



## Modeling Tree Mortality for *Eucalyptus camaldulensis* (Dehnh) Stands in Afaka Forest Reserve, Kaduna-Nigeria

B. Abubakar<sup>1\*</sup>, S. B. Shamaki<sup>1</sup>, A. Dantani<sup>2</sup>, Z. Y. Gada<sup>1</sup> and M. A. Gupa<sup>3</sup>

<sup>1</sup>Department of Forestry and Environment, Faculty of Agriculture, Usmanu Danfodiyo University, P.M.B. 2346, Sokoto, Nigeria.

<sup>2</sup>Department of Forestry and Wildlife Management, Faculty of Agriculture, Bayero University, P.M.B. 3011, Kano, Nigeria.

<sup>3</sup>Department of Forestry and Wildlife, University of Maiduguri, P.M.B. 1069, Borno State, Nigeria.

### Authors' contributions

This work was carried out in collaboration among all authors. Authors BA and SBS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript.

Author AD managed the analyses of the study. Authors ZYG and MAG managed the literature searches. All authors read and approved the final manuscript.

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### ABSTRACT

This research was conducted to investigate mortality using logistic regression (Models) for River red-gum (*Eucalyptud camaldulensis* Dehnh) in Afaka Forest Reserve, Kaduna, Nigeria. Stratified random sampling and proportional sampling allocation were used in selecting plots and individual trees for measurements. Data on live and dead trees were recorded, variables measured are diameter, total tree heights, spacing and age of the stands within the plots. Diameter at the breast height (DBH) was measured using diameter tape while Haga Altimeter was used in taking the total height of the sampled stands. The Data collected were divided into four portions. Three portions (75%) for model calibration adopting logistic regression model, 25% were used for model validation of logistic model generated. Chi square test of goodness-of-fit, Negelkerke R<sup>2</sup>, Cox and snell R<sup>2</sup>

\*Corresponding author: E-mail: [adbabatrading@gmail.com](mailto:adbabatrading@gmail.com);

values were used for model evaluation. The positive regression coefficients (16.737, 49.266 and 1.992) showed by Dbh, Height and age (as independent variables) indicated positive future mortality effects on the stands; as the trees ages and increases in size and height, the chances of mortality will increase. At the present age and sizes of the stands the fitted model shows no significant relationship between the current age, height and size of the stands, as such the notion held by the management of the plantation that Eucalyptus cannot grow for many years and in large sizes is not true. There is therefore, need for periodic re-measurement of the stands to evaluate future effect of the variables (Age, Dbh and height) on mortality.

**Keywords:** *Eucalyptus*; mortality models; diameter; tree height; logistic regression.

## 1. INTRODUCTION

Forest is a biological community or ecosystem dominated by trees offering numerous benefits. The significance of forest ecosystem is enormous to any society and at any scale, they provide both timber and non-timber forest products from a wide range of species of flora and fauna [1,2]. Forest provide food, fuelwood and pharmaceutical products [3] and financial benefits from the sales of tree leaves and root, honey, fruits, seeds, fire wood, bush meat, mushrooms, and snails [4]. Forest and the forest sector play a vital role, they provide a multitude of benefits that can be categorized as economic, ecological, and social; forests improve degraded land, sequester carbon dioxide and therefore combat climate change and provide employment and revenue [2]. Thus, these benefits however, depend on the growth attained by a tree or stand usually on a sustainable basis.

Model describes a relationship between two or more variables (example; how diameter growth relates to the height of a tree), model also describe an aspect of the ecosystem i.e growth, mortality, regeneration etc. [5]. Forest growth and mortality models attempt to quantify the growth of a forest, and are commonly used to predict the future status of a forest, nature of any harvests from the forest [6]. Growth and yield as well as mortality models are used to predict the growth and yield of a stand at a given period and models provide an efficient way to prepare resource forecasts. However, mortality, growth and yield models assist forest researchers and managers in predicting future yields and to explore silvicultural options for a particular forest. Growth model is an abstraction of the natural dynamics of a forest stand, and may encompass growth, mortality, and other changes in stand composition and structure [5]. It is an essential part of forest management to be able to forecast the future timber volume and products that will be produced from the forest. This is important in

both operational and financial planning for all forest owners. For example, models might be used in deciding when a forest road should be built or whether a particular forest for sale is of suitable investment.

Tree mortality is a critical ecological process that affects stand composition, structure and productivity. Tree mortality is the death of forest trees [7,8,9]. However, Plant death is a complex process, which is influenced by environment, age, etc. In general, trees die when they cannot acquire or mobilize sufficient resources to recover from stress, heal injuries, or when they are killed by some external factors; local fire, wind, snow or insect attack, trees compete with each other and with other plants for the sunlight available on a site. When trees get overtopped and shaded by others, their access to sunlight is reduced or eliminated. As a result, the growth of overtopped trees slows or halts. Depending on the species, trees may eventually die after being overtopped [10]. The interactive and sequential nature of mortality mechanisms make it virtually difficult to produce a definitive classification of what caused the ultimate death of a tree. There is regular mortality (non-catastrophic), which results from competition for light, water and soil nutrients within a stand [9] and irregular mortality (catastrophic), which may result from autoecological disturbances such as local fire, wind, snow or insect outbreaks [11].

*Eucalyptus camaldulensis* (Dehnh), (River red gum), is a tree of the genus *Eucalyptus* from Myrtaceae family, it is plantation specie in many parts of the world but is a native to Australia, where it is widespread [12]. *E. camaldulensis* is perennial tall tree reaching 30 m in height although some authors recorded the tree to have reached 45 m in height [13]. There are more than 500 species of eucalyptus, several of them were introduced to Nigeria but of all the species tried, only *Eucalyptus Camaldulensis*, *Eucalyptus*

*Terticornis* and *Eucalyptus Saligana* are the most promising as plantation species in the Savannah area [14,15]. These species are widely used in Nigeria as shelterbelts, pulpwood and as house construction materials. Their use in agro-forestry for inter cropping is limited to the Savannah due to their tendency of inhibiting the growth of other trees in the vicinity. Other uses of *E. camaldulensis* include lumber production, plywood, veneer, solid and engineered flooring, fiberboard, wood cement composites, mine props, poles, firewood, charcoal, essential oils, honey, tannin and landscape mulch as well as for shade, windbreaks and phytoremediation. Eucalyptus oil is also used in very small quantities in food supplements especially sweets, cough drops and decongestants. It also has insect repellent properties and is an active ingredient in some commercial mosquito repellents [16]. Savannah zone of Nigeria have many Eucalyptus plantation as a result of afforestation programs being that the region is affected by many environment problems ranging from desertification, deforestation mining etc.

Lack of clear understanding of the growth and yield dynamics of the Eucalyptus stands in Afaka Forest Reserve is causing allot of managerial problems which invariably leads to poor management. The understanding of the management team of the Afaka plantation is that Eucalyptus stands do not have the potentials of growing into larger sizes over the years without mortality which is the more reason why they open up the area for exploitation within short periods of stands development. Management and or land use in Afaka forest reserve is however, one of the contributing factors causing death of the planted *E. camaldulensis* trees as some of the Eucalyptus stand had weeding done once a year while others, once every two years. Some stands were given out to local farmers for taungya activities. Hence, all these among other factors might contribute to the mortality of some of the eucalyptus trees.

The fate of forests is of particular interest because they cover almost four billion of hectares worldwide and provide an important ecosystem service [17]. Mortality is an important process in forest dynamics and succession, [18]. Several models for predicting mortality have been developed using data from small survey plots. However, the technique mostly used for developing models for individual tree mortality is logistic regression, for instance, at the individual

tree level, the binomial nature of mortality makes gaussian model inappropriate for expressing the probability of a tree dying or surviving. In Spain, logistic regression has been used to model individual-tree mortality for mixed-species and uneven aged stands [19]. The aim of this research work was to develop and fit mortality model for six stands of *E. camaldulensis* in Afaka Forest Reserve, broken down as follows, obtain planting record, Determine the diameter growth and mortality of the trees planted at different stands and to fit logistic regression model for projecting mortality.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The study was conducted at Afaka Forest Reserve in Igabi Local Government Area, Kaduna State, Northern Guinea Savannah Zone of Nigeria, occupies an area of 12,243.76 hectares [20]. It is within the latitude 10°34'24" N and 10°96'51" N and longitude 6°23'74" E and 6°63'73" E. The elevation varies across the forest region but it is generally a plain land with an average of 610m above mean sea level. The forest reserve has a tropical climate, which is characterized by two clearly distinct seasons of dry and wet seasons, the dry season lasts from October to early April, while the remaining months constitute the rainy season. The forest temperature is high throughout the year with mean minimum and maximum temperatures of 23°C and 34°C, respectively [20]. The mean annual rainfall is 1266.0mm based on annual rainfall record of 43 years (1969 – 2012) [21].

Afaka Forest Reserve was established in 1954 as an experimental plantation site, in order to increase the productivity of the Savannah and arrest desertification in some parts of Northern - Guinea Savannah of Nigeria [22]. The forest reserve provides a mixture of both man-made and natural vegetation. Some of the indigenous and exotic trees in the forest reserve include *Parkia biglobosa*, *Ceiba pentandra*, *Khaya senegalensis*, *Mangifera indica*, *Eucalyptus spp*, *Tectona grandis*, *Pinus caribea*, *Gmelina arborea* among others. The forest reserve is the main source of electricity pole for most part of the state in addition to providing wood for fuelwood and the construction industry [23].

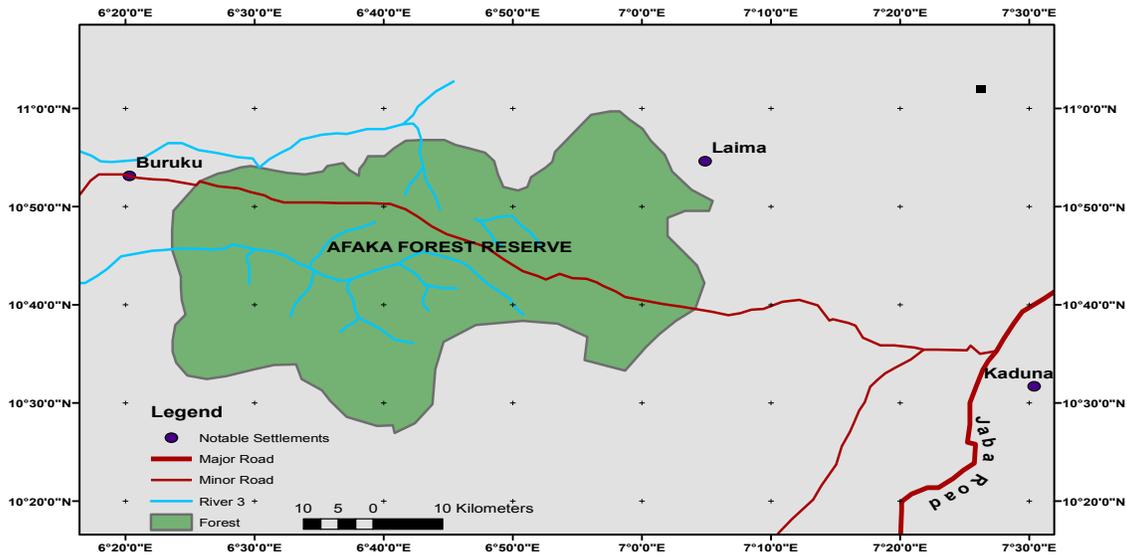


Fig. 1. Map of Afa forest reserve

Table 1. No. of sample plots used per stand

Stand	Hectares /Stand	Sampling plots (20X20m) within each stand	Sampling plots (20X20m) Proportionally selected
2005	10.0	250	3
2006	19.4	485	6
2007	5.9	147.5	2
2011	21.6	540	7
2012	19.8	495	7
2013	7.1	177.5	2
Total		2,095	

Source: Field survey, 2017

### 2.2 Sampling Procedure

Stratified random sampling and proportional sampling techniques were used in this study, this involve the partitioning to Eucalyptus stand in to different strata and then selecting individual trees based on age (proportionally)

- i. The six stands (2005, 2006, 2007, 2011, 2012 and 2013 stand) were considered as strata.
- ii. The sampling plots of each stand were selected randomly through balloting for the measurement.
- iii. 30 sampling plots (20 X 20 m) were set for the research to determine number of sampling plots for each stand using proportional sampling allocation technique. Thus;

$$n_i = \frac{(N_i)n}{N} \tag{1}$$

Where;  $n_i$ = No. of plots to be used for sampling on each stand proportionally,  $N_i$  = No. of plots within each stand,  $N$  = Total No. of all the plots in all the stand  $n$  = No. of plots set for the research work.

### 2.3 Data Collection

This involves the following;

- i. Counting and recording the live and dead trees.
- ii. Measuring the Diameter of the live and dead trees at Dbh. Tree-trunk diameter was measured at breast height (termed diameter at breath height or Dbh), defined as the diameter of the tree 1.3 m above ground on the uphill side of the tree. However, flexible measuring tape was used to measure tree trunk circumference, which was divided with the value of pie

- (3.142) to determine the tree diameter (in cm).
- iii. Tree height, total tree height is the distance from ground level to the upper tip of the tree crown. Haga altimeter was used in taking the height measurement (in meter).
- iv. Inspection of planting spacing and age of each stand was conducted on all the sample plots.

**2.4 Data Analysis**

Data collected were organized and screened to ensure validity prior to model calibration. Field measurement values were further grouped into different diameter and height classes with a view to determine the size class with higher mortality at a certain age. Mortality was set as dependent variable, while, Basal Area, Dbh, spacing, and age as independent variables. SPSS Statistical Software Version 20 was used in data analysis.

**2.5 Model Calibration**

Data collected were divided into four portions. Three portions (75%) were used for model calibration (Training), while the remaining 25% was used for model validation (Test). Logistic regression model was adopted for the calibration (training) of 75% of data collected which has the following form:

$$P = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \dots + \beta_n X_n)}} \tag{2}$$

Where, P = is the probability of tree mortality,  $\beta_0$  = intercept,  $\beta_1 - \beta_n$  = are parameters to be estimated,  $X_1 - X_n$  = are explanatory variables,  $X_1$ = Diameter,  $X_2$ =Height,  $X_3$ =Basal Area,  $X_4$ = Age, e = is an exponential.

**2.6 Model Evaluation and Validation**

The 25% independent data set was used for model evaluation and validation. Chi square test of goodness-of-fit was used to validate the logistic model generated. Some statistics generated like neigelkerke R<sup>2</sup> and Cox and snell

R<sup>2</sup> values were also used to evaluate the model and validity of application.

**3. RESULTS**

**3.1 Descriptive Statistics of the Independent Variables**

Table 2 presents summary statistics of the data obtained on 1323 trees from 27 plots. The variables measured were included as the independent variables for model development include Dbh, Tree Height and Basal Area. Scattered plot of Diameter against the total number of trees in order to show diameter distribution pattern is presented as Fig. 2 (the curve indicates positively skewed and around 700 trees has a distribution of all the dbh size recorded for the measurement.

**3.2 Summary of Trees Measured per Plot**

Table 3 Show the summary of average number of trees measured per plot as well as average number of dead trees per plot.

**3.3 Results of Logistic Regression**

Regression coefficients and odd ratio values generated from logistic regression modeling are presented in Table 4 considering Dbh, H, Basal area and Age of the stand as independent variables for predicting mortality.

**3.4 Result of Model Validation**

Result of chi square test of goodness-of-fit used to validate the logistic model generated is presented in Table 5.

**4. DISCUSSION**

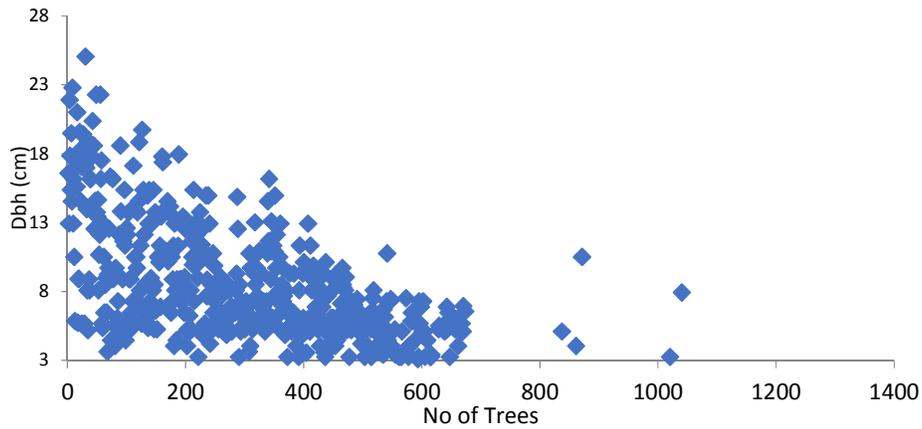
**4.1 Descriptive Statistics of the Independent Variables**

Summary statistics of the field data revealed that the data set is suitable for logistic regression analysis, with relatively low mean standard error of the independent variables (Dbh, H and Basal area) indicating low chances of making error in

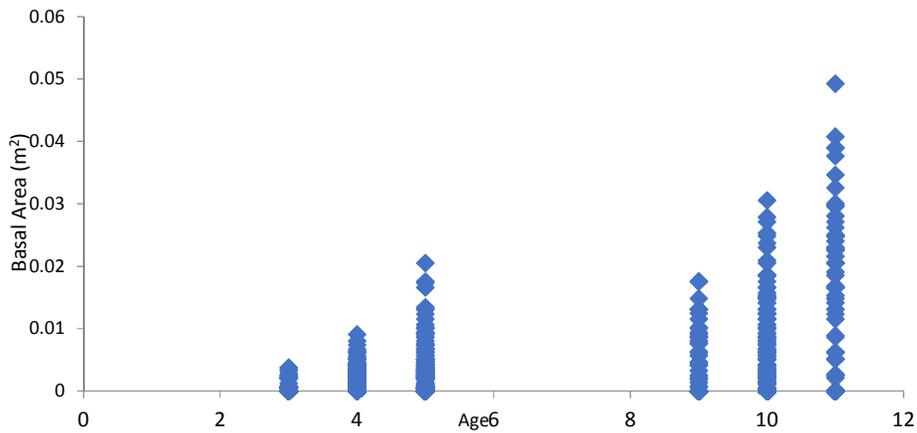
**Table 2. Descriptive statistics of the independent variables**

	<b>N</b>	<b>Range</b>	<b>Min</b>	<b>Max</b>	<b>Mean</b>	<b>SD</b>	<b>SE</b>
Dbh (cm)	1323	25.051	8.51	25.051	3.5803	4.8128	0.13231
Height (m)	1323	34.40	3.74	34.40	4.85	6.721	0.185
Basal Area (m <sup>2</sup> )	1323	0.0493	0.0028	0.0493	0.0028	0.0057	0.00016

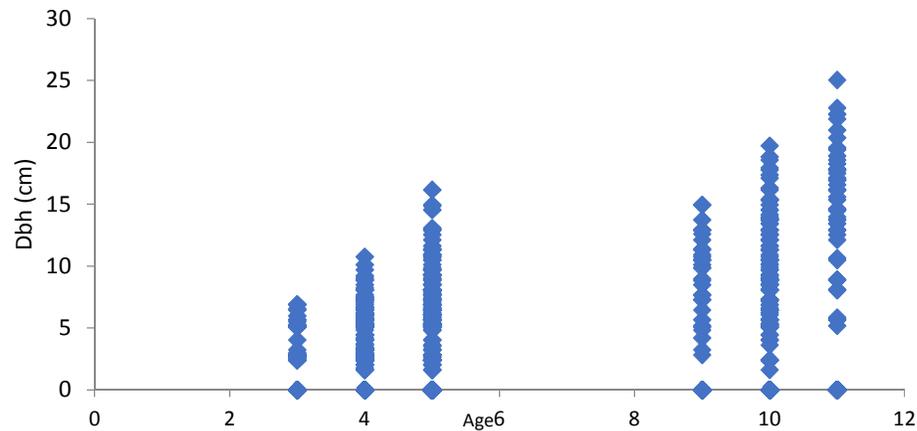
Source: Field Survey, 2017; N= number of trees, SD = Standard Deviation, SE= Standard error



**Fig. 2. Dbh distribution in respect to no of trees**



**Fig. 3. Relationship between basal area and age**



**Fig. 4. Relationship between Dbh and age**

the prediction of what may cause the mortality from the Variables used for the prediction. Scattered plot (Fig. 3) described the distribution of dbh size to the number of trees in the research area and the curve indicates right skewed

distribution (positive skewness). Hence, around 700 trees have a distribution of all the dbh size recorded for analysis and in all the stands the planting spacing was 3 X 3m, this also is within the planting practices of Eucalyptus plantations

as reported by [24] that adopted and used 3X3 m spacing for *Eucalyptus spp.*

**Table 3. Summary of mortality**

Age classes	Average trees per plot	Average mortality per plot
11	49	21
10	56	23
9	62	26
5	72	22
4	75	23
3	77	29

**Table 4. Logistic regression and odds ratio for mortality**

Variables	Coefficient	OR	P-Value
Constant	1287.596	0.000	0.994
Dbh (cm)	16.737	0.000	0.999
H (m)	49.266	0.002	0.968
Basal area (m <sup>2</sup> )	-5487.139	0.000	1.000
Age of stand	1.992	0.000	0.998
Cox & snell R <sup>2</sup>			0.75
Nagelkerke R <sup>2</sup>			1.00

Source; Field Survey, 2017; Note: OR=Odds ratio

#### 4.2 Logistics Regression

All the variables in the logistic regression model appeared to produce positive coefficients except the basal area which is an indication of possible future mortality with increasing age, sizes, height and competition. Even though, the current age and sizes of the plantation (all the stands) do not show any significant relationship with tree mortality, the odds ratio values were almost at zero level for all the independent variables and having the potential of moving higher with increasing age and sizes of the stands. The implication of these logistic values is that current ages and sizes of the six stands in the plantation were not significant enough to influence tree mortality, hence the non-significant relationship of the regression parameters. At lower Dbh classes however, the regression coefficients recorded negative values which is an indication of the small size tree stands of becoming more vulnerable to environmental factors causing mortality with increasing heights Fig. 4. All the height classes appeared to have negative slope estimates of the regression line, thereby having a higher chance of mortality when the size of the tree is not increasing. Increasing tree height of the Eucalyptus stands should be concurrently with the diameter increase so as to have a positive tree basal area which will in turn give a better yield in terms of tree volume (total or merchantable). The result of the research

conforms to the study conducted by [25] which revealed that, "unknown" was the largest single category recorded under causes of mortality.

**Table 5. Chi square and likelihood ratio**

Variables	Chi square	Likelihood Ratio	P – Value
Dbh – Class	1102.508	1387.64	0.000
Height – Class	1132.823	1315	0.000
Age of stand	21.852	22.00	0.001
Basal area	1107.637	1414.778	0.000

Source; Field Survey, 2017

In respect to the usage of logistic regression for the analysis of the data obtained also [26,27, 28,29] utilized logistic regression to model tree survival using the Binary Logistic procedure, also [30] developed a multilevel logistic regression model for predicting the probability of mortality in individual trees for Pyrenean oak (*Quercus pyrenaica* Wild.) stands. Opposed to that [31] applied the Cox proportional hazards model to the tree mortality using data derived from monitoring of the permanent plots.

#### 4.3 Model Validation

In trying to further validate the result of logistic regression. Some statistics generated in the course of modeling the relationship were used for model evaluation. The model developed is perfectly fitted considering nagelkerke R<sup>2</sup> value (1.00) and as well strongly fitted in respect to Cox and snell R<sup>2</sup> value; 0.75 indicating that, the model is valid. This is in line with [26] that used R<sup>2</sup> values on validating the model generated from logistic regression, on the other hand [31] utilized akaike information criterion (AIC) in selecting the appropriate model for the mortality estimation of seedlings and saplings subterranean termite in eucalyptus plantation. Moreover, Chi-square test of Goodness-of-Fit was used for model validation considering the 25% validation data set. All the independent variables (Age, BA, Dbh and Height) considered in the model showed significant fitting in the model considering the p-values generated. Therefore, the model significantly fit the equation. However, the technique mostly used for developing models for individual tree mortality is logistic regression [30].

#### 5. CONCLUSIONS AND RECOMMENDATION

Findings of this study revealed the following; At the early stage of stand development the mortality could be high possibly due to

mismanagement, deforestation and competition. The independent variables; Dbh, height and age of the stand used in predicting mortality do not show a positive response in terms of mortality of the trees on the research site at present age and sizes but showed positive implication to have future effect to mortality while, the coefficient of basal area showed a negative implication to have future effect on mortality at the time of conducting the research. Model evaluation and validation confirms the use of logistic regression in modeling mortality of the six stands of *E. camaldulensis* as appropriate.

For effective and proper mortality prediction of the stands by age and size distributions, there is a need for establishing permanent sample plots (PSPs) to evaluate future effect and possibility of independent variables on mortality, management of Afaka Plantation is advised to allow the stands to grow beyond their current status, management of Afaka forest reserve should improve on their management practice for instance beating up operation and ensure thorough supervision for the survival of the planted trees of *E. camaldulensis*

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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