Hindawi
International Journal of Forestry Research
Volume 2022, Article ID 9914209, 10 pages
https://doi.org/10.1155/2022/9914209

Research Article

Effect of Different Growing Niches on Stand Structure of Highland Bamboo (*Yushania alpina*) in West Amhara, Northern Ethiopia

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Received 29 January 2022; Revised 7 May 2022; Accepted 2 June 2022; Published 17 June 2022

Academic Editor: Ahmad A. Omar

The study was conducted to investigate the effects of different growing niches on the stand structure of highland bamboo (*Yushania alpina*) in west Amhara national regional state, northern Ethiopia. Four districts were selected purposively based on the existence of bamboo in different agroforestry practices. Inventory was carried out from 324 randomly selected plots of bamboo stands. The height of bamboo culms ranged between 12.2 ± 0.14 and 14.7 ± 0.12 m, and the diameter was between 4.9 ± 0.12 and 6.1 ± 0.11 cm with a mean value of 5.7 ± 0.102 cm. Growth performance (diameter and height size) based population distribution (histogram visualization) of bamboo stand indicated the normal distribution of height and diameter of culms. Density of culm varies between $19{,}188 \pm 336$ and $23{,}129 \pm 390$ culms ha^{-1} with an age composition of 26 : 45 : 29 ratio with 1 and 3 age classes. Diameters of the bamboo culms have inverse relationship with the age of bamboo culm. Clump stocking of highland bamboo varies between 953 ± 40 and 1220 ± 48 clump ha^{-1} with a culm : clump ratio of $1:47 \pm 5$ and $1:82 \pm 6$. Information on the stand structure of bamboo culms across niches is important to identify the productive plantation niche and develop a management plan for sustainable management and utilization of the bamboo resource.

1. Introduction

Bamboo is a plant, which belongs to Poaceae, with more than 1,200 species. It grows in tropical and subtropical regions of the world except Europe [1–3]. It is one of the fastest growing plants that can meet the needs of humans in a short period of time [4]. The bamboo resource covers an area of more than 14 million ha of land globally [5]. The share of Africa is about 10.7% of the global bamboo resource and comprises about 40 species.

Highland bamboo ((*Yushania alpina* (K. Schum.) W.C. Lin) and lowland bamboo (*Oxytenantheria abyssinica* (A. Rich.) Munro) are indigenous bamboo species that Ethiopia is endowed with [1, 6, 7]. The total area covered by these two species is about one million ha which accounts for 67% of the African bamboo resources [5, 8]. Highland and lowland bamboo resources covered about 100,000 and 800,000 ha, respectively [5]. The highland bamboo grows naturally in the south, southwest, central, and north-west highlands of the country at an altitude ranging between 2200 and 4000 m. The lowland bamboo grows in the western part of the country, mainly, in the border of Sudan within the altitudinal range of 1,100–1,700 m [7, 8]. The growth of the bamboo stand is characterized by the increase in the length, the number of culms and biomass [9], and increment in weight and length from the rhizome system underground and the culms aboveground [10]. Highland bamboo is grown by small-scale farmers in different niches, such as farmlands as patches, riverbanks, farm boundaries, roadsides, homesteads, and urban areas [11]. It is commonly grown as small-scale plantation or as an agroforestry species to generate income and improve livelihoods at the household level. However, lowland bamboo is found as natural stand in the lowlands.

Currently, bamboo utilization is shifting from household use to industrial raw material. It is subjected to high-technology industrial raw material and substitute for wood [12]. It is used for value-added commodities, such as laminated panels, boards, pulp, paper, mats, prefabricated houses, and quality clothes. Bamboo shoots are also used for food. This scenario seeks for bamboo culms that have good diameter and height to increase the products and enhance the efficiency of industries.

Consequently, to propagate and harvest good bamboo culms, identification of plantation practices that provide optimum stand structure of bamboo becomes a first-hand activity of researchers and development workers. On the other hand, bamboo forest degradation is observed in the highlands of west Amhara due to overexploitation and expansion of other exotic tree species (e.g., *Acacia decurrens* Willd. and *Eucalyptus* species). In addition to the resource base of bamboo, the stand conditions and management has to be investigated to know the status of the bamboo forest. Farmers plant and manage bamboo in different niches; however, there is little information available on bamboo stand structure across different niches. Previous studies focused mainly on growth rate [9], resource distribution assessment [6], and species characterization [13]. Knowledge on stand structure has theoretical and practical importance in understanding and managing forest ecosystems [14]. It is used to manipulate the management objectives following the establishment of a forest stand in order to understand productivity, thereby estimating the products [15].

Dendrochronology, chronosequence, or pollen analyses are the known methods to construct the long-term forest dynamics [16, 17]. However, these methods cannot show the details of the population trend, including regeneration, composition, and density of the forest in the respective area [16]. Hence, observations from sample plots in different growing niches need to be described to further plan and establish permanent plots for long-term study.

This study aimed to characterize the stand structure of bamboo forests across different growing niches for planning and management of the forest for sustainable production. Hence, the research questions were as follows: (a) how do stem density and culm size change over different growing niches? How growing niches influence the current stand structures bamboo forest?

2. Materials and Methods

2.1. Study Site and Niche Selection. The study sites were Farta, Banja, Sinan, and Dega Damot districts, northern Ethiopia (Figure 1). These sites were selected purposively because they are bamboo growing areas of west Amhara national regional state (ANRS).

Farmers have also long years of experience on bamboo forest management and development. Five dominant highland bamboo plantation niches were selected to characterize the growth of the highland bamboo. These niches were farm boundary, homestead, river bank, roadside, and woodlot plantation practices that farmers are exercising for plantation management of highland bamboo for their productive, protective, and/or both benefits of the resource.

Reconnaissance survey was conducted prior to the starting of the field work to design the sampling procedures. Accordingly, first sampling phase involved the selection of representative kebeles (lowest administrative units) from identified districts. After getting representative kebeles, quick supervision of plantation niches of highland bamboo was conducted to ascertain and mark spots of bamboo stand that get relatively similar management interventions.

2.2. Plot and Sample Size. Bamboo stands, which obtained relatively similar management interventions (mode establishment, aim of plantation, methods, time of harvesting, and reason of harvesting) along similar growing niches, were selected as sample plots. These sample plots were laid out at an average of 200 m distance. A square plot with a size of 10×10 m (100 m^2) was used for conducting inventory from the woodlot, riverbank, and homestead planation niches, while a rectangular plot having a size of 10×4 m (40 m^2) was used for enumerating in a farm boundary and roadside plantation niches (since these two plantation niches were established as line plantations). Accordingly, a total of 324 plots (72 plots per niche for woodlot, homestead, and riverbank planation niche and 54 plots per niche for roadside and farm boundary plantation niches) were used for data collection. Consequently, 90 plots were inventoried in each of the three districts (Banja, Sinan, and Dega Damot districts) and 54 plots in Farta district.

2.3. Data Collection and Analyses. The trend of the population structure was investigated using recruitment rate, mortality, change in stem density, and tree size variability. The culm (in bamboo, woody ringed stems, which are typically hollow between the rings (nodes) and grow in branching clusters from a thick rhizome (underground stem) (https://www.britannica.com/science/culm, accessed on 04/08/2020)) diameter at breast height (DBH) and height were measured by caliper and graduated bamboo culm, respectively. Count per plot was carried out for bamboo culm density estimation. Clump (a characteristic of bamboo where each rhizome turns upward to form a culm (https://lewisbamboo.com/clumping-vs-running-bamboo/, accessed on 04/08/2020)) characterization was conducted in each sample plot. Data on clump characteristics (clump stocking and culm-to-clump ratio) were collected by counting the number of clumps within a sample plot, whereas the culm-to-clump ratio was determined by dividing the number of culms in each clump.

Culm-to-clump ratio (C : C) was evaluated using the following formula:

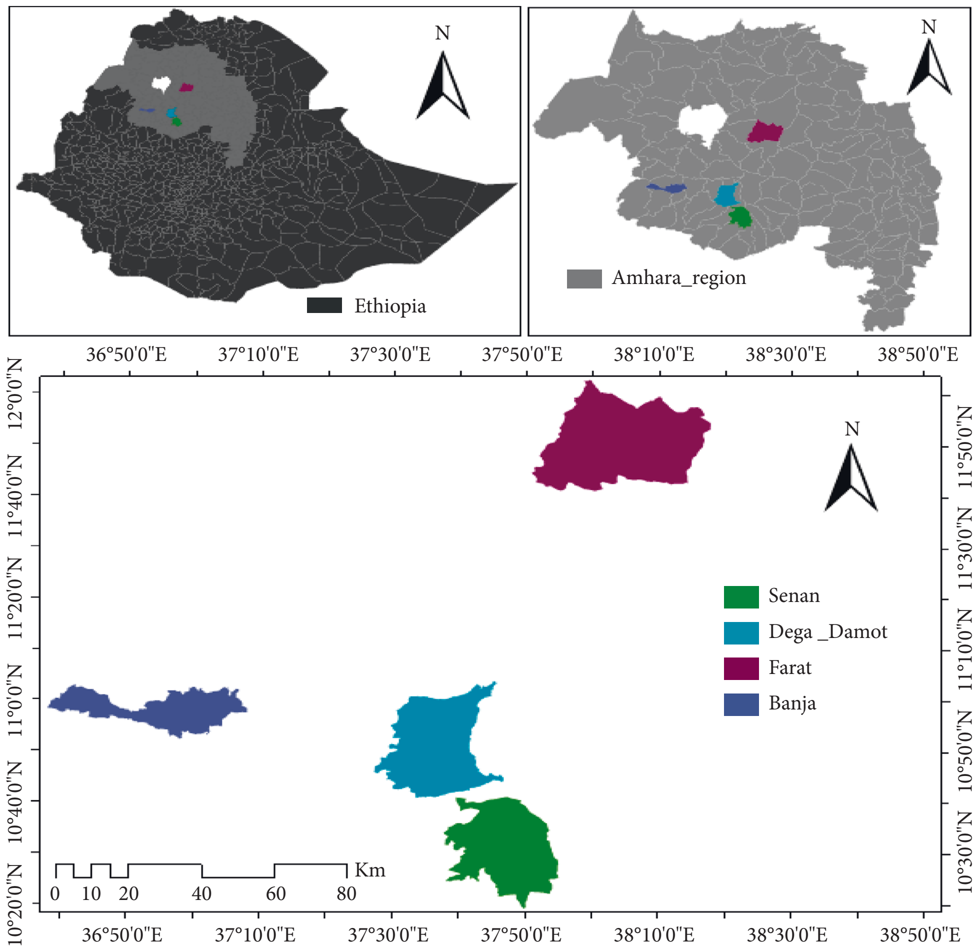

Figure 1: Map showing the study areas.

$$C:C = \frac{\text{number of culms}}{\text{clump}}. \quad (1)$$

The number of culms in each plot were classified into three age categories (less than one year, one to three years, and older than three years) to evaluate age composition of bamboo stands in each planation niche. Age composition was estimated with the farmer and development agent in addition to the use of a manual [18]. The age and size distribution were dealt to examine the regeneration patterns in a bamboo forest, and it was evaluated as follows:

$$\text{age composition} = \frac{\text{number of culms of } i\text{th age}}{\text{total number of culms}}. \quad (2)$$

Growth characteristics, i.e., diameter and height, of bamboo culm were measured with a caliper and graduated bamboo culm (a bamboo culm which partitioned into divisions of centimeter units), respectively. The relation of age with growth performance (diameter and height) was evaluated by comparing it with its respective age. The frequency distribution of size classes (diameter at breast height and height) was identified to indicate the bamboo population trend.

The size-regularity degree (denoted by "U") which refers to size variation of culms in a bamboo stand was expressed using the ratio of the mean breast-height diameter of culms and their standard deviation (SD) [19].

$$\text{size regularity degree } (U) = \frac{\text{DBH}}{\text{SD}}. \quad (3)$$

2.4. Statistical Analysis. The long-term growth structure of bamboo was described on the basis of an analysis of data from 324 plots in 5 growing niches. Stand structure was characterized by diameter, height, and stem density, age, and size variability. Stand density and clump density were estimated from the total number of culms and clumps counted in each plot, respectively. Following Kolmogorov–Smirnov and Shapiro–Wilk and Q-Q plots of normality tests, analysis of variance (ANOVA) was applied to determine the relationship among the effects of plantation niches on stand structure of bamboo by using SPSS version 25 and Microsoft Excel. Duncan's mean separation test was used to analyze mean differences between plantation niches ($\alpha = 0.05$).

3. Results

3.1. Height and Diameter of Highland Bamboo Culms. Homestead and riverbank growing niches produced better size bamboo culms, while bamboo culms from roadside planation niches gained smaller height and thickness performance (Figure 2). Culms from roadside plantation niche showed the least productivity as compared to other growing niches as road side bamboo plantation is mostly managed for buffering other than culm production (the management interventions are different from niche to niche based on the aim on establishment) (Figure 2).

3.2. Diameter and Height Distributions of Highland Bamboo Culms. The skewness of diameter distribution of bamboo culms indicates normal distribution with some discontinuities (Figure 3), which indicates the predominance of big culms, often from 6 to 8 cm in diameter. The frequency distribution of size classes (DBH) showed continuous size structures with a large number of smaller culms at the roadside and a small number of larger ones in farm boundary growing niches. However, the homestead, river bank, and woodlot plantation niches showed larger culm size because of protection or management interventions [20, 21].

The frequency distribution of culm thickness or diameter (Figure 3) and height (Figure 4) showed discontinuous/continuous and periodic patterns with average peak ages of 5–7 years. These periods would be related to the culm harvesting, and the new shoots start to initiate. Complete removal of the bamboo forests also affected the emergence of new shoots, and the bamboo forest stand varied with the different niches. Although the diameter (culm thickness) distribution showed a discontinuous pattern, the farmers were able to produce culms every year to subsidize their household demands [22, 23].

The observed big-sized culm distribution indicates the dominance of the stand by marketable culms.

3.3. Culm Density and Age Composition of Highland Bamboo. Analysis of results on density or stocking revealed the significant variation ($p = 0.001$) in different bamboo plantation niches and growing areas (Table 1). The highest and least densities of culms were observed from the farm boundary and woodlot plantation, respectively. The difference in density among planation niches is due to variation in site condition, tending operations, harvesting intensity, and purpose of the plantation.

Maintaining a single age plant in bamboo forest stands is not possible like other even-aged forest stands due to the yearly recruitment of new shoots from the rhizome of the standing vigorous and young healthy culms. A single clump of bamboo provides culms that are not of different ages, which is an indicator of sustainability and yield status of the bamboo stands (Table 1).

The current finding indicated that bamboo stand in west ANRS is composed of a proportion of 26, 45, and 29% culms within a single stand accounted by culms of less than one year, 1–3 years, and older than 3 years, respectively (Table 1).

3.4. Growth Characteristics of Bamboo Culm across Age Classes. The relationship of the age of bamboo culm with its height (Figure 5) shows unique characteristics compared with other forest tree species. The culm age-height relationship of highland bamboo along plantation niches shows negative relationship (the height of culm decreases slightly as the age of culm increases), and this phenomenon of bamboo growth was confirmed by farmers and our observations during our field data collection.

The younger culms attained higher diameters than the older culms and, even, the mean diameter of the bamboo stand (Figure 6).

3.5. Clump Characteristics of Highland Bamboo. One of the unique natures of bamboo is the fact that a single clump develops several culms. Clump characteristics, i.e., clump stocking and culm-to-clump ratio, are one of the basic features of the species that can indicate a stand structure of bamboo [24] and describe, by stocking of the clump itself (number of clumps per unit area), the number of shoots or culms it holds and culm-to-clump ratio [23].

From the common plantation niches practiced, homestead and riverbank showed the lowest culm-to-clump ratio (Table 2), which might be due to intensive harvesting of culms as a source of household income because of the better and market preferable diameters of culm (Figure 3).

Farm boundary and roadside plantation niches were endowed with the highest clump stockings, while sparse clumps were recorded in the homestead plantation niche ($p = 0.001$; Table 2).

3.6. Size Regularity Degree of Highland Bamboo. Size regularity degree is a measure of size uniformity of bamboo culms in a given bamboo stand [19]. According to the results (Figure 7), roadside plantation niche showed lower value of size regularity degree.

4. Discussion

4.1. Growth Performance and Culm Size Distribution of Highland Bamboo. The observed mean diameter distributions of bamboo culms along plantation niches and growing areas are in line with those reported by Mulatu and Fetene [9] and Chen et al. [10]. The result of the diameter distribution of bamboo might be related to the age composition ratio of the stand for the plantation niche (Table 2).

Generally, the results show the existence of spatial heterogeneity in culm diameter size of the bamboo stands without consideration of culm age because of differences in physical disturbance damage due to anthropogenic pressures associated with the intensity of harvesting [25, 26]. The reason is similar to height increment. The bamboo stands that are grown primarily for production of culm received more attention and continuous tending operation than those planted for protection and buffering [27, 28].

The governing factor for this variation is, mainly, management intervention and road or market access. Variation in the management of bamboo resulted in variation in height and diameter [10]. Since bamboo established in roadside plantation niche was grown as buffer zone and live fence, there is little tending operation, which is also not periodical. If the aim of the bamboo forest is for culm

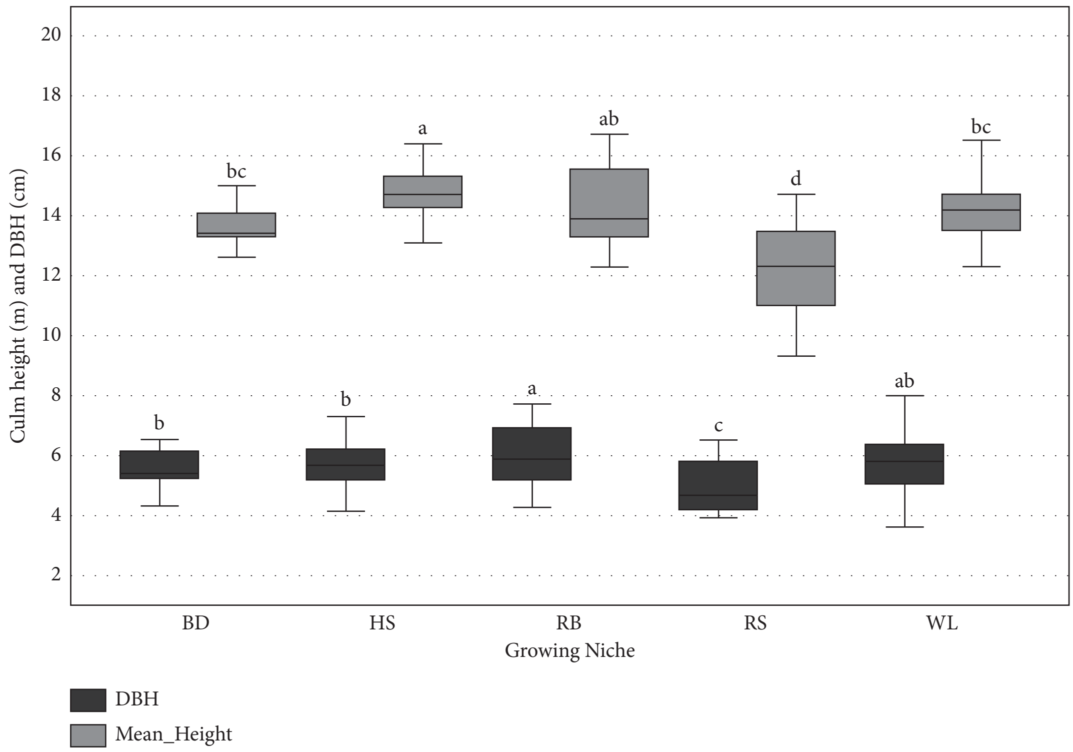

Figure 2: Culm size of highland bamboo (BD = boundary; HS = homestead; RB = river bank; RS = roadside; WL = woodlot plantation niches; values with different letters across bars are significantly different (at $\alpha < 0.05$)).

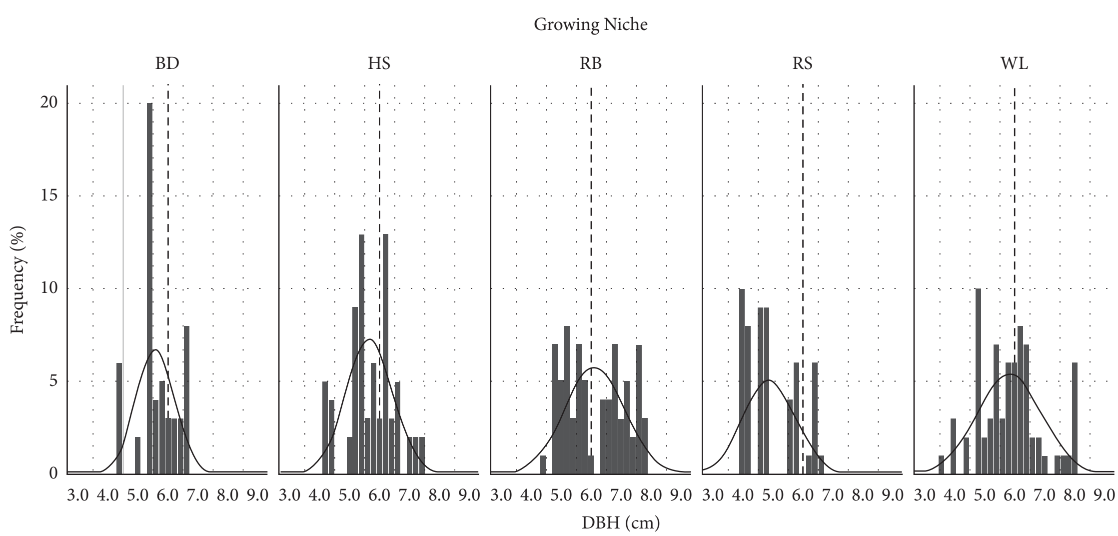

Figure 3: Diameter distribution of bamboo culms (BD = boundary; HS = homestead; RB = river bank; RS = roadside; WL = woodlot plantation niches).

production, the management is intensive and focused on biomass optimization. Farmers planted bamboo with indigenous tree species as mixed plantation (such as homestead and woodlot growing niches), if the intention of growing bamboo is for production purpose. This may lead to competition for light, contributing directly or indirectly to height increment [26, 29, 30].

The age composition of standing bamboo in a given bamboo forest is one of governing factors for diameter class distribution. The overall diameter distribution of bamboo is a function of culm age composition [10], and as the proportion of younger culm becomes higher, the bamboo stand will be composed of bigger culm sizes than the older culms. In other words, the dominance of bamboo stand, with a bigger diameter class, is an indicator of good management and healthiness of the given bamboo forest stand [23, 31].

The culm size distributions of our finding are in line with those reported by Chen et al. [10] who reported that the

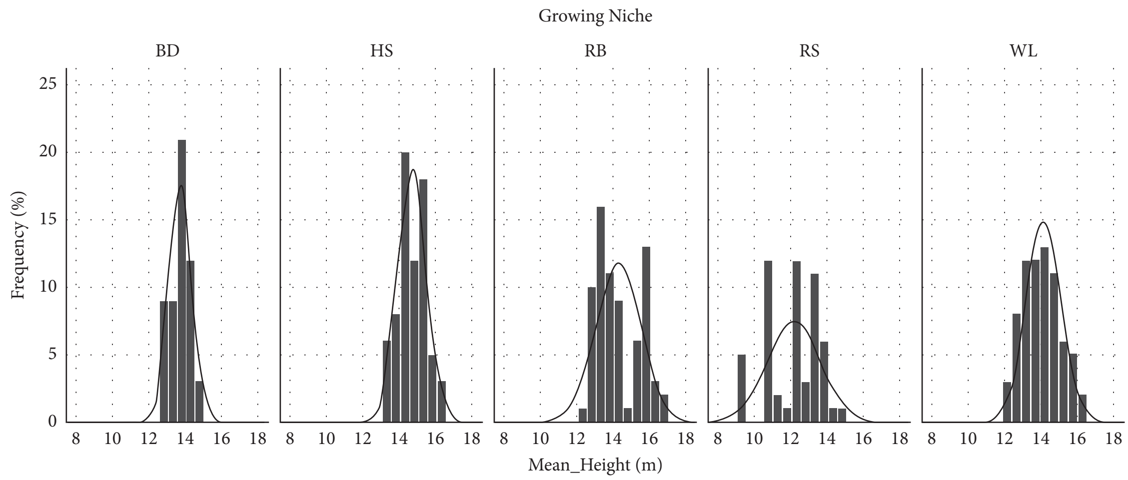

Figure 4: Height distribution of bamboo culms (BD = boundary; HS = homestead; RB = river bank; RS = roadside; WL = woodlot plantation niches).

Table 1: The density and age composition of bamboo culms (mean standard ± error).

Niche	Density (individuals ha^{-1})	Age of culm			Age proportion
		<1 year	1–3 years	>3 year	
BD	23,129 ± 390[a]	5,050 ± 291	10,650 ± 363	6,391 ± 367	24 : 47 : 29
HS	22,019 ± 336[ab]	5,921 ± 243	9,915 ± 302	6,182 ± 306	27 : 45 : 28
RB	21,145 ± 336[bc]	5,471 ± 243	8,853 ± 302	6,182 ± 291	26 : 42 : 32
RS	20,517 ± 390[bc]	4,785 ± 291	9,531 ± 363	5,161 ± 367	25 : 49 : 26
WL	19,188 ± 336[d]	5,427 ± 243	8,675 ± 302	5,086 ± 306	28 : 45 : 27
Grand mean	20,784 ± 198	5,510 ± 474	9,528 ± 568	6,091 ± 586	26 : 45 : 29
	Grand proportion	26	45	29	

BD = boundary; HS = homestead; RB river bank; RS = roadside; WL = woodlot plantation niches; values in columns with different letters are significantly different (at $\alpha < 0.05$).

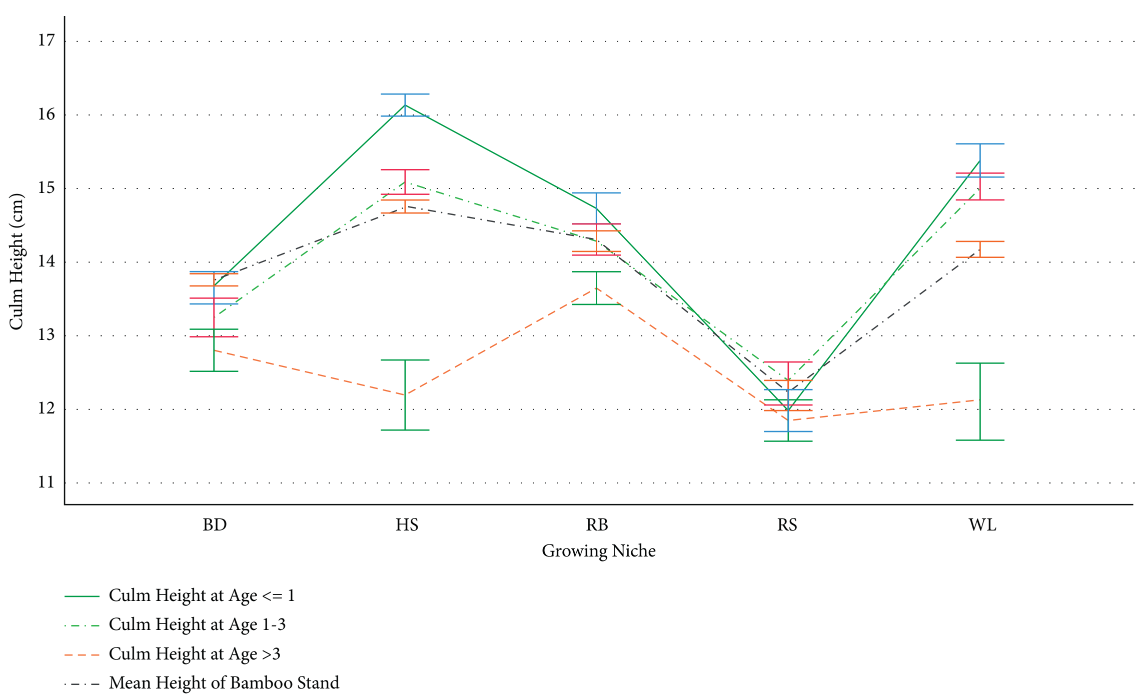

Figure 5: Height-age relationship of bamboo culms (BD = boundary; HS = homestead; RB = river bank; RS = roadside; WL = woodlot plantation niches).

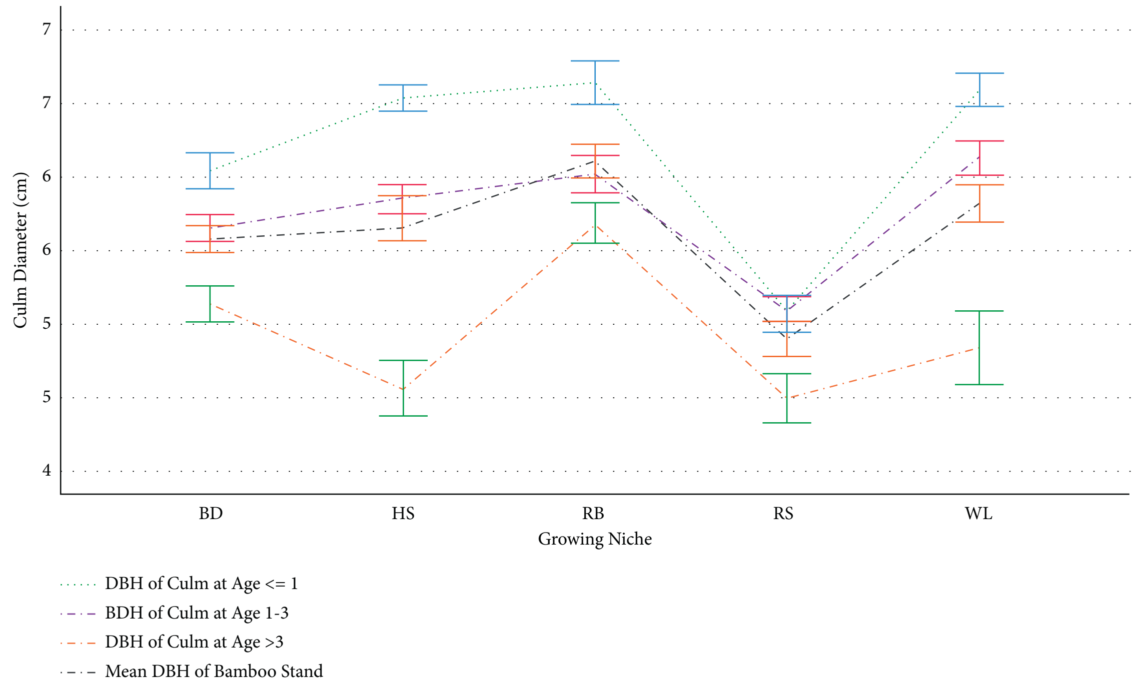

Figure 6: Diameter age relationship of bamboo culms (BD = boundary; HS = homestead; RB = river bank; RS = roadside; WL = woodlot plantation niches).

Table 2: Clump characteristics of bamboo culms (mean standard ± error).

No	Niche	Density of clump ha^{-1}	Density of culm clump^{-1}	C : C
1	BD	$1{,}161 \pm 48^{q}$	21 ± 1.0^{ab}	$1:69 \pm 5^{b}$
2	HS	953 ± 40^{c}	25 ± 1.0^{a}	$1:47 \pm 5^{c}$
3	RB	999 ± 40^{b}	24 ± 1.0^{a}	$1:54 \pm 4^{bc}$
4	RS	$1{,}220 \pm 48^{a}$	17 ± 1.0^{b}	$1:82 \pm 6^{a}$
5	WL	$1{,}010 \pm 40^{b}$	20 ± 1.0^{ab}	$1:60 \pm 5^{b}$

BD = boundary; HS = homestead; RB = river bank; RS = roadside; WL = woodlot plantation niches; C : C = culm-to-clump ratio; values in columns with different letters are significantly different (at $\alpha < 0.05$).

population structure/diameter distribution shape of bamboo stand established with production goal showed positively skewed pattern due to selective harvesting and application of silvicultural interventions.

4.2. Culm Stocking and Growth Distribution across Age Classes. The results differ from those by Mulatu and Fetene [9] who reported 22, 34, and 44% new culms with the same age class in Choke Mountain, respectively, but is in line with age structure composition reported for *Schizostachyum dullooa* (Gamble) R.B. Majumdar which had an age structure ratio of 30%, 50%, and 20% *Pseudostachyum polymorphum* with 24%, 45%, and 31% and Munroand *Melocanna baccifera* (Roxb.) Kurz stands in the ratio of 30%, 40%, and 30% [32]. Privately owned stands managed by individual farmers attend higher culm density than natural stands [5, 19]. This, in turn, influenced the amount of culm and biomass yield and intensity of harvesting [33].

It is also observed that variation in soil fertility status determined the number of sprouts and survival [34, 35]. Farmers apply manure and water to improve the survival of new sprouts/shoots. Soil amendment and availability of soil moisture improved the culm density in homestead, farm boundary, and river bank plantations. Supplementing bamboo stands with manure and water in the dry season creates favorable conditions for newly emerging bamboo shoots that, in turn, determine bamboo stand structure [36, 37].

Density of culm is a function of mortality rate, type of growing/plantation niche, and clump characteristics [38] in addition to several anthropogenic and natural disturbances. Culm density does not affect culm size; instead, age composition, and management interventions play a significant role for culm size of highland bamboo. The density variation in the different growing niches showed that there is no uniform pattern/relation between stocking and culm size of highland bamboo.

Variation of the age composition of highland bamboo stand reported by Mulatu and Fetene [9] might be due to increased harvesting intensity of bamboo culms in most of the areas as a result of increased demand of raw materials for various products and distant trading. Generally, the results are in line with the report of Chen et al. [10], which recommends selective cutting to make the proportion of older culms in lower proportion. Moreover, this report highlights that overstocking of older culms can affect the sprouting ability of the rhizomes, which, in turn, can affect the sustainability of the bamboo resources.

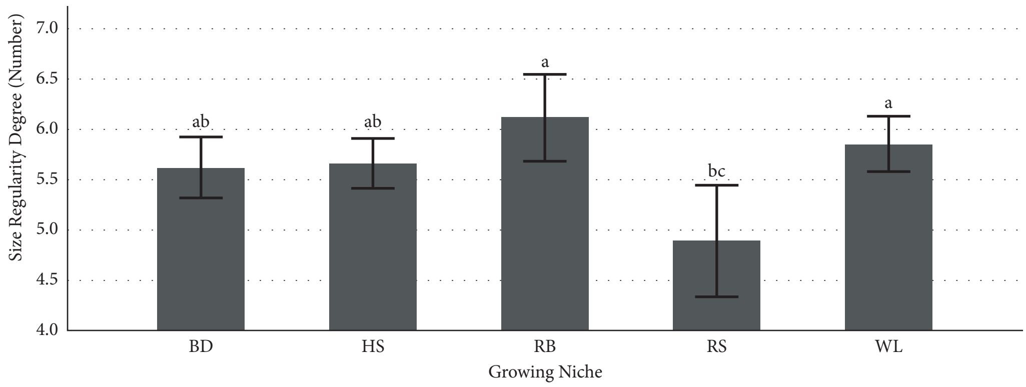

FIGURE 7: Size regularity degree of bamboo culms (BD = boundary; HS = homestead; RB = river bank; RS = roadside; WL = woodlot plantation niches; values with different letters across bars are significantly different (at $\alpha < 0.05$)).

The relationship of dimensional growth (diameter) of bamboo culms is due to the growth nature of bamboo. New shoots of bamboo stands are relatively bigger than the mother culm and selective harvesting scheme supports recruitment of marketable new shoots [31].

The bamboo culm age-height relationship reported here corresponds with the findings of Midmore [39]. The height of older bamboo culms (culm >3 years) is lower than the grand mean of young culms of the bamboo stand (Figure 5). This has occurred due to the harvesting strategy of growers. In most of the bamboo growing areas, farmers harvest marketable bamboo culms and maintain small-sized culms for protection and as a contingency for their fencing [40]. Plantation goals have impacts on dimensional growth characteristics of the bamboo culm (Figure 6). The newly sprouted culms (newly emerged shoots) of bamboo are mostly bigger in growth parameters (culm diameter and height) than the culm from which they originated [23].

4.3. Clump Characteristics and Size Regularity Degree of Highland Bamboo Forest Stands. The main reason for farmers to plant dense clumps in farm boundary and roadside plantation niches is because of the aim of the plantation, i.e., for boundary demarcation and live fencing. The driving force for the lower stocking of culms per clump is because of the continuous harvesting of thin bamboo culms for fencing and making bamboo ropes.

Culm-to-clump ratio (C : C) is the measure of the sprouting potential of a given clump. The results revealed that the plantation niche affects highly the culm-to-clump ratio (C : C) (Table 2). This is probably due to differences in management interventions [40] and harvesting intensity [41]. These practices also varied with the objective of the management of bamboo forests in each niche. Low sprouting is the result of low growth performance due to overstocking (competition) and the age of the stand (old bamboo forest).

The reason for lower size regularity value (an indication of relative size variability of culms with the stand) in roadside plantation niche could be due to culm dieback because of frost damage before two years in 2017. Farmers confirmed that bamboo stands of roadside were severely damaged by the frost as the roadside stand with planted as monoculture. This implies a culm size regularity degree is the effect of management, anthropogenic factors, and site.

The clump characteristics (clump density and number of culms per clump) reported in this study concur with those of Thomas [42] who reported that Ochlandra setigera Gamble exhibited a range of 108 ± 59 and 115 ± 65 clumps ha^{-1} and 29 ± 25 and 30 ± 25 culms $clump^{-1}$.

5. Conclusions and Recommendations

The aim or intended goal of plantation niches determines the stand structure of highland bamboo (*Y. alpina*). Highland bamboo plantation niches targeted for the production of bamboo culms get greater attention and intensive management interventions than plantation niches intended for buffering and live fencing (buffering). Application of intensive management interventions, especially the frequency of harvesting and selective cutting (culm harvesting), affects the stand structure of highland bamboo culms.

The result suggested that the concentrated young ages of the bamboo stands were due to their management and demands from the household. For long-term bamboo forest, development can be designed to have multistructure and sustainable product using a cyclic bamboo forest management. Future bamboo stand management should be planned and decisions made based on such results have to consider sustainable production.

Our observation during data collection indicated that mixed stand of highland bamboo with indigenous and exotic forest tree species will result in a good and productive stand structure of highland bamboo. Thus, a mixed plantation scheme of highland bamboo with other preferable forest tree species should be developed for solving the shortage of land and diversifying sustained income from the forest products.

Because of disease, land competition with monoculture plantations, underutilization and overexploitation, and sustainability of *Y. alpina* are under question. Therefore, to create a healthy stand structure of the bamboo forests and secure their sustainability, identification of existing and possible potential enemies of bamboo and developing preventive and controlling mechanisms of such enemies should be explored and implemented.

A comparison of the stand structure of the existing landraces (varieties) should be undertaken since it will help for generating baseline information for establishing healthy and productive stand structure for each landrace (variety).

Data Availability

The data used for this manuscript can be available with special permit of authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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