Whereas Vázquez-López et al. (2004) reported that harvesting of *Otatea acuminate* bamboo increased shoot production, Sheil *et al.* (2012) did not find any positive effect of harvesting localised mature culms on the regeneration of new shoots. Even though available evidence suggests that bamboo shoot production is a function of photosynthetic products transported from parent bamboos through the rhizome system (Li *et al.,* 2000; Tomar, 1963), it has been suggested elsewhere that to improve sprouting and maintain the vigour of bamboo stands, one-fifth of older culms should be removed every year (Yen *et al.,* 2010).

Given the ecological and socio-economic importance of bamboo resource, its distribution, utilisation, conservation and regeneration has been a subject of interest to researchers and biodiversity conservationists. However, most of these studies are from Asia (Wang *et al.,* 2006; Hakim *et al.,* 2002; Singh and Singh, 1999; Sharma, 1980), South America (Vázquez-López *et al.,* 2004) and East Africa (Bihariho and Mosango, 2005; Embaye *et al.,* 2005; Embaye, 2000), making generalisation to the Ghanaian situation a major limitation. Even though in Ghana it is estimated that bamboo covers between 250,000 and 300,000 hectares (Obiri and Oteng-Amoako, 2007), and that indiscriminate harvesting and handling pose a serious threat to the resource (Obiri and Oteng-Amoako, 2007), there is a lack of field measurement to give a more accurate picture of the distribution, harvesting and regeneration of bamboo at the clump level. Additionally, few studies on the distribution of bamboo have focused on bamboo on agricultural lands (e.g. Bih, 2006), while no attention has been paid to the distribution and regenerative ability of bamboo in its natural stands where harvesting hardly takes place. Moreover, most of these studies elsewhere were cross-sectional (e.g. Sheil *et al.,* 2012), relying on data collected at a single point in time. This limitation makes it difficult to understand how seasonal changes affect the productive capacity of harvested and unharvested bamboo clumps. It is therefore important to provide accurate data on bamboo resource on both agricultural lands and on protected areas to help quantify the available resource stock and regeneration. Knowledge of the available bamboo stock, its distribution and regeneration is crucial for sustainable management of the resource (Obiri and Oteng-Amoako, 2007; Bitariho and Mosango, 2005). Thus, motivated by lack of knowledge on the distribution, harvesting and regeneration of bamboo on agricultural lands and in the protective areas in Ghana, the primary aim of this study was to quantify the distribution of culm types (shoot, young, mature and dead) of *B. vulgaris* in the Owabi wildlife sanctuary and on the adjacent agricultural farmlands in the Atwima District in the Ashanti Region of Ghana. Additionally, this study investigated the harvesting of bamboo at the clump level and assessed how regeneration of bamboo is affected by harvesting (or non-harvesting) of mature and dead culms and how seasonal changes affect the regeneration of culms in the two vegetative types. Specifically, the productivity levels of bamboo on the agricultural farmlands and in the sanctuary were compared. The results of this study will increase our understanding of regenerative capacity of unharvested *B. vulgaris* in its natural stands and harvested *B. vulgaris* on agricultural farmlands.

Materials and methods

Study sites and Context

Owabi Wildlife Sanctuary (OWS) was established in 1971 and is located approximately 23 km northwest of Kumasi in the Ashanti Region of Ghana. OWS lies on 6°44'50'' N and 1°42' W. Rainfall in the sanctuary is bimodal with a mean annual amount of 1444mm. The mean monthly temperature is 28°C with an average diurnal range of 10.2°C (Hall and Swaine, 1981). Covering an area of 1300 ha (IUCN/PACO, 2010), OWS centres upon a reservoir formed by a dam across the Owabi stream in the 1940's to provide water supply for Kumasi. The area around the dam was initially protected as a catchment area for Owabi Waterworks. Under L.I. 171 of the Wild Animals Preservation Act, 1961 (Act 43) Owabi Waterworks area became a game reserve in 1962. The area was expanded and re-designed Owabi Wildlife Sanctuary by L.I. 710 in 1971 (Department of Game and Wildlife, 2002). OWS is found in the moist-deciduous secondary forest zone (Hall and Swaine, 1981) of Ashanti Region of Ghana. About one-third of the area consists of open water and inlets covered by aquatic plants and encroaching reeds, ferns and other marsh plants. The sanctuary is classified into three main habitats (*Celtis-Triplochiton* forest, *Cassia siamea* plantation and *Riverine forest* (Oduro and Aduse-Poku, 2005).

Ecotourism is very high at OWS because of the closeness of the sanctuary to the regional and district capitals. The sanctuary is popular with bamboo and bamboo is one of the tourist attractions. In fact, the OWS has been 'nicknamed' bamboo paradise. Most tourists would like to visit the bamboo paradise because of its cool and peaceful natural setup that refreshes the mind and it makes one appreciate nature (Forestry Commission, 2010). Like most of the protected areas, the communities around the sanctuary are prohibited from harvesting the bamboos. Consequently, most of the bamboo clumps have been in their natural stands since the establishment of OWS. The management of OWS was concerned about the large number of mature and dead culms in the clumps. The fear is that this could inhibit the regeneration of new shoots and the sanctuary could therefore lose the bamboo paradise which has so far been the epicentre for social gathering such as picnics and meetings (Forestry Commission, 2010). Similar concern has been expressed elsewhere where lack of regeneration of bamboo sprouts was attributed to non-harvesting of bamboo culms (Sheil *et al.,* 2012).

Adjacent to OWS is an agricultural farmland with patches of *B. vulgaris* along the Owabi stream. Because of high population density of Kumasi and its environ, the demand for bamboo for housing and energy is very strong. Additionally, the anthropogenic activities such as farming and burning have threatened the growth and regeneration of *B.vulgaris* on the farmland. Thus, the bamboos in OWS and on the agricultural farmlands present two contrasting conditions: Bamboo clumps in its natural stands in the sanctuary versus bamboo clumps on the agricultural farmlands that have been heavily harvested.

Field methods

Density of rare and clustered populations is difficult to estimate precisely using conventional sampling design (Bih, 2006). For such rare and clustered populations such as *B. vulgaris*, adaptive cluster sampling has been found to be more effective (Thompson and Seber, 1996; Christman, 1997; Brown, 2003). This sampling method was employed in this study in order to take advantage of the population characteristics of *B. vulgaris* and to allow for more precise estimates of the population parameters. The two study sites (the agricultural farmlands and OWS) were stratified using the Owabi stream as basis on the assumption that *B. vulgaris* are concentrated in patches around the stream and any bias would be negligible (Bih, 2006). At randomly selected starting point on the stream, 50x50 m plots were located on both sides of the stream. Systematic plots of the same configuration as the first were then laid along the stream on both sides of the starting point at 500 m interval. Sampling along the stream was done with a rule that if no such observations were found in five consecutive plots, the site is abandoned. Where an observation of any bamboo clump is made, 50x50m adaptive adjoining plots are made till a network of plots with zero observation edge units is formed. In March 2011, (at the beginning of the rainy season) I installed 40 50x50 m plots each in the sanctuary and on the agricultural farmlands. The concern however was that not all the plots had similar canopy gaps and this could render the comparison of regenerative capacity of the clumps invalid. In order to control for gap differences, only plots with 100% open gap were included in the study. This resulted in 25 and 35 useful plots in the sanctuary and on the agricultural farmlands, respectively.

Population and reproductive ability of B. vulgaris

The population and the reproductive capacity of the clumps were determined by counting the number of culms in each clump. For each clump identified in the plots, fifty culms were randomly sampled and their culm diameters were measured at breast height (DBH) using digital calipers (Yen & Lee, 2011). The determination of bamboo age was based on the features of culm sheath, the development of leaves, and external colour of the culm (Yen et al., 2010). The culms were identified as shoots, young, mature and dead/old culms following the description by Vázquez-Lopez et al. (2004). Shoots referred to green culms with sheaths and no development of leaves. Young culms referred to green culms with their sheaths on but have their leaves developed. Mature culms were those with green-yellowish culms while old/dead culms referred to completely yellow to greyish culms without culm sheaths or foliage and with brittle culms (Vázquez-Lopez *et al.,* 2004). For easy assessment of regeneration of bamboo culms, shoots and young culms were re-classified as juvenile culms. Assessment of the threats on *B. vulgaris* population in the sanctuary and on the agricultural farmlands was based on the counting the number of harvested culms (Hakim *et al.,* 2002). In order to predict the number of culms in each clump, the circumference of the clumps was measured (Hakim *et al.,* 2002). Data were collected at the beginning of the rainy season (March, 2011) and this was repeated at the end of the rainy season (end of September, 2011).

Statistical Analysis

The results of one-sample Kolmogorov-Smirnov goodness of fit test for normality showed that the data did not meet the normality assumption needed for a parametric t-test to be used to compare the differences in the culm types (shoot, young, mature, dead and harvested) between the clumps in the sanctuary and on the agricultural farmlands. A non-parametric version of t-test (MannWhitney U test) was therefore used to compare the differences in the culm types between the sanctuary and the farmland. I used two-way ANOVA to test the effects of site (sanctuary or non-harvested and agricultural farmlands or harvested), season (beginning of rainy season and end of rainy season) and the interaction between the site and season on bamboo regeneration. Paired t-test was used to compare if there were significant differences in the proportion of juvenile bamboo before and after the rainy season at both sites. In order for the data to meet the normality, homoscedasticity, and additivity assumptions, percentage data were arcsin square root transformed prior to the paired t-test and the two-way ANOVA test (Zar, 1984; Wang *et al.*, 2006). All analyses were performed using the Statistical Package for Social Sciences (SPSS, version 17.0). Differences were considered significant at the 5% level of probability.

Results

Distribution of culm types of B. vulgaris at Owabi sanctuary and adjacent agricultural farmlands

At the beginning of the rainy season (March, 2011), the median shoots per clump in the sanctuary and on the agricultural farmlands were 5.0 and 6.0, respectively, and this difference was found to be non-significant (Mann-Whitney U=1044.5, p=0.086) (Table 1). 25% of the clumps in the sanctuary and the agricultural farmlands had more than 8 and 9 shoots, respectively. However, after the rainy season (September, 2011), significant difference was detected between the median shoots per clump in the sanctuary (29) and on the agricultural farmland (19) (Mann Whitney U=883.5, p=0.001). 25% of the clumps in the sanctuary had more than 42 shoots while the same percentage of clumps on the agricultural farmland had more than 26 shoots (Table 2).

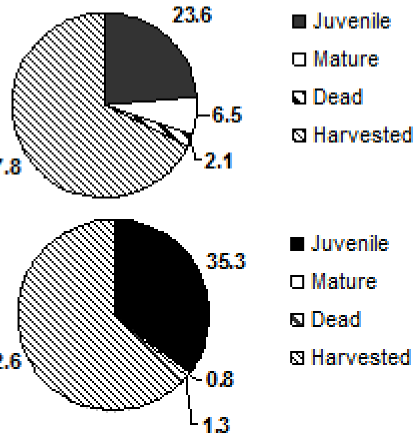

Fig. 1. Percentage distribution of culms in the forest reserve (a) at the beginning of the rainy season and (b) at the end of the rainy season

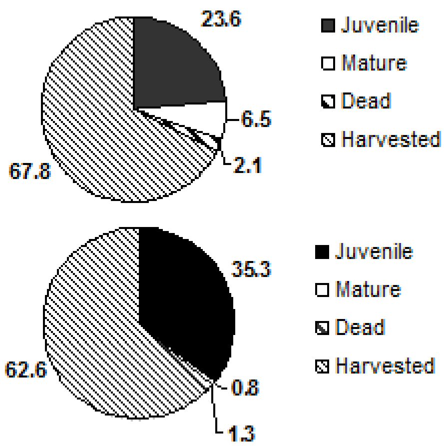

Fig. 2 Percentage distribution of culms on the agricultural farmlands (a) at the end of the rainy season and (b) at the end of the rainy season.

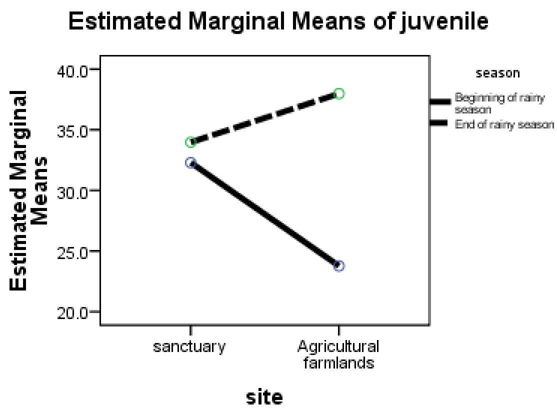

Fig. 3. Interaction between site and seasonal changes on the recruitment of juvenile culms.

At the beginning of the rainy season, the median young culms in the sanctuary was higher than that on the agricultural farmland (44.5 versus 35.5) but this difference was non-significant (Mann Whitney U=1107, p=0.206). A quarter (25%) of the clumps in the sanctuary and on the agricultural farmlands had more than 80.5 and 54.5 young culms, respectively. Similarly, no significant difference was detected between the median young culms in the sanctuary (52) and on the farmlands (46) at the end of the rainy season (Mann Whitney U=1259, p=0.159) (Table 2). A quarter (25%) of the clumps in the sanctuary had more than 102 young culms compared to 63 for the clumps on the agricultural farmlands.

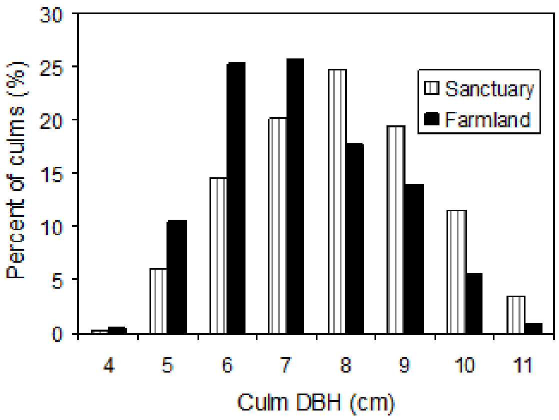

Fig. 4. Overall size class distribution of culms of B. vulgaris in the Owabi sanctuary and the adjacent agricultural farmlands.

Significant differences were detected between the sanctuary and the agricultural farmlands in terms of the median mature, dead and harvested culms both before and at the beginning of rainy season. At the beginning of the rain season, 25% of the clumps on the agricultural farmlands had more than 183 of the culms harvested and this increased to 201 (9.8%) at the end of the study period.

Approximately one-third (32.1%) of the total culms in the sanctuary was mature culms while only 6.5% of the culms on the agricultural farmland were mature culms. The mature culms per clump in the sanctuary averaged 32.0 ± 13.96%, with 25% of the clumps having more than 40.2% mature culms. On the agricultural farmland the mature culms averaged 6.5 ±3.63% per clump, with 25% of the clumps having more than 9.6% of the culms in the form of mature culms. Dead culms in the sanctuary was about one-third (36.3%) of the total culms while only 2.1% of the total culms on the agricultural lands were dead. The dead culms in the sanctuary averaged 26.5±20.28% compared to the average of 1.9 ±2.03% dead culms per clumps for clumps on the farmland. Twenty five percent of the clumps in the sanctuary and on the farmland had more than 41.5% and 3.3% of the culms in the form of dead culms respectively. Two out of three (67.9%) of the total culms on the farmland were harvested (Fig. 3), with the number harvested culms per clump averaging 64.0 ± 14.12% and 25% of the clumps having more than 76.9% of the culms harvested. The harvested culms in the sanctuary were only 3.8% of the total culms, averaging 6.8 ± 14.0% culms per clump. Twenty five percent of the clumps had only more than 4.6% of culms harvested (Table 1). Forty of fifty-five (73%) clumps in the sanctuary had none of the culms harvested while 8 of 55 (14.5%) clumps had ≥22% of culms harvested.

Effect of site and seasonal changes on the production of juvenile culms of B. vulgaris

At the beginning of the rainy season, about 27.9% of the culms in the sanctuary were in the form of juvenile culms, averaging 32±17.78% juvenile culms per clump and this increased to 31.5% (average 34±15.5) at the end of the rainy season (Fig. 1). This difference was, however, found to be non-significant (d.f. 98.635, t= -0.577, p=0.565). At the beginning of the rainy season, the proportion of juvenile culms in the clumps on the farmlands (23.8%) was significantly higher than that of juvenile culms (38%) at the end of the rainy season (Fig 2) (d.f. 102.801, t= -5.067, p<0.001). Effect of site on the recruitment of juvenile culms was non-significant (d.f. 1, F=1.174, MSE=264.971, p=0.280). Seasonal changes, on the other hand, had a significant effect on the recruitment of juvenile culms (d.f. 1, F=14.566, MSE=3286.227, p<0.001). Similarly, the interaction between the site and seasonal changes on the recruitment of juvenile was also found to be significant (d.f. 1, F=9.049, MSE=2041.407, p=0.003) (Table 3; Fig. 3).

Table 1. Distribution of culm types of *B. vulgaris* before rainy season

Culm type	Sanctuary			Agricultural farmland			Test result
	median±SE	LQ	UQ	median±SE	LQ	UQ	
Shoot	5.0±0.96	0.0	8.0	6.0±0.786	4.0	9.0	U=1044.5, p=0.087, n=102
Young	44.5±6.54	23.8	80.	35.5±3.66	25.0	54.5	U=1107, p=0.206, n=102
Mature	39.0±13.23	29.8	63.	11.0±1.45	7.0	17.8	U=108, p=0.001, n=102
Dead	33.0±20.22	10.0	88.	3.0±0.86	0.0	6.0	U=373, p=0.001, n=102
Harvested	0.0±2.53	0.0	5.5	121.0±10.90	98.5	182.5	U=22.5, p=0.001, n=102

LQ=lower quartile; UQ=Upper quartile; U=Mann Whitney U-test; n=sample size

Table 2. Distribution of culm types of *B. vulgaris* at the end of the rainy season

Culm type	Sanctuary			Agricultural farmland			Test result
	median±SE	LQ	UQ	median±SE	LQ	UQ	
Shoot	29±3.079	18	42	19±1.584	14	26	U=883.5, p=0.001, n=102
Young	52.0±8.38	31.0	102.0	46.0±5.98	30.0	63.0	U=1259,p=0.159, n=102
Mature	56.0±7.83	42.0	91.0	0.0±1.02	0.0	4.5	U=61.5,p=0.001, n=102
Dead	102.0±17.62	41.0	174.5	0.0±1.29	0.0	0.0	U=72.0,p=0.001, n=102
Harvested	0.0±8.26	0.0	16.0	135.0±11.49	66.0	201.0	U=331.5, p=0.001, n=102

LQ=lower quartile; UQ=Upper quartile; U=Mann Whitney U-test; n=sample size

Table 3. ANOVA table for comparison of proportion of juvenile culms in the sanctuary and on the farmland

Response variable	Source of variation	*df*	*F*-value	*p*-value
Juvenile culm	Site	1	1.397	0.239
	Season	1	13.587	<0.001
	Site×Season	1	10.345	0.002
	Residuals	206		

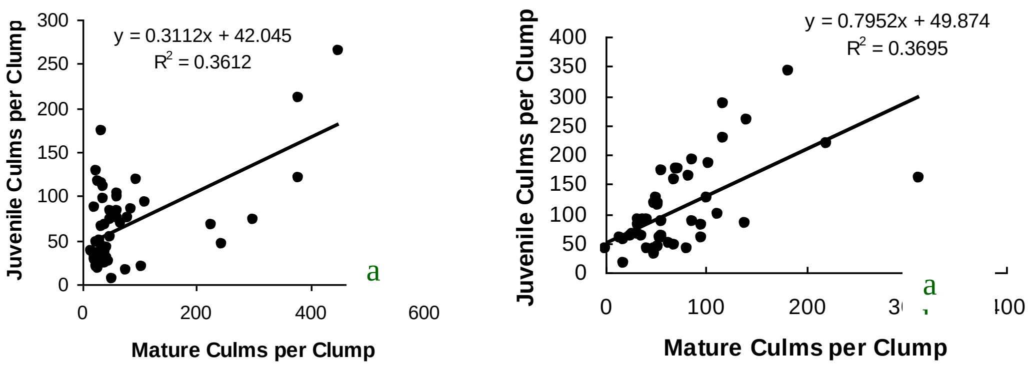

Fig. 5. Relationships between number of mature culms per clump and number of juvenile culms per clump; (a) beginning of rainy season (b) end of rainy season

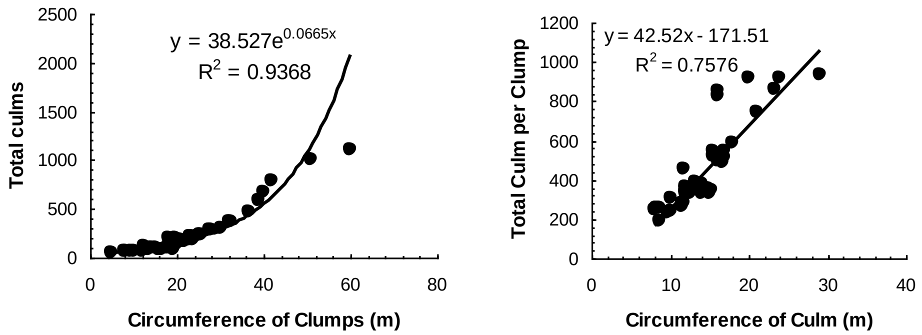

Fig. 6. Relationship between circumference of clumps and total culms per clump.

The juvenile culms were predicted from mature culms (Fig. 4). The number of juvenile culms per clump increased linearly with the number mature culms in the clumps. For both seasons, the mature culms explained about 36% of the variation in the number of juvenile culms in the clumps sampled from the sanctuary. For every ten mature culms increase in the clumps would result, on the average, about three and eight increase in the number of juvenile culms before and end of rainy season, respectively.

Discussion

Distribution of culms of B. vulgaris at the study sites

It is worth mentioning that even though the sanctuary was classified as non harvested site, few of the clumps at the fringes of the sanctuary had some of their culms harvested. However, judging from the fact that forty of fifty-five (73%) of the clumps in the sanctuary had none of their culms harvested, it could be reasonable to classify the site as non-harvested.

Before the rainy season, the median shoot production in the sanctuary (5.0±0.96) was similar to shoot production on the farmland (6.0 ±0.79). However, at the end of the rainy season, the median shoot production in the sanctuary was significantly higher than that on the agricultural farmland (29 versus 19). However, no significant differences in the young culm production were detected between the two sites and in both seasons. While few dead culms (2.1%) were observed on the agricultural farmlands, about one out of every three culms in the sanctuary (36.3%) was dead. Whereas hundred percent gap opening in all the sampled plots was to allow for comparison, this could potentially lead to intraspecific competition for resources, thereby increasing the propensity for high shoot mortality rate, greater proportion of dead culms and reducing shoot production (Wang *et al.,* 2006). On the average, more than half (64%) of the culms in the sampled clumps from the agricultural farmlands were harvested, with a quarter of the clumps having more than 76.9% of the culms harvested, suggesting that the demand for bamboo culms in the district is strong.

The recruitment of juvenile culms of *B. vulgaris* between the two seasons (March to September) was about 11.7% and 3.6% for the clumps on the farmland and in the sanctuary, respectively. Taylor and Zisheng (1987) reported average annual recruitment of culms between 8.2% (*Fargesia spathesia*) and 13.7% (*Fargesia scabrida*) in bamboos which form the dominant understorey under montane and subalpine forests of Sichuan, China. Effects of seasonal changes and the interaction between the site and seasonal changes were found to be significant, with the clumps on the agricultural farmlands (23.6% versus 35.3%) responding more positively to the juvenile culm recruitment than those in the sanctuary (27.9% versus 31.5%) (Fig. 3 and 4). Thus, despite high harvesting rate of bamboo on the agricultural farmlands, regeneration of new culms was induced during rainy season. Harvesting of bamboo increases shoot production, stimulates growth of rhizomes and roots (Vázquez-López *et al.,* 2004). Thus, rainfall can better stimulate culm production at harvested clump sites than unharvested clump sites. This study did not, however, estimate the optimum harvesting levels of bamboo that could result in maximum culm production. It has, however, been reported elsewhere that in order to promote culm production, about one-fifth of the older culms should be removed (Yen et al., 2010). The harvesting level of culms found in this study (64%) is well above the recommended value, suggesting that the current harvesting level may not lead to optimum juvenile culm production

The DBH of *B. vulgaris* ranged between 4cm and 11cm with most of culms having DBH in the range of 6-9cm (Fig. 5). These DBH values are similar to published values (e.g. Obiri and Oteng-Amoako, 2007). Diameter distribution of culms in the sanctuary was significantly higher than that on the farmland, therefore reflecting the exploitation levels of bamboo in the two sites.

Prediction of juvenile culms from mature culms

A linear relationship was found between the number of juvenile culms per clump and the number of mature culms per clump in the sanctuary, similar to the trend observed in the previous studies (Vázquez-López *et al.,* 2004, Singh and Singh, 1998, Taylor and Quin, 1993). The average ratio of juvenile culm production to the number of mature culms at the beginning of the rainy season was 3:10 compared to 8:10 at the end of the rainy season (Fig. 4), also suggesting that the interaction between mature culms and seasonal changes could significantly stimulate new culm production. In both seasons, about one-third of the variation in the juvenile culms was explained by the number of mature culms present in a clump with the strength between juvenile culms and mature culms being about 60%. Similar observation was made by Vázquez-López et al. (2004). This suggests that the number of mature culms in a clump can be used to predict the number of juvenile culms in the clump with a reasonable level of accuracy. The presence of mature culms supports the regeneration of new culms. The growth of new shoots depends entirely on photosynthetic products transported from parent trees through the rhizome system (Li et al., 2000). The older and mature culms supply nutrients to the rhizomes and the root system to induce new shoots production.

Prediction of the total culms from models

Counting of culms within clumps is necessary for the purpose of bamboo inventory. Due to the clustered nature of the clumps, culm counting of *B. vulgaris* presents a major challenge. Models were therefore developed to predict the bamboo culms within the clumps of *B. vulgaris*. Previous study (Bih 2006) used the orthogonal area of clumps as a predictor of the total number of culms within clumps and the predictor variable explained about 55% of the variations in the number of culms within the clumps. In this study, the circumference of the clumps was used to predict the number of culms in the clumps. Circumference of the clumps is much easier to measure than the orthogonal area of clumps. The predictor variable explained about 94% and 76% of the variations in the number of culms within the clumps in the sanctuary and on the agricultural farmlands, respectively. In the sanctuary, the model predicted total culms of 12,243 compared with the observed culms of 12,711 leaving a prediction error of about 3.83%.

Conclusions

The harvesting levels of bamboo in the Owabi Wildlife Sanctuary and the adjacent agricultural farmlands present two dichotomous situations, with the harvesting of bamboo on the farmlands posing a serious threat to the sustainability and conservation of bamboo in the district. Therefore, the OWS offers a safe haven for the bamboo conservation in the district. In this study, the regenerative capacity of harvested and non-harvested *B. vulgaris* bamboo clumps was compared. Previous studies provided mixed results, thus making the effect of harvested culms on bamboo regeneration inconclusive. Site (harvested versus non-harvested) did not show any significant effect on bamboo regeneration. However, seasonal changes and the interaction between site and seasonal changes showed significant effect on bamboo regeneration, with harvested sites responding more positively to regeneration than the non-harvested site. The average ratio of juvenile culm production to the number of mature culms per clump before rainy season was 3:10 compared with 8:10 at the end of the rainy season, suggesting that the presence of mature culms could potentially stimulate the regeneration of juvenile culms. Despite the ability of mature culms to stimulate culm regeneration, the contribution of non-harvested site to regeneration was far less compared to the contribution of harvested site to regeneration. Based on the findings of the study, the following conclusions are drawn: (1) The current harvesting levels of bamboo on the agricultural farmlands do not pose any serious threat to the regeneration of bamboo. (2) Optimum sprouting of culms could be achieved in the bamboo clumps at the sanctuary if older culms are harvested. It is therefore recommended that the managers of OWS should allow a regulated harvest of bamboo by the fringe communities in order to stimulate sprouting of bamboo shoots.

Acknowledgements

Many thanks to University of Education, Winneba for funding this research. I am also indebted to the Park Manager of Owabi Wildlife Sanctuary (OWS) for granting me permission to conduct the research in the sanctuary. I am also grateful to the staff of OWS for assisting in the field work.

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