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Biomass Energy Resource of the Highland Bamboo (*Yushania alpina*) and Its Potential for Sustainable Exploitation in Southern Aberdares Forest

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Abstract

Yushania alpina is the only bamboo species native to Kenya and covers about 150,000 ha growing in pure or mixed stands in the montane forests. The Aberdare forest is one of the natural habitats for *Y. alpine* occupying an area of 6419 ha mainly in the water catchment areas. The growing human population and depletion of other forest resources have necessitated the exploration of *Y. alpine* as a source of energy. This paper assessed the quantity of *Y. alpine* available for biomass energy and its potential for sustainable exploitation. Plots were laid on area maps to cater for altitude and distance from farms. The study area was stratified into three altitudinal zones: A (2220 - 2330 m), B (2331 - 2440 m) and C (2441 - 2550 m). The initial sampling plot of 10 m × 10 m was located randomly 500 m from the edge of the forest while the subsequent plots were laid out systematically at intervals of 500 m. In each plot, a total enumeration and biomass estimation of bamboo clumps were done using Muchiri and Muga (2013) [1] method. Bamboo samples and those of commonly used biomass energy sources were analysed for calorific value using bomb calorimeter. In addition, data for quantities of biomass energy used by some local industries were used to estimate the amount of bamboo required. The mean stocking was 19,981 (20,000) culms ha^{-1}, and varied significantly among altitude strata and distance from adjacent farms. The mean biomass density and energy content were 86 tons/ha and 380,893 Kca/ha respectively with the higher altitudinal stratum (zone C) having the highest means (114 tons/ha) while the lower stratum (zone A) had the lowest (65 tons/ha). The energy needed by sampled local industries was 416,276,266 Kcal per year against 2.4 billion Kcal available in the bamboo forest. This implies that the bamboo forest in its present stocking can provide biomass energy for these local industries for more than five years. With bamboo maturing with less than five years, the forest can sustainably provide the required energy while still providing its environmental services.

Keywords

Bamboo, Biomass, Altitude, Calorific Value

1. Introduction

Bamboo is a non-wood forest product that is common in forest ecosystems of the world. It has been regarded as a weed for a long time but has gained increasing attention as a renewable fast growing energy resource with short growth cycles of 4 - 7 years (Kigomo, 2007) [2]. There are over 87 genera and 1500 bamboo species in the world playing vital role in the industrial and domestic economies of China, Japan, Thailand, Cambodia, India and Vietnam (Divakara *et al*., 2001) [3]. Only one species is native to Kenya, the species *Yushania alpine*; it covers about 150,000 ha growing in pure or mixed stands in montane forest of Kenya (Kigomo, 2000) [4]. Pure bamboo forest comprises about 30% of the vegetation types of the Aberdares forest (KFS, 2010) [5].

These bamboo forests have historically been used to conserve water catchment areas in Kenya. Utilization has been confined to domestic usage such as fencing, making tea picking baskets, energy feedstock and construction of food storage structures.The country has less than 20% high potential land against growing human population (Kinyanjui, 2009) [6]. The population growth with increasing economic development and energy needs has resulted to depletion of other forest resources leading to bamboo forests being explored for commercial exploitation to replicate their uses in Asian countries (Muchiri & Muga, 2013) [1]. One of the options was to explore bamboo as renewable sources of biomass energy due to its fast growth thus contribute to mitigating pressure on slow growing forest resources and the growing demand for qualitative timber.

The global demand for energy is soaring and is expected to worsen (Asif, M., & Muneer, T., 2007) [7]. Energy sources are changing due to concerns over high fossil fuel prices, greenhouse gas emission and fossil fuel import dependence (Cherubini *et al*., 2009) [8]. The use of bio fuels such as biomass energy has been given much attention by governments around the world especially in increasingly energy-hungry nations as a way to address these concerns because it's abundant, inexhaustible and environmentally friendly (Asif, M., & Muneer, T., 2007) [7].

Yushania alpina offers such an alternative source of energy due to its prolific regeneration and fast growth besides its vast distribution in the study area (KFS, 2010) [5]. Past studies on bamboo have mainly focused on physical, mechanical and nutritional properties of the species and less on energy potential such that it has been neglected by the bio energy industry as a potential energy alternative (Engler *et al*., 2012) [9]. The purpose of this study was to assess the quantity of *Y. alpina* available for biomass energy and determine its potential for sustainable exploitation.

2. Materials and Methods

2.1. Study Site

Figure 1 is the location map of the study area; it lies in the Southern end of the Aberdares which is part of the larger Aberdare forest Ecosystem that consists of Aberdare National park and Aberdare forest reserve. It is a public forest under the management of the Kenya Forest Service in Kiambu County. It lies between 00˚50'S and 00˚55'S, 36˚40'E and 36˚45'E and rises from 2100 m to 2600 m above the sea level. It covers an area of 17,977 ha which comprises of indigenous forests, forest plantations, grasslands and bamboo. The area of bamboo forests is approximately 6419 ha.

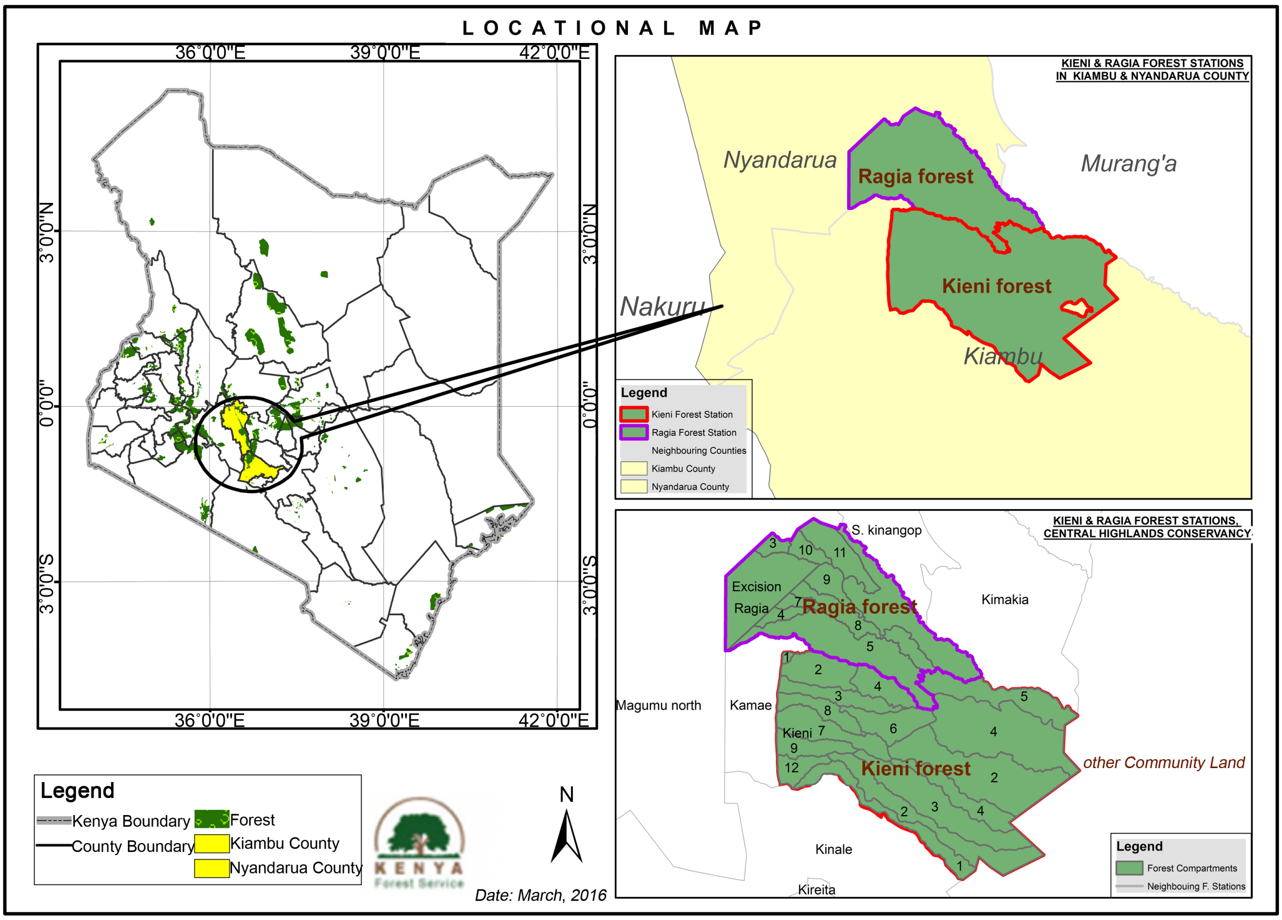

Figure 1. Location map (source-Land sat image 2015).

The rainfall ranges from 1400 mm to 2500 mm with a bimodal distribution whereby long rains are from March to July and short rains from October to December. The soil type is Andosols, deep, fertile and well drained. The monthly mean temperature ranges between 8˚C and 23˚C. The lowest temperatures are experienced in the months of July and August.

2.2. Sampling Design

The Aberdare forest reserve is an Afromontane forest with a rugged terrain and steep sided slopes and valleys. The appropriate sampling design under such a terrain is stratified systematic sampling. A shape file of contours at 10 m intervals was used to create three altitudinal Zones for plot establishment as follows; Zone A (altitude 2220 - 2330 m.a.s.l), Zone B (altitude 2331 - 2440 m.a.s.l) and Zone C (altitude 2441 - 2550 m.a.s.l). The initial sample point was put randomly 500 m from the edge while subsequent points were systematically laid at 500 m intervals in the forest on East-West direction in each stratum. There were forty sample points in total. They were mapped, coordinates recorded, loaded into a GPS and traced on the ground for measurements. Besides, systematic line transects running from east-west direction were established in each plot to explore bamboo damage by human beings.

2.3. Plot Layout

Sample plots each measuring 10 × 10 meters in size were established at the Geo referenced points aligned to the North-South and East-West grids for assessment. The plots were distributed as five plots in stratum A, twenty one in stratum B and fourteen in stratum Cas shown in **Table 1**.

In each plot, all bamboo clumps were identified and their culms classified into four age categories: young, mature, old and dead based on the internodes colour (Muchiri and Muga, 2013) [1]. The young were green in colour and vigorously growing, mature were greenish brown, old were brown and covered by moulds whereas dead were dry without foliage. Permanent markers were used to classify bamboo culms by age class. In each of the plots, data on stocking density, age category distribution and human damage were obtained and recorded. Three culms were randomly selected per category and diameter at breast height (dbh) measured to determine biomass density using the formula of Muchiri and Muga (2013) [1]. From each stratum, three mature culms of bamboo were selected and billets of 1m length extracted for determination of calorific value.

2.4. Bio-Energy Industry Interviews

Manufacturing industries adjacent to the forest and known to depend on wood biomass as a source of energy were identified. These included seven tea factories, one oil refinery and one textile industry. Information was sought on the amount of wood biomass consumed by each industry; this included annual consumption, species used and source of the wood. Bamboo biomass equivalent required by each company to meet their energy needs were estimated from the stock density

Table 1. Geographical location of the sample plots.

Altitude zone	Plot No	Easting's	Northing's	Altitude.
A	1	239,945	9,904,401	2224
A	2	240,834	9,904,401	2290
A	3	241,723	9,904,401	2312
A	4	242,612	9,904,401	2326
A	5	240,834	9,905,608	2330
B	6	241,723	9,905,608	2331
B	7	242,612	9,905,608	2334
B	8	243,501	9,905,608	2336
B	9	245,279	9,905,608	2340
B	10	243,501	9,906,814	2340
B	11	244,390	9,906,814	2346
B	12	245,279	9,906,814	2362
B	13	246,168	9,906,814	2384
B	14	242,612	9,908,021	2391
B	15	243,501	9,908,021	2391
B	16	244,390	9,908,021	2394
B	17	245,279	9,908,021	2398
B	18	246,168	9,908,021	2399
B	19	240,834	9,909,227	2400
B	20	241,723	9,909,227	2402
B	21	242,612	9,909,227	2405
B	22	243,501	9,909,227	2405
B	23	244,390	9,909,227	2411
B	24	245,279	9,909,227	2414
B	25	246,168	9,909,227	2424
B	26	241,723	9,910,434	2436
C	27	242,612	9,910,434	2442
C	28	243,501	9,910,434	2446
C	29	244,390	9,910,434	2447
C	30	245,279	9,910,434	2448
C	31	246,168	9,910,434	2451
C	32	243,501	9,911,640	2459
C	33	244,390	9,911,640	2459
C	34	245,279	9,911,640	2459
C	35	242,612	9,912,847	2460
C	36	243,501	9,912,847	2460
C	37	244,390	9,912,847	2460
C	38	242,612	9,914,053	2465
C	39	243,501	9,914,053	2465
C	40	242,612	9,915,260	2498

and the calorific values. Scheduled harvests were drawn using age/area structure corresponding to a normal forest and sustainable yields. This implies having equal size and continuous supply of *Y. alpina* biomass energy every year; the amount of resource obtained from the schedule is replaced by regrowth.

2.5. Calorific Value Assessment

A total of 36 samples were analysed for calorific value. The samples were collected, labelled, tagged in bags and assembled in the laboratory. There were nine bamboo samples, nine eucalyptus, nine cypress and nine pine samples. They were dried to a constant weight in an oven set at 105˚C for 24 hours. The dry samples were ground into a powder and then one gram of each sample weighed in duplicate and wrapped with a weighed tissue paper of known calorific value. These were then tied individually with an ignition wire (platinum) of known calorific value. Both ends of the wire were connected to the bomb calorimeter electrodes and placed in the bomb and firmly closed. Thirty kg of oxygen was led into the Diabetic bomb calorimeter model 1013-B and the bomb immersed into the cylinder filled with distilled water up to 2100 g. The bomb calorimeter was calibrated with benzoic acid of known calorific value, samples were burned to a constant temperature recording initial and final temperatures.

The formula used to calculate the calorific value was:

$$\begin{aligned} \text{C.V} = {} & \text{Water equivalent}(\text{g}) + \text{water quantity of inner cylinder}(\text{g}) \\ & \times \text{Rise in Temperature}(\text{q}) \\ & - \text{Calorie Correction}/\text{Quantity of Sample}(\text{g}) \end{aligned}$$

Bamboo calorific value was compared with that of other common wood fuels. Its biomass energy was estimated as the product of the biomass density and calorific value per unit of biomass. Sustainable harvesting schedule was proposed based on the bamboo energy resource available and a proposed rotation cycle in the forest.

2.6. Data Analysis

ANOVA was used to identify whether there were significant differences of bamboo energy resource among altitudinal zones and the age categories. Analysis was also carried out to determine whether there were significant differences between bamboo and other biomass energy sources.

3. Results and Discussions

3.1. General Findings

The biggest culm had 8.6 cm diameter while the heaviest bamboo culm was 14.2 kg (dry weight). The mean stocking was 19,981 (20,000) culms per hectare with a mean standing biomass of 86.0 tons per hectare. It was observed that bamboo leaf fall creates a rich layer of self-perpetuating compost/mulch which assists the regeneration of new bamboo shoots.

3.2. *Yushania alpina* Stocking and Distribution

The stocking of bamboo culms differed significantly (P = 2.63E−10) among altitudinal zones with Zone C (altitude 2441 and above) having the highest stocking of 24,493 culms per hectare as compared to zone B (altitude 2331 to 2440 m.a.s.l) with 19,600 culms per hectare and zone A (Altitude 2220 - 2330 m.a.s.l) with 15,850 culms per hectare (**Table 2**).

Only zone C recorded a stocking density higher than the 21,000 culms ha^{-1} reported by Muchiri and Muga (2013) [1]. However, it is noted that the previous study did not stratify the forest by altitudinal zones and therefore the current finding supplement the findings of the previous study. Moreover the current study has provided information on some factors that may influence bamboo stocking showing the ideal habitats for bamboo growth. Kleinhenz and Midmore (2001) [10] stated that altitude is one of the factors that influence bamboo stocking and this is confirmed by the current study. It is also in line with Wang *et al.* (2013) [11] assertion that culms with extreme density and wide range of distribution extend from broadleaved forest in the low elevations to conifer forest on high mountains.

These findings illustrate that bamboo stocking may vary within the stands and among altitudes. However, this could also be influenced by, human activity that was evident during field work where culms had been cut as high as one meter above the ground leaving hazardous, sharp and jagged stumps. The resource is located between 1 and 9 km from the community and though bamboo cutting is not permitted, there are still illegal removal mainly for domestic usage such as making tea picking baskets, fencing, house and food storage construction. Considering the dense bush and the heavy canopy closure inside the forest, the illegal activities are confined within not more than 2 km from the edge. As a result, this might have affected the stocking in Zone A which had close proximity to the public compared to Zones B and C respectively.

The study found out that the bamboo forest does not undergo any silvicultural management despite the existence of technical guidelines (Kigomo, 2007) [2]. This has resulted to poor quantity and quality of bamboo among age categories which was easily distinguished from each other in the bamboo forest. Shanmughavel (1997) [12] described such bamboo forests as characterised by a decline in photosynthesis, congestion and reduction in the number of upcoming culms

Table 2. *Yushania alpina* stocking among zones.

Zone	Culms/ha	Distribution (%)			
		Young	Mature	Old	Dead
A	15,850	23	8	37	32
B	19,600	28	7	40	25
C	24,493	30	8	41	25
Mean	**19,981**	**27**	**7.7**	**39.3**	**26.3**

and generally a poor regeneration cycle which makes the potential exploitation of the forest weak. The most dominant age category of bamboo was the old; which justifies their exploitation and commercialization through selective harvesting to allow for the regeneration and growth of the young culms. Kuster's *et al.* (2001) [13] pointed out that sustainable bamboo management programme is attained through timely removal of the mature and old culms.

The bamboo forest was found to be an ideal habitat for large herbivores like elephants and in all the investigated plots, there were obvious signs of the animals including paths and droppings of elephants and buffaloes. They damage the mature bamboo culms as they move and consume the young shoots and dig the soil. The animal droppings provide nutrients to a new generation of bamboo while fragmentized parts of the rhizomes enhance vegetative propagation (Hemp 2006) [14].

3.3. *Y. alpina* Biomass Production

Bamboo biomass calculated using the bamboo culm density and the allometric equation (Muchiri and Muga, 2013) [1] differed among altitudinal zones (**Table 3**). The mean values were 65 tons ha^{-1} for zone A, 81 tons ha^{-1} for zone B and 114 tons ha^{-1} for zone C. Analysis of variance showed a significant difference in biomass density among the zones.

The mean biomass density of *Y. alpina* in this study is slightly higher than that of 70 tons ha^{-1} reported by Muchiri and Muga (2013) [1] in a similar vegetation type. This variation may be due to a wider coverage of altitudinal range and variation within the altitudinal zones which were catered for in this study. The current study is able to illustrate the bamboo growing characteristics, for example most of the culms in zone A (altitude 2220 - 2330) had small diameter sizes, poor stocking and majority being old and dead which contributed to the low biomass production.

The quantity of *Y. alpina* in the forest increased with distance from the edge of the forest and elevation. This is supported by Bruijnzeel, *et al.* (2011) [15] who reported that elevation, rainfall; climatic conditions and soil type are some of the factors affecting bamboo biomass density.

The mean biomass was 86.6 tons ha^{-1} and lower than the 138 tons ha^{-1} recorded for the bamboo forest in the Mau forest complex (Kinyanjui *et al.*, 2014) [16].

Table 3. *Yushania alpina* biomass production and distribution among zones and age classes.

Zone	Biomass (tons/ha)	Distribution (tons)			
		Young	Mature	Old	Dead
A	65	13	5	26	21
B	81	22.7	6.2	31.4	20.4
C	114	35.3	9.6	45.1	24
Mean	**86.6**	**23.6**	**6.9**	**34.2**	**21.8**

This could possibly be an indication of lower productivity potential of the Aberdare forest as compared to the Mau forest complex. It could also illustrate the effect of bamboo exploitation that has occurred in the study area lowering the potential stocking. Kigomo (2007) [2] observed that the ideal bamboo stocking zones in Kenya range from 2200 m - 3200 m but their growth potential may vary with altitude.

3.4. The Energy Resource of the Bamboo Forest

Detailed analysis of bamboo samples was done at Kenya Forestry Research Institute (KEFRI) and the results are tabulated below (**Table 4**).

There was a wide range of moisture content, volatile matter, ash content and fixed carbon.The moisture dries very fast because of the unique structure of bamboo, it is a grass with a circular form and hollow sections making it very light.It has low ash content and alkali index which are important fuel characteristics for estimating the quality of bamboo fuel material. The volatile matter represents bamboo yield on the carbonization process, it provides more data on combustion properties and provide a basis for selling and procuring bamboo fuel material. Its combustion was found to generate high heat energy within a very short period of time, flame was strong with a yellowish colour and this changed to bluish gradually. Burnig requires maximum airflow, large amounts of smoke and tar are created with insufficient oxygen. Clinker is also formed when bamboo is burnt wet.

The calorific value of bamboo compared to other biomass fuels showed that there was no difference between bamboo and the other fuels. The calorific values were 4.0 Kcal/g, 4.2 Kcal/g, 4.3 Kcal/g, and 4.5 Kcal/g for *Eucalyptus saligna*, *Cupressus lusitanica*, *Pinuspatula* and *Yushania alina* respectively. This shows that bamboo provides biomass energy equivalent to the other biomass energy sources which are preferred by the local industries. It can be used by the tea

Table 4. *Yushania alpina* calorific value.

Sample No.	Moisture content %	Volatile Matter %	Ash Content %	Carbon Content %	Calorific Value Kcal/g
1	10.78	71.78	3.73	13.71	4.786
2	14.13	69.25	1.76	14.86	4.843
3	11.61	71.27	3.48	13.64	4.675
4	12.67	71.37	3.76	12.20	4.461
5	13.04	73.28	2.17	11.51	4.236
6	14.85	70.36	3.56	11.23	4.130
7	14.90	70.98	2.55	11.57	4.519
8	15.41	69.16	4.15	11.28	4.258
9	24.5	60.66	4.75	10.09	4.185

industry to feed into their boilers as whole, split, chipped or in an automated process. Chipped bamboo can as well be used to heat steam and drive a turbine generator set to produce power. Steam turbines produce energy providing self-sufficient power supply to the plant. This helps to reduce running costs, provide reliable power and also power the local villages and community with the surplus power. It is therefore a promising energy crop for the future with great potential of being an alternative for fossil fuels as stated by Truong and Le (2014) [17].

The calorific values multiplied by the bamboo biomass stocks available in the forest gave a mean stock of 380,893 Kcal/ha of bamboo energy resource (**Table 5**).

Although the stocks for these other sources of energy far exceed stocks for bamboo per unit stem, the bamboo stock in the forest is more compared to the trees available for the provision of the equivalent energy resource. Their regeneration is also faster implying their ability to provide sustainably.

The bamboo energy resource available in the 6419 ha can provide 2.4 billion Kca if all of it is harvested and used to generate energy. However, the study notes the varied uses that bamboo provides in the forest including biodiveristy conservation and water catchment and proposes a harvesting cycle that would not compromise such improtant roles while providing the needed energy resource. The annual demand by the local industries was 416,276,266 Kcal which implies that the bamboo forest can provide that energy over a 5 year management programmeensuring sustainable yield and a normal forest. **Figure 2** shows the age structure of *Yushania alpina* given in four age categories.

A sustainable annual allowable cut could be fixed at 1284 ha per year (**Figure 2**). However, the age structure is skewed with large areas with, old and dead materials, while the area under mature materials is quite limited. There is also considerable natural regeneration, with proper management interventions; they will develop into good stands as shown in the harvesting schedule in **Table 6**.

The area required to supply the industries with biomass energy annually is 1100 ha while the annual allowable cut is 1284 ha. This theoretically means there is excess biomass energy hence sustainability is assured.Kenyans and manufacturing industries that depend on wood as a source of energy should start using bamboo as a strategy to diversify the energy supply, reduce the effects of climate change and conserve the forests.

Table 5. *Yushania alpina* biomass energy among zones.

Zone	Distribution of Energy content of *Y. alpina* in four age categories				
	Young	Mature	Old	Dead	Totals
A	57,200	22,000	114,400	92,400	286,000
B	99,880	27,280	138,160	89,760	355,080
C	115,320	42,240	198,440	105,600	501,600
Mean	**104,133**	**30,507**	**150,333**	**95,920**	**380,893**

Table 6. Harvesting schedule.

Harvesting Year.	Area (ha).			
	Dead	Old	Mature	Young
Year 1	1284	-	-	-
Total	**1284**			
year 2	386	898	-	-
Total	**1284**			
Year 3	-	1284	-	-
Total	**1284**			
Year 4	-	340	494	450
Total	**1284**			
Year 5	-	-	-	1283
Total	**1283**			
Grand Total	**6419**			

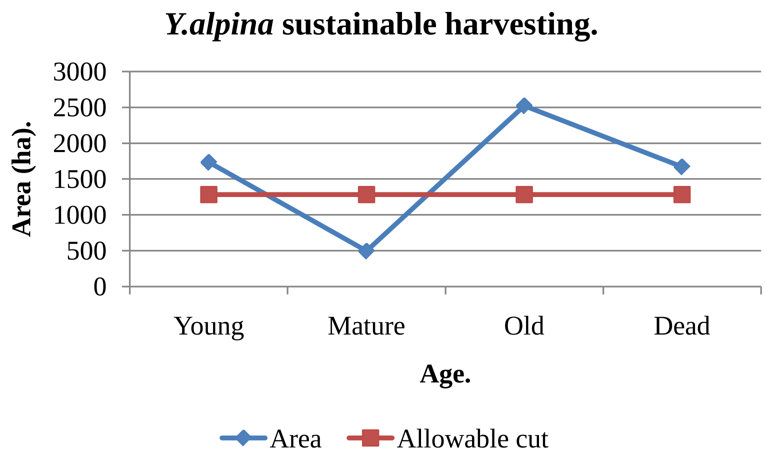

Figure 2. Age class distribution for *Yushani alpina*.

Bamboo is fast growing, develops dense stands of vegetation, matures in between 4 - 7 years and can be harvested for as many as 40 - 80 years (Kigomo, 2007) [2]. Therefore, bamboo offers an opportunity to bridge the energy demand which is currently limited due to the increasing population and associated development bearing in mind that biomass energy is still a major source of energy in Kenya (Charles *et al.*, 2007) [18]. However, for such a programme to be implemented, the resource requires to be managed, which may significantly increase the supply and address problems of wood resource shortage in the country (Shanmughavel, 1997) [12]. In addition, bamboo planting in agricultural land scapes can guarantee a sustainable supply of energy resources. This would reduce dependency on forest wood as well as enable community to participate in the global carbon trading regime such as the REDD+ scheme.

4. Conclusions

Kenya is blessed with an amazing natural resource on the southern end of the Aberdares; there are a lot of bamboo stocks cloaking the hillsides in a natural monoculture. Factors that influence their stocking were identified and this is good for a management programme. Its biomass production is good and provides energy equivalent to the preferred biomass sources of energy. It is therefore an ideal alternative source of energy and is in agreement with national programmes for management of bamboo forests.

An even flow of biomass energy is achievable over a five year sustainable management programme by having harvest schedules based on age/area structure corresponding to a normal forest and sustained yield. Harvesting requires selective cutting of a few hectares of bamboo which cannot cause a threat of depletion considering size of the bamboo forest area, its fast growth and renewable characteristics which enable rapid creation of dense vegetation on a large scale.

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