Advanced Journal of Agricultural Research
Vol. 1(004), pp. 045-050, August, 2013

http://www.advancedjournals.org/AJAR

Full Length Research Paper

A Markov Model for Bamboo Harvest Forecasting in South Nyanza Region, Kenya

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Accepted 8th August, 2013

The introduction of bamboo in South Nyanza region in Kenya as an alternative source of income initially met pessimism due a lengthy wait, of at least three years, before harvesting. To convince the farmers to plant bamboo, they needed to know the expected quantity of harvest, its timing and consequently its associated income. The harvest is determined by the height and multiplicity of bamboo clumps. This varies from place to place due to diverse environmental conditions and other growth factors. A Markov model for forecasting bamboo harvest is introduced. The study sites included Rangwe and Suba (in Homa Bay County), Ngege and Kuria/ Ikierege (in Migori County) in South Nyanza region, Kenya. The major cash crop in the selected areas has been predominantly tobacco. Time series data on growth measures progressively collected from the four project sites, each with 30 experimental gardens, was used to determine probability distributions of growth measures at discrete time intervals. Since the growth measures were random in nature, the stochastic modeling approach by Markov chains was applied. The resultant estimates from the model were 2,640 poles of *Bambusa vulgaris* and 1,188 poles of *Dendrocalamus giganteus* per acre of land per year. The model was tested for validity during the actual harvesting and found to be a good estimate of the actual values.

Key words: Bamboo, Markov chains, *Bambusa vulgaris, Dendrocalamus giganteus*, harvest forecasting, Kenya.

INTRODUCTION

The rapid growth and short life-cycle of bamboo makes it one of the most renewable natural resources in the world (Farrelly, 1984). Furthermore, it can be harvested on a regular basis without causing significant damage to its surrounding ecosystem. Intensified interest on bamboos has resulted in its emergence as potentially the most important non-timber forest resource to replace wood. Its strength, straightness, lightness combined with extraordinary hardness, range in size, abundance, easy propagation, and short vegetation period to attain maturity, make it suitable for a variety of purposes and uses (Espiloy, 1994). Furthermore, bamboo as a woody plant is uniquely suited to agroforestry. Some of the many uses of bamboo in agroforestry are: intercropping;

riparian vegetation filter; constructed wetlands; living screens; and perm culture (Diver, 2001).

Giant bamboo (*Dendrocalamus giganteus*)

This is a tight clumping bamboo species with pachymorph rhizomes. Originally from Southeast Asia, it has been introduced in numerous countries including India, Bangladesh, China, United States of America and Australia. It grows naturally in humid tropical highlands, up to 1200 m above sea level and grows successfully in tropical lowlands on rich alluvial soils. Its culms extend to heights of 35 m with a diameter of up to 25 cm (Rao et al., 1985) and walls of 25 mm thick while its leaves can grow almost two feet long and four inches wide. Young shoots of the species are distinguished by their purple colour. The full extension of the culm is achieved within three and a half months. The full giant size of the culm is attained only after 10 to 15 years. Thinning of the clump may begin 4 years after planting, removing the oldest culms and leaving space for the development for new shoots. 7 to 8 years after planting large 3 year old culms may be harvested. New shoots annually increase in size until the plant reaches maturity. The large culms of the species have many uses including construction, scaffolding, water pipes, buckets and paper pulp. The young shoots are edible and are distinguished by their creamy texture (Kibwage et al., 2008).

Bambusa (Bambusa vulgaris)

This is a medium sized clumping bamboo species with pachymorph rhizomes. The species, as its Latin name suggests, an ordinary bamboo in the sense that it is very common and widespread. It is cultivated throughout the tropics and is easily propagated by traditional means including culm cuttings.

Bambusa vulgaris is a multipurpose bamboo with culms of 10 to 16 m in length. The diameter of the culms is 5-10 cm with a wall thickness ranging from 7-15 mm. It is used for paper-making, scaffolding, fencing, construction, poles, and handicrafts. The shoots of the species are edible, and consumed throughout south-east Asia (Rao et al., 1985).

B. vulgaris (variety striata) grows wild in the warmer parts of Kenya up to an altitude of 1,500 m, thriving best near river banks. It is a highly versatile bamboo and is extensively used. The culms are relatively soft and posses long fibers, making them a valuable source of paper pulp. *B. vulgaris* has perpetually remained vegetative with no flowering reported (Kibwage et al., 2008).

One of the goals of modern plant population ecology is to understand population phenomena in terms of the behaviour of individuals. The development of a stand of plants results from the growth of individuals, as altered by interactions among these individuals. It is known that plant growth is sigmoid (Hunt, 1982; Vanclay, 1994), and several sigmoid growth models with biologically interpretable parameters have been proposed to describe the growth of individual plants, such as the logistic and Gompertz models. In most sigmoid growth models, initial growth is exponential, and a negative term reduces the relative growth rate as size increases, resulting in an asymptotic maximum size (Zeide, 1993). The main difference among different sigmoid growth models is the inflection point, the size at which the plant experiences its maximum absolute growth rate (Seber and Wild, 1989).

There is increasing interest in including the variation among individuals in the modeling of population growth with hierarchical models, in which some parameters are estimated at the level of the population, whereas other parameters are assumed to vary among individuals according to a specific distribution (e.g. a normal distribution), where the mean and the variance of the distribution can be estimated (Camet al., 2002; Clark et al., 2004; Fox et al., 2001; Schneider et al., 2006).

A plausible example of such models is the Agricultural Production System sIMulator APSIM. APSIM (Keating et al., 2003) is a cropping systems modeling environment specially designed to allow a plug-in-pull-out approach for the integration of various simulation models via a common modeling protocol (Moore et al., 2007). It is a product of the Agricultural Production Systems Research Unit (APSRU). APSIM can be configured with modules suitable for the simulation of many different systems. Whilst these initially concentrated upon dry-land cropping systems, APSIM's usage has broadened and now it is also being used in the study of forestry (Paydar et al., 2005), agroforestry (Huth et al., 2002) and pasture systems (Snow et al., 2007). Horticultural crop models are now being included into the suite of crop models available within APSIM

A cost benefit analysis of bamboo over tobacco has

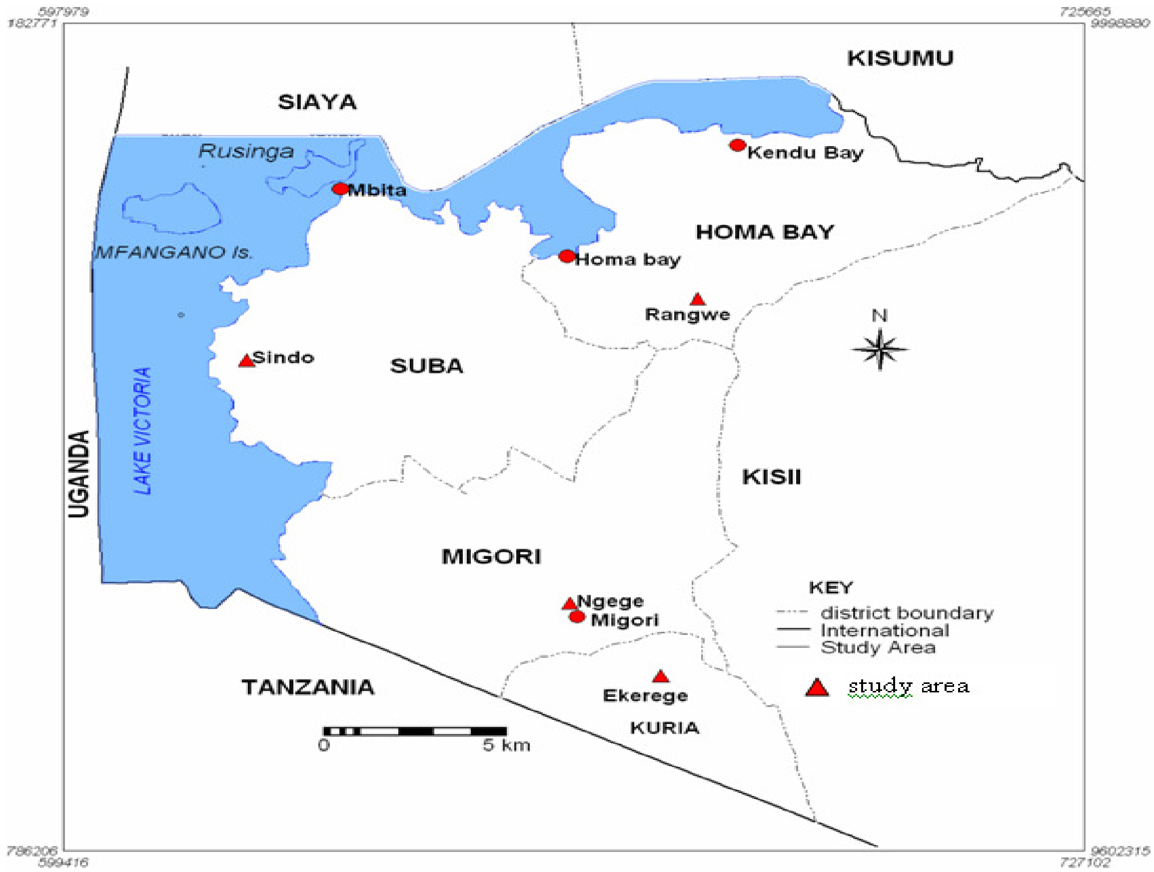

Figure 1. Specific study sites.

been carried out and findings show that bamboo is four times more profitable than tobacco when sold at farm gate or more than tenfold when processed into different high quality bamboo products (Peter et al., 2012).

In this paper, we give a Markov model approach to bamboo growth and harvest modeling. This model provides a basis for determination of the expected harvest, given the survival probabilities at various stages of bamboo growth.

METHODOLOGY

Study area

The study was carried out in four sites in the South Nyanza region of Kenya. These were Rangwe and Suba (in Homa Bay County), Ngege and Kuria/ Ikierege (in Migori County) (Figure 1). The South Nyanza region cover an area of about 7,778 km^2 (5,714 km^2 land area and 2,064 km^2 water), which is 48% of the land area of the former Nyanza Province. To conduct this study, 120 farmers in the region were selected forming four bamboo farmers' cooperative societies, each initially with 30 farmers. The cooperatives included Migori Bamboo Farmers Cooperative Society Ltd, Kuria Bamboo Farmers Cooperative Society Ltd, Homa Bay Bamboo Farmers Cooperative Society Ltd and Suba Bamboo Farmers Cooperative Society Ltd.

The farmers were selected on the basis of whether or not one was a tobacco farmer, gender, age, poverty status, farming scale, access to water and the willingness to provide land for the bamboo experimentation.

A total of 2,420 bamboo cuttings consisting of 1210 giant and 1210 *Bambusa* species were planted. The cuttings were sourced from Githumbuini estate in Thika district, near Nairobi City. The sympodial type of bamboo was selected because of its smoothness and high resistance to wear. Its commercial value is also higher than monopodial type of bamboo. Each farmer was

Plate 1. Giant bamboo tagged.

Plate 2. Common bamboo tagged.

given 20 bamboo cuttings (that is, 10 each of giant bamboo and common bamboo). Each cutting was planted in a cubical hole measuring 0.6 x 0.6 x 0.6 m. Spacing between two-bamboo cuttings was 5 m.

To reduce sampling errors thereby enhancing sampling precision, 50% of bamboo clumps were randomly selected. The selected clumps were tagged with codes indicating the site, farmer's number, species and the clump number for easy identification and monitoring. Survival rates, number of culms, culm heights and diameters, among other modeling parameters were measured.

Plates 1 and 2 illustrate the tagging exercise on the two species grown .

Data collection and analysis

Assessments of the bamboo performance parameters were carried out at an interval of 3 months from the time of planting for the first year and after every 6 months for the remaining 2 years.

Collected time series data was entered into spreadsheets and filtered using Excel and SPSS. During data analysis, a descriptive analysis of growth measures was performed. Then time series data was fitted with regression models (curve fitting). The average growth measures at each time interval were computed. These were used in the Markov model.

The Markov chain model

Classification of the states of a clump was done as follows:

state: O ➔ Just planted seedling.
state: A ➔ Survived and 6 months old.
state: B ➔ Survived and reproducing 12 months old.
state: C➔ Survived and reproducing 24 months old.
state: D ➔Reproducing and 36 months old.
state: E ➔Stagnates at any age .
state: F ➔ Dead at any age.
state: G ➔Mature and ready for harvest.

The percentage was determined by the average number of mature culms per clump collected. The matrix of transition probabilities is as follows:

0	**0.8**	**0**	**0**	**0**	0.05	0.15	0
0	**0**	**0.85**	**0**	**0**	0.05	0.1	0
0	**0**	**0**	**0.9**	**0**	0.05	0.05	0
0	**0**	**0**	**0**	**0.9**	0	0	0.1
0	**0**	**0**	**0**	**0**	0	0	1
0	0	0	0	0	1	0	0
0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	1

Model assumptions

1. Clumps that are 2 years old and above do not die.
2. Mature culms are all harvested at the end of the 3rd year.
3. Culms older than two years do not stagnate in growth to maturity.

With the matrix model formulated, the steady state absorption probabilities were computed. Note that the purple section is a matrix of transition probabilities within transient states while the green section has the matrix of transition probabilities from the transient states to the absorbing states. The blue area has a matrix of zeros and the yellow area, the identity matrix.

Following steps in Markov analysis", the fundamental matrix *F* is:

$$F = (I - T)^{-1}$$

Where I is the identity matrix of the same order as the transient states matrix T.

Let $A = (I - T)^{-1}$ then the inverse matrix of A ,

$$A^{-1} = F = \frac{1}{DetA} \times AdjA$$

Det (A) = 1

The probabilities of eventual absorption *F.A* are:

Stagnant	Dead	Harvested
0.124	0.264	0.612
0.0925	0.1425	0.765
0.05	0.05	0.9
0	0	1
0	0	1

This shows that over 60% of culms in each clump will eventually be ready for harvest (after 3 years).

RESULTS AND DISCUSSION

One acre of land can accommodate approximately 220 clumps of bamboo spaced 5 square meters apart.

For *B. vulgaris*, it is expected that 80% (176) of the clumps will survive to maturity. Each clump will averagely have 25 culms, each with an average height of 7 meters. The average diameter of each is estimated at 4.6 cm. 60% (15) of all culms, clump will be ready for harvesting at the end of the 3rd year. The total expected number of poles for an acre of land will therefore be 2,640 poles. If all are sold locally each at Kshs. 100/= then a total of 264,000/= will be realized in the first harvest. This translates to a yearly revenue of 88,000/= for the first three years.

For *D. giganteus*, it is expected that 60% (132) of the clumps will survive to maturity. Each clump will averagely have 15 culms, each with an average height of 10 meters. The average diameter of each is estimated at 8.3 cm. 60% (9) of all culms in a clump will be ready for harvesting at the end of the 3 year. The total expected number of poles for an acre of land will therefore be 1,188 poles. If all are sold locally each at Kshs. 200/ then a total of 237,600 will be realized in the first harvest. This translates to a yearly revenue of 79,200/= for the first three years.

The giant species of bamboo takes longer time (4 years) to mature. At the end of this time it is expected that more culms of larger sizes will have emerged and the statistics will change significantly.

Conclusion and recommendations

The use of Markov analysis to determine bamboo harvest was achieved. Results from use of the model agree with earlier computations using a queuing model (Peter 2012). Moreover, the Markov model is stochastic (probabilistic) and therefore more realistic than the queuing model that is deterministic. Since the study period was 3 years, we were unable to study the behavior of shooting and culm development after harvesting. This is left as an item for further research and will future harvests.

ACKNOWLEDGEMENT

This study was made possible by a grant from International Development Research Center (IDRC), Canada. We are also indebted to research collaborators including International Network for Bamboo and Rattan (INBAR), South Eastern Kenya University (SEKU) and Maseno University for providing an enabling environment and personnel towards the success of this research. We also acknowledge all farmers who volunteered to give relevant information. We are also indebted to all research assistants who participated in the data collection. However, the content herein is attributed to the authors and not the supporting institutions or individuals.

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