Juxtaposing Parameters behind Baobab *Adansonia digitata* Damage Triggered by African Elephant *Loxodonta Africana* in a Mosaic Landscape

[1]Courage Mutema,[2,3]Johannes Machinya, [1]Cuthbert Maravanyika, [1]Mercy Sai, and [4]Steven Long

[1]Zimbabwe Parks and Wildlife Management Authority, Corner Borrowdale Road/ Sandringham Drive, P.O Box CY140, Causeway, Harare

[2]H&J Consultancy, Harare

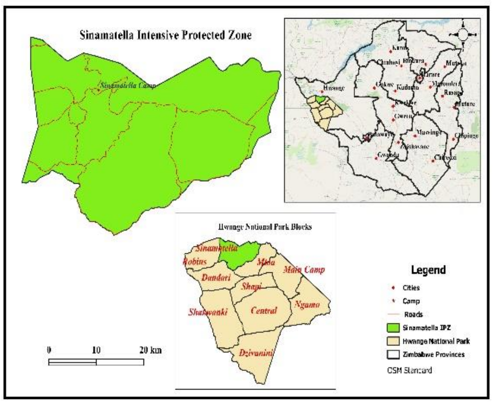
[3]University of Notre Dame, Indiana, USA

[4]Sinamatela IPZ, Hwange National Park, Bag 5009, Hwange

Corresponding Author: cmutema@zimparks.org.zw

Graphical abstract

Sinamatella Intensive Protection Zone (Hwange National Park) and the adjacent Deka Pool (Matetsi Safari Area) of Zimbabwe make up a mosaic landscape critical for wildlife and cultural heritage conservation in Zimbabwe and are part of the Okavango Zambezi Transfrontier Conservation (KAZA) landscape.



Objectives

- *To determine the distribution of Adansonia digitata trees within the Sinamatella and Deka safari areas,*
- *To determine the extent of damage to baobab trees,*
- *To assess parameters explaining Adansonia digitata damage,*

Methods and Data Analysis Approach

- R programming
- *Five machine learning models were used, including Support Vector*

Regression, Ridge Regression, LASSO Regression, Decision Tree Regression, and Random Forest Regression.

Results

- *The Random Forest Regression and Ridge Regression models were the most accurate in estimating the level of elephant damage to baobab trees.*
- *The Random Forest Regression model had an R-squared value of 90.75%, making it the best successful at describing the variation in the response variable.*
- *The most important indicators were distance to a water source, stem circumference at 1.3 m (cm), and long (horizontal) canopy diameter.*

Recommendations

- *There is a need to set up Adansonia digitata refugia areas in protected areas*
- *Elephant populations or densities should be constantly monitored to prevent exceeding ecological carrying capacities*

Abstract

Protected area managers are concerned about the rate at which *Adansonia digitata* trees are being damaged by fires, climate change-induced droughts, human intervention to control tsetse flies, and feeding by other big species, most notably elephants.

This study was carried out in 2023 to enable the development of fresh suggestions to provide park management with science-based, informed preservation and conservation plans to conserve the *Adansonia digitata* trees. The goal of this research was to identify the variables that cause damage to *Adansonia digitata* trees in the Sinamatella and Deka safari zones. The following aims were examined: (1) Determine the distribution and extent of damage to *Adansonia digitata* trees in the Sinamatella and Deka safari zones, and (2) Identify variables that explain *Adansonia digitata* damage.

One hundred and three trees were sampled using a systematic technique along class 1 and 2 highways in each zone. The machine learning models utilized in this work were support vector regression, ridge regression, LASSO regression, decision tree regression, and random forest regression. Random forest regression model performed the best in determining the extent of elephant damage to baobab trees. The random forest regression model explained the most variance in the response variable, with an R-squared value of 90.75%.

This study's major factors were the distance to a water source, stem circumference at 1.3m (cm), and horizontal canopy diameter. These factors play an important role in predicting elephant damage to baobabs.

Recommendations include creating *Adansonia digitata* refugia zones in protected regions and limiting elephant populations or densities to ecological carrying capacity.

Keywords: Land use landscapes, intense protection zone, Adansonia digitata refuges, ecological carrying capacity.

1 INTRODUCTION

The baobab (*Adansonia digitata*) plant is important for conservation in Africa because it is an ecologically significant keystone species (Buchmann et al. 2010; Schumann *et al.* 2010; Symes & Perrin 2004; Wickens & Lowe 2008). Elephants are the only herbivores that have been shown to have a significant impact on the mortality pattern and ecology of Adansonia digitata trees by destroying saplings and causing an accelerated reduction in densities and overall natural populations, resulting in a lack of recruitment (Caughley 1976; Barnes 1980, 1985, 1994; Weyerhaeuser 1985; Edkins *et al*. 2008; Mpofu *et al*. 2012; Sanchez *et al*. 2011; Swanepoel 1993). Drought (De Smedt *et al*. 2012), other herbivores (Mashapa *et al.* 2014), human activities (O'Connor & Campbell 1986), fire (Edkins *et al*. 2008), bush clearing in anti-tsetse fly (Glossina sp.) operations (Tafangenyasha 1997), climate change (Sanchez et al. 2011), and soil type all complicate the impact of elephants on *Adansonia digitata*.

The *Adansonia digitata* species is recognized as one of Africa's most amazing trees, having substantial ecological and commercial importance (Jan-Nan Wan 2020). However, baobab populations are under multiple challenges, including habitat loss, climate change, and changed disturbance regimes. In South Africa's Mapungubwe area, diminishing water levels have been connected to induced baobab recruitment to secure the species' survival. climatic change, including climatic cycles such as the El Nino-Southern Oscillation (ENSO), is disrupting the delicate balance of African savannas, posing a severe danger to baobab populations, growth, and death patterns (Nicholson 2017). Similarly, a study by Jan-Nan Wan et al. (2020) found that the increase in frequency of the ENSO due to climate change is expected to induce drought events and accompanying wildfires in Madagascar, thus decreasing natural vegetation. Thus, knowing how native species in Africa, such as baobab trees, adapt to climate change is crucial for conservation efforts. Previous research has shown that episodic recruitment, in which baobabs regenerate only under rare favorable conditions, makes the baobab population vulnerable to climatic variability (Nicholson 2017; Ndoro *et al*. 2017; Kupika 2014). Ndoro *et al.* (2016) emphasized that environmental pressures and human-caused disturbances, such as elephant effects, are equally important in altering baobab populations.

Elephants rely on a variety of tree species, including *Adansonia digitata*, in most protected areas (Biru & Bekele 2012; Hayward & Zawadzka 2010; O'Connor *et al.* 2007), particularly in times of resource constraint. One of the primary reasons elephants target *Adansonia digitata* trees is their conspicuous nature and emblematic aesthetic appearance (Pamo & Tchamba 2001; Conybeare 2004; GNP 2010), as well as their high nutrient content in calcium and nitrogen (Napier-Bax & Sheldrick 1963). This is exacerbated by elephants' social behavior, which entails indiscriminate tree damage, particularly by male groups (Hofmeyr *et al.* 2007).

In areas with high elephant densities, baobabs were killed both by browsing and by trampling. In a 10-year study in Tanzania, Barnes et al. (1994) found that *Adansonia digitata* populations declined when elephant populations increased and recovered when elephant populations were reduced as a result of poaching. Elephant foraging behavior and its effects on *Adansonia digitata* have been studied in Mana Pools National Park, northern Zimbabwe (Swanepoel 1993; Swanepoel & Swanepoel 1986), and Gonarezhou National Park, southern Zimbabwe (for example, Kupika *et al.* 2014; Mashapa et al. 2014; Mpofu *et al.* 2012). Severe damage to Adansonia digitata may suggest that the elephant population, regardless of its absolute abundance, has already caused significant vegetation changes in an area (Swanepoel & Swanepoel 1986).

The rising African elephant (Loxodonta africana) population in southern Africa influenced the composition and organization of savanna vegetation communities (Mpofu et al. 2012). Few studies have investigated how elephants affect the population structure of keystone tree species such as *Adansonia digitata*. Elephant damage to *Adansonia digitata* trees has been a source of concern for park managers in Hwange National Park, particularly because excessive feeding on flowers, bark, and immature fruit can result in decreased fruit yield, damage to adult trees, and eventual tree death (Department of National Parks and Wildlife Management 1998)

1.1 Aims of the study

The purpose of this study is to identify characteristics that explain the harm caused by *Adansonia digitata* trees in the Sinamatella and Deka safari regions combined. The following aims were investigated: (1) determining the distribution and severity of damage by *Adansonia digitata* trees in the combined Sinamatella and Deka safari area; and (2) determining parameters that explain the damage by *Adansonia digitata.*

2 MATERIALS AND METHODS

2.1 Study area

The study area lies in the northern part of Hwange National Park in Matabeleland North Province, Zimbabwe (Figure 1). The Sinamatella Intensive Protected Zone (located at 18º35′S, 26º29′E) comprises an area of 1 328 km² (as indicated in the Hwange General Management Plan, 2016-2026) and is part of the broader HNP that spans 14 651 km² of semi-arid savannah in Northern Zimbabwe. It is sandwiched between the Robins region (2 679 km^2) to the west and the Main Camp area (10 765 km^2) to the south and east. Sinamatella IPZ is located in Zimbabwe’s Agro-Ecological Region IV. The area receives less than 635 mm of rainfall per year and has recurrent droughts (Hubbard & Haynes 2012). The Lukosi and Inyantue rivers dominate the drainage system, with monthly average temperatures ranging from 24°C in June to 33°C in October (Rogers, 1993).

The vegetation features of the Sinamatella IPZ are primarily determined by geology. The two main rock types found in Sinamatella are basalt and sandstone(Sithole ,1994). The soils that dominate Sinamatella IPZ include escarpment grit and sandy soils made from Karoo sediments that run across the region through ridges and Madumabisa mudstone, or the bottom complex, the decays to a fine and forms the flatlands between the ridges.

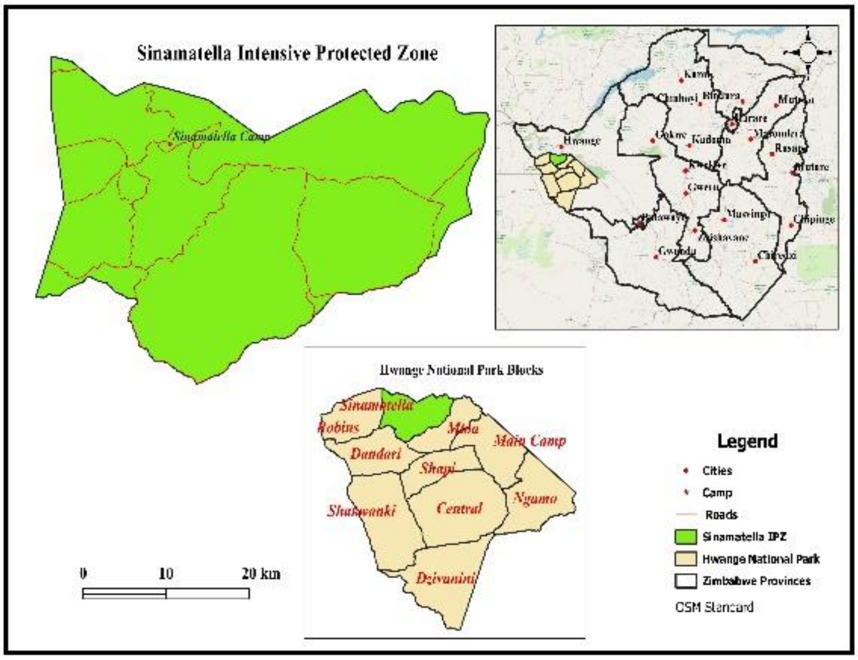


FIGURE 1: Location of Sinamatella IPZ, HNP, Zimbabwe

Diospyros quiloensis and different *Combretum species*, such as *Combretum collinum*, Combretum eleaginoides, and *Combretum apiculatum*, cover the escarpment grit ridges the most. *Colophospermum mopane* dominates the lower Madumabisa mudstones, typically in virtually pure stands but occasionally with *Erythroxylum zambesiacum* and *Diospyros quiloensis. Minor vlei* and riverine vegetation has large trees such as *Faidherbia albida*, as well as patches of *Combretum mossambicense*. The Shumba pans are surrounded by patchy Main Camp flora, which includes *Baikiaea plurijuga* and *Guibourtia coleosperma.*

3 DATA COLLECTION

3.1 Data collection procedure

The data gathering technique involved two groups of five volunteer tourists, each headed by an ecologist who handled the technical lead, moderation, and recording. These groups changed over the winter data gathering period, which ran from April to October 2022. During the summer season at Sinamatella IPZ, roads are impassable, and it is difficult to identify baobab species owing to the abundance of foliage.

Participants were informed about the study's purpose and criteria for measuring or estimating parameters to eliminate redundancy and systematic and random mistakes. The investigation identified the complete population of baobab trees in both non-hunting and hunting zones that had been damaged by elephants. The researchers chose baobab trees from our starting point, Sinamatella Camp, where two groups divided to the east (from Sinamatella IPZ to Deka Safari Area) and south (from Sinamatella IPZ to Mandavu Dam, Masuma Pan, and Shumba Pan). A belt transect was established in research regions using existing photography and sport hunting routes. The researchers meticulously examined and documented essential characteristics for each baobab tree encountered throughout the transect. These characteristics include bark peeling, tusk marks, damaged branches, and uprooted trees. The researchers objectively evaluated characteristics for each tree, such as distance from the permanent water supply, tree height, stem circumference at the base level, stem circumference at the 1.3 m level, long canopy diameter, and small canopy diameter. The level of damage to each selected tree was determined and classified as no damage (0), mildly injured (1), substantially damaged (2), severely damaged (3), and dead tree (4). Following the study by Ndoro *et al*. (2016), each selected baobab tree site was registered into a Garmin Geographical Positioning System (GPS) unit, and the distance from the permanent water source was assessed using a rangefinder.

A standard recording sheet of data captures the date, baobab occurrence zone, group reference, geographic location, and six key parameters: distance to the nearest permanent water source, tree height, stem circumference at the base, stem circumference at 1.3 meters above ground, long canopy diameter, and short canopy diameter. It also includes notes on the degree of damage. The collected data was compiled into a CSV file in Excel for analysis and mapping.

4 DATA ANALYSIS

4.1 Mapping and determining the degree of damage in QGIS

QGIS Version 3.16 was used to map or determine the distribution of baobab trees in the research region (Sinamatella IPZ and HNP's Deka Safari region). The Excel spreadsheet was transformed into a comma-separated values (CSV) file that may be edited and overlayed in a GIS. The mapping depicts the location of individual sample baobabs as well as a color coding indicating the level of damage to each selected tree, which was examined and classified as no damage (0), mildly damaged (1), moderately damaged (2), severely damaged (3), and dead tree (4).

4.2 Correlation and regression data analysis

All data analysis was done using R. For the normality check of the data distribution, a One-Sample Kolmogorov-Smirnov test was conducted, and then data visualization was done using box plots, stem-and-leaf plots, and histograms. **Five machine learning models were implemented in R**: (i) Support Vector Regression, (ii) Ridge Regression, (iii) LASSO Regression Model, (iv) Decision Tree Regression, and (v) Random Forest Regression for predicting and analyzing baobab damage in the Sinamatella IPZ and Deka Safari Area. From these five models, their performance was found to be relatively similar regarding the accuracy of the predicted variables in explaining baobab damage.

4.2.1 Models fitted

The methodology of this study began with outlier detection by Cook's distance leverage analysis to detect which of the data are outliers for selecting appropriate models for analysis. Afterwards, PCA was conducted to determine the number of valid predictors within the dataset; following this, a correlation analysis was performed to detect multicollinearity and select the most proper model for analysis. Pre-development of the machine learning regression models, a structured approach to data acquisition and evaluation was followed. The major steps involved in this process included:

I. Outliers in the data were identified and screened using Cook's distance and outlier leverage analysis to ensure accuracy and prevent extreme values from biasing the study's results.

II. Principal Component Analysis (PCA), a statistical approach, was used to find helpful predictors in the dataset. This strategy decreases dimensionality by breaking down the variables into a smaller collection of uncorrelated components known as principal components.

III. The correlation analysis is very useful to identify the multicollinearity problem, which means if two or more variables of a dataset are highly correlated, then regression analysis will fail. For this reason, it is of essence to identify the problem and take necessary actions before one start designing a regression model

IV. Model selection: Outlier, PCA, and correlation analysis results were used to select a regression model by the researchers.

V. The research methodology with be rely on the following machine learning regression models: the Decision Tree Regression (DTR), Ridge Regression (RR), Random Forest Regression (RFR), Support Vector Regression (SVR), and LASSO Regression (LR).

4.2.2 Model evaluation procedures

This study utilized a variety of performance metrics to evaluate the effective of various regression models on the test data. The performance measures applied by the researchers included the following:

1. Mean squared error (MSE) evaluates the discrepancy between predicted and actual values with lower MSE values suggest better performance.
2. Root Mean Squared Error (RMSE) is determined by taking the square root of the Mean Squared Error (MSE) and measuring it in the same units as that variable. A lower RMSE suggests greater model performance.
3. Mean Absolute Error (MAE) quantifies the average absolute difference between predicted and actual values, with smaller MAE values reflecting better model performance.
4. R-squared (R^2): This metric measures the proportion of variance in the response variable explained by the predictor variables, with higher R^2 values indicating stronger model performance.

5 RESULTS

5.1 Descriptive statistics

Table 1, illustrates the varying impacts of elephant activity on the baobab trees. Whereas 63% of the trees had light damage, 18% were seriously injured, and 17% were either badly damaged or dead. One baobab tree did not appear to have been affected at all. These results indicate that elephants can significantly affect baobab trees, although some trees are more susceptible than others.

TABLE 1: Extent of damage

Degree of Damage	Meaning	Number	Percentage
0	No effect	1	9%
1	Slight	66	63%
2	Moderate	19	18%
3	Severe	18	17%
4	Dead	1	9%

Figure 2 shows a bar chart depicting the extent of baobab damage, Figure 3 shows boxplots for various tree characteristics such as distance to the water source (km), height (m), stem circumference at the base (cm) and top (cm), long (horizontal) canopy diameter, and short (vertical). The boxplots show that outliers exist in variables like as height, long canopy diameter, and short canopy diameter, indicating the necessity for more outlier analysis.

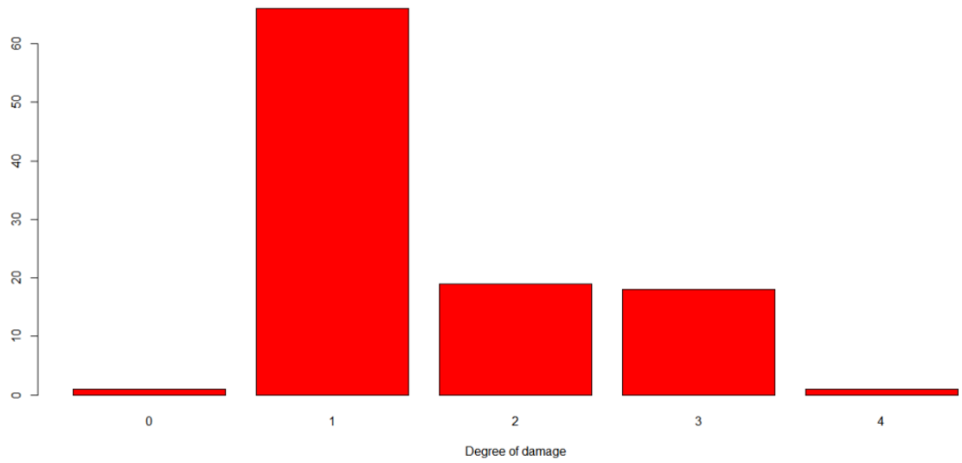


FIGURE 2: Bar plot for Baobab Degree of Damage

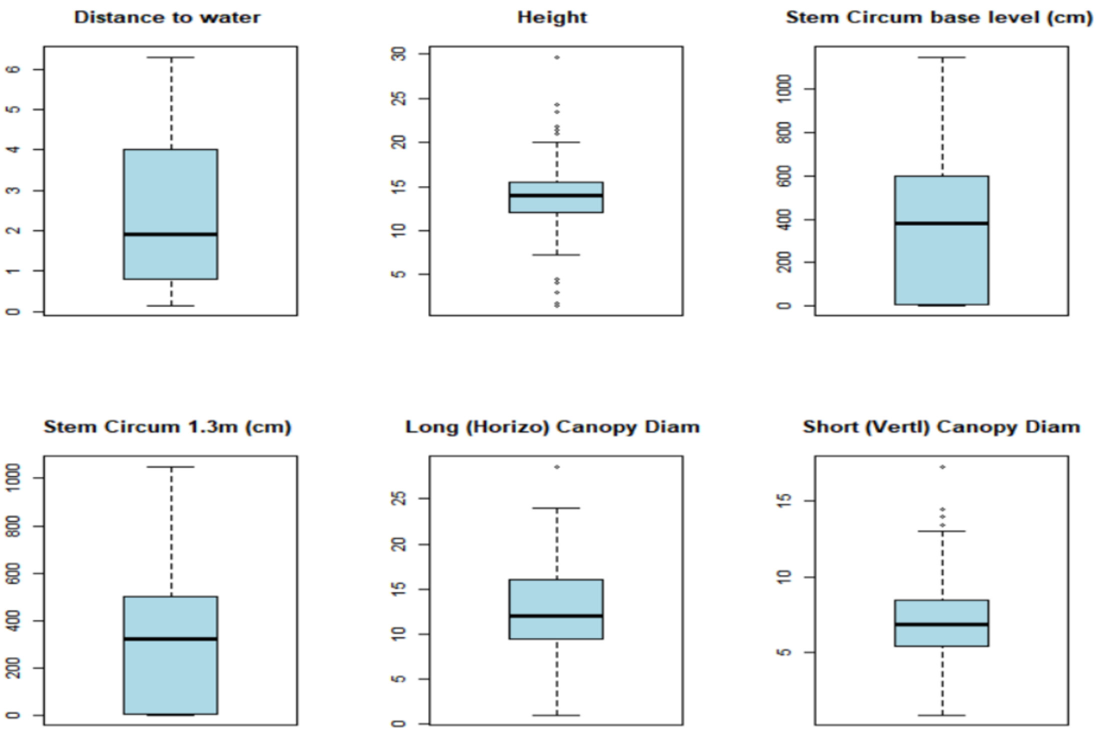


FIGURE 3: Box plots for the predictors

5.2 Determining the distribution and degree of damage of *Adansonia digitata* trees in Sinamatella and Deka Safari area

Figure 4 shows the distribution and mapping of *Adansonia digitata* trees in Sinamatella IPZ and Deka SA.

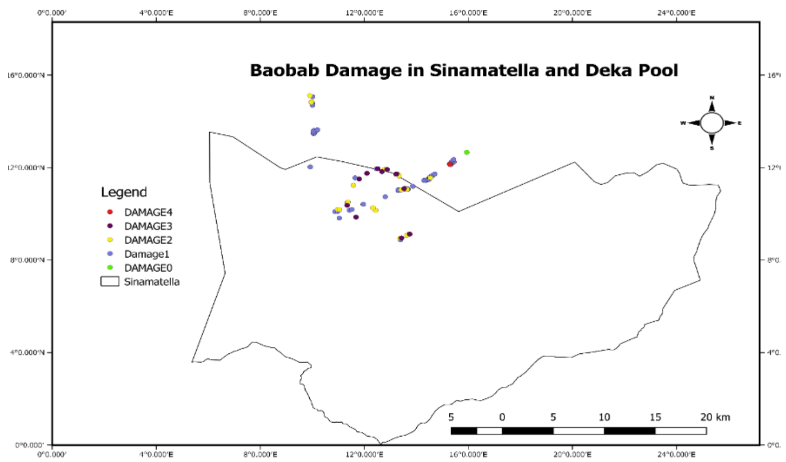


FIGURE 4: The distribution of *Adansonia digitata (baobab)* trees based on the degree of damage in Sinamatella Intensive Protection Zone (IPZ) and the Deka Safari Area

5.3 Principal component analysis

Figure 5 shows a biplot of the analysis' main components. A scale of 0 was used to appropriately scale the arrows, ensuring an accurate portrayal of the primary components' loadings.

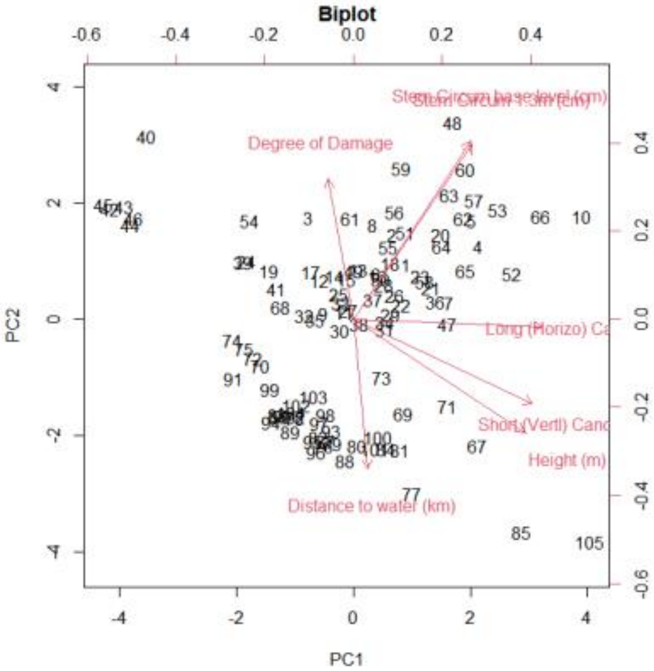


FIGURE 5: Biplot of the primary components in the principal component analysis

The scores on the two main components define the position of each point in the biplot, allowing the dataset's observations to be shown in two dimensions. In the same space, the dataset's variables are represented by arrows, with the length and direction of each arrow indicating the degree and orientation of the variable's effect on the main components.

5.4 Ascertaining parameters explaining *Adansonia digitata* damage

5.4.1 Decision tree

Figure 6 depicts the prediction of the degree of damage using the first four main components, which account for at least 90% of the variance in the dataset. The function returns a summary of the tree structure, including the factors and split points utilized for predictions. The top node, or root, of the tree reflects the whole dataset. Each subsequent node reflects a subset of the data depending on the values of specified predictor variables. The tree's leaves indicate the projected "disp" values for each subgroup in the dataset.

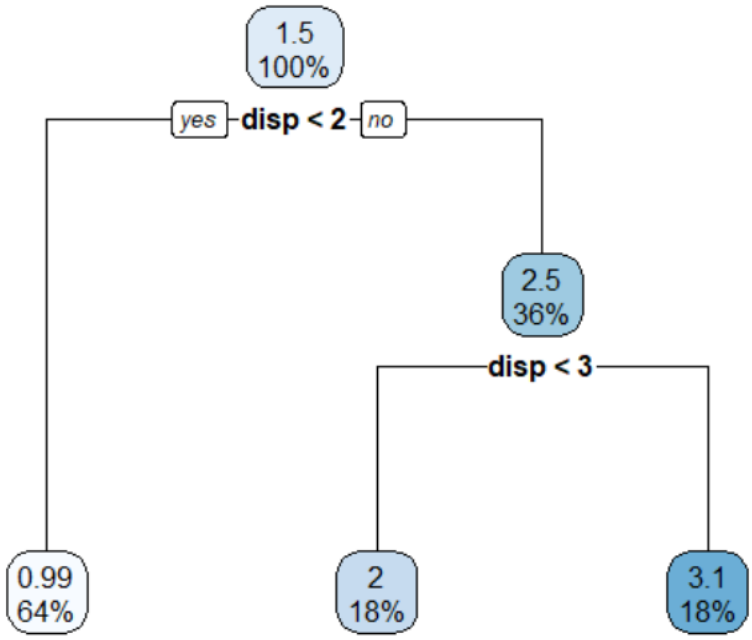


FIGURE 6: Decision tree model for the PCA

Figure 7 illustrate a very strong relationship between the variables "stem circumference" and "stem base," with a correlation coefficient of 0.99, as determined by the correlation matrix. Such variables may serve as redundant predictors for regression, complicating the ability to identify each variable's independent contribution to explaining the response variable. This is a typical difficulty in regression analysis. Potential options include removing one of the highly correlated variables or using regularization techniques like Ridge Regression or LASSO, which were both used in this study.

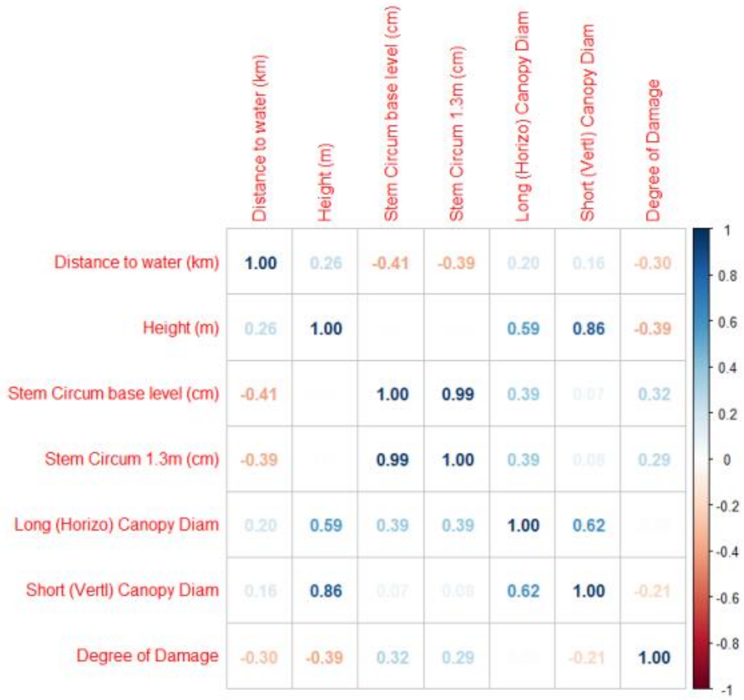


FIGURE 7: Correlation Matrix

5.4.2 Random forest regression model

Figure 8 shows the relative relevance of each predictor variable in the model, with larger values indicating more significance. The graph contains standard error bars for each variable to show the range of significance score estimations. The most important variable is stem circumference at the base (cm), followed by short (vertical) canopy diameter (cm) and long (horizontal) canopy diameter (cm). These characteristics have the greatest bars, suggesting that their significance score estimates are more reliable. In contrast, the variables height (m) and distance to water (km) exhibit lower relevance ratings and narrower error bars, suggesting less significance and greater consistency in their score estimations.

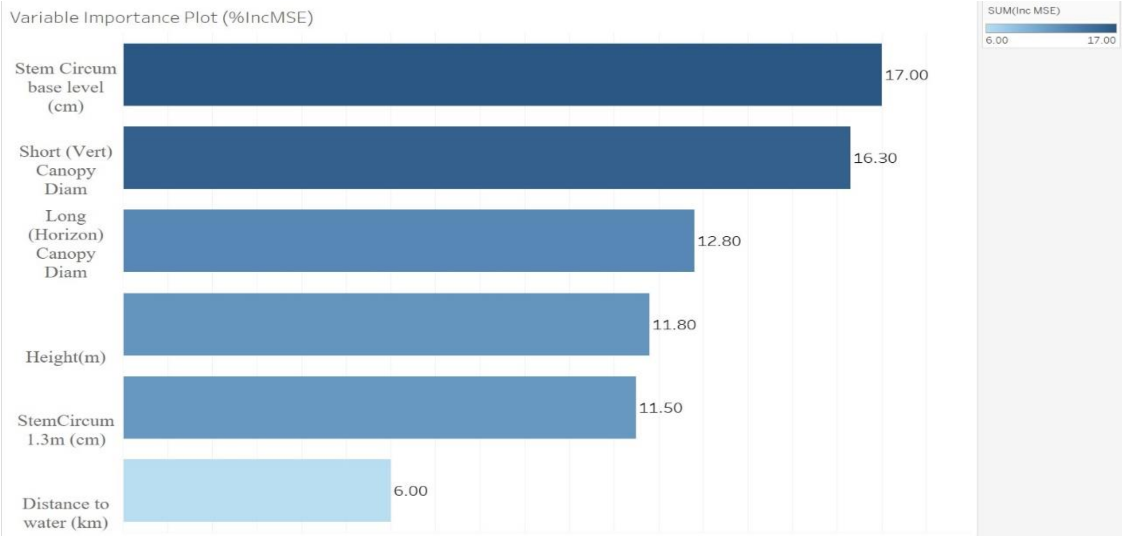


FIGURE 8: Random forest regression model showing the variable importance scores

5.4.3 Comparing the fitted models

Table 2 shows the fitting model metrics. Given that RF earned the greatest R-squared value of 90.75%, the lowest Mean Absolute Error of 21.95%, and the lowest Root Mean Squared Error of 30.42%, it may be considered the best successful model for Damage Severity Prediction. The SVR model performed the poorest among all models, achieving an R-squared value of just 7.51%, a high MAE of 72.21%, and a RMSE of 96.17%.

TABLE 2: Model performance on the test set

Model	R-squared (%)	MAE	RMSE
LR Model	33.21	62.86	81.72
RR Model	64	49	60
SVR Model	7.51	72.21	96.17
RFR Model	90.75	21.95	30.42
DTR Model	64	34.10	51.91

6 DISCUSSIONS

The findings of this study demonstrate that stem circumference at base and 1.3 m (both indicating stem width) are linked to *Adansonia digitata* tree deterioration in Sinamatella IPZ and Deka Safari Area. This collection of findings is consistent with numerous previous studies, including Swanepoel and Swanepoel (1986). The results suggest that elephants tend to preferentially utilize larger baobabs. This interpretation is supported by the significantly higher percentage of larger baobab classes recorded with moderate to severe damage-a result consistent with those of Swanepoel and Swanepoel (1986) but at variance with the findings of Barnes (1980) and Weyerhaeuser (1985), which indicated that elephants showed a preference for smaller baobabs. The utilization by elephants of baobabs in northern Gonarezhou National Park is not viewed to be a serious threat to smaller trees, for example, those with less than 5 meters girth, since there was only one recorded dead small baobab within the study. Areas around permanent water courses, often with difficult access, had a higher percentage of damaged baobabs, especially where the ground was easily accessible for elephants.

This study discovered a substantial link between the level of tree damage and both long horizontal and short canopy diameters. Both canopies and circumferences are connected, therefore (old and mature) wide-circumference trees are more likely to have longer canopies. As such, the two are proxies, implying that this study verifies the previous study's conclusions that elephants prefer huge trees over tiny ones.

The findings contradict Kupika *et al.* (2014), who claim that in Gonarezhou National Park, a higher proportion of elephant-damaged baobabs are found near permanent water sources. However, locations near permanent water sources had greater baobab recruitment and regeneration rates. Edkins *et al.* (2008) also observed a bell-shaped size class distribution at sites further distant from permanent water supplies, indicating limited recruitment. This low recruitment rate may imply that the baobab population in northern Gonarezhou National Park is declining in regions far from water sources. According to Wickens and Lowe (2008), herbivory by animals such as elephants, which consume and destroy baobab seedlings and saplings, can have an effect on recruitment. During field data collecting for the present study, elephants and other big herbivores were also seen grazing in baobab populations.

It has also been proposed that damage to any tree is determined by its proximity to water, elephant population density, and the time of the initial damage, such as early or late in the dry season (Edkins *et al*. 2008). Elephants are more likely to meet baobabs near permanent water sources during the dry season, especially if they are conveniently accessible, before or after drinking. Because fodder is short during the dry season, bark stripping and vegetation degradation are more likely (Brits *et al*. 2002; Gandiwa *et al*. 2011; Gandiwa *et al*. 2012; Mukwashi *et al*. 2012; Swanepoel 1993; Tafangenyasha 1997). In Mana Pools National Park, Zimbabwe, it was concluded that there was high disturbance pressure on baobabs close to water sources, and this seemed to influence baobab abundance and structure (Ndoro *et al.*).

Elephants' influence on vegetation near water sources has been documented in numerous protected areas in African savannas (De Beer *et al.* 2006; Gaugris & Van Rooyen 2010; Gandiwa et al. 2011), and the mechanisms that cause variations in impacts are well recognized (Gandiwa *et al.* 2016, Staub et al. 2013). Brits *et al*. (2002) found that in Kruger National Park, South Africa, shrub density was lower near to water sources and higher farther away, but tree density varied in proportion to distance from water sources. Gandiwa *et al.* (2012) discovered a reduction in wood density near natural water sources, implying forest degradation in Gonarezhou National Park, Zimbabwe.

7 LIMITATIONS OF THIS RESEARCH STUDY

The study highlights the impact of elephants *on Adansonia digitata trees;* however, it is critical to recognize its limitations and the necessity for further research to have a more complete of understanding of this complex subject. The research may have overlooked other significant factors due to the restricted number of predictors included in the models and the inability to obtain data for other variables. For example, critical criteria such as the age of the *Adansonia digitata* trees and the quantity of elephant grazing were not taken into account, despite their possible impact on the degree of damage detected.

8 CONCLUSION AND RECOMMENDATIONS

In conclusion, this study emphasizes the significance of machine learning methodologies in identifying the degree of elephant damage to *Adansonia digitata* trees. This provides valuable insights that are useful for conservation strategies in attempts to conserve *Adansonia digitata* trees and their ecosystems by identifying critical predictors of tree damage.

Adansonia digitata trees are very crucial in supporting elephant survival; the trees provide water reserves in dry periods. Protection of all *Adansonia digitata* trees in the whole Sinamatella IPZ or HNP is impracticable. Conservation efforts shall be directed towards the protection of selected trees at critical areas, such as those along game drive roads, and in and around camps, *Adansonia digitata* refugia, and other tourist hotspots.

Zimparks should consider the following strategies:

I. To ensure the survival of *Adansonia digitatas*, managers should reduce elephant density and confine them to a specific number. The Kruger National Park (KNP) in neighboring South Africa follows similar technique, which means that if the figure of 0.5 elephants per km2 is applied (as appears to be the case for KNP (Whyte et al. 2003), 2 800 elephants are ideal for Sinamatella IPZ, which is around 1 400 km^2.

II. In conjunction with suitable quota setting, it is important to encourage the yearly migration of elephants into buffer zone regions for trophy shooting.

III. Translocation of elephants to receiving protected areas is necessary.

IV. Large culling operations should be performed every 5-10 years. There have been no recent culls in Zimbabwe, in part because the ivory trade prohibition prohibits the selling of slaughtered elephant tusks to cover management and protection expenses (Dunham 2012).

V. Consider monitoring initiatives, such as plots in significant stands of Adansonia digitata. *Adansonia digitata* refugia reserves might be established and maintained at many places, including the Sinamatella Plateau Station and staff housing, Dabashuro Mountain, the Tshakabika Mountain Range, and Bumbusi Camp. To conserve threatened species and ecosystems, zones and elephant-free reserves inside parks have been proposed (Whyte *et al.* 1999; Edkins *et al.* 2008).

Adansonia digitata refugia reserves can assist avoid early dry season fires. Lewis (1987) noticed that elephants migrated out of burnt areas in the early dry season due to a lack of grass feed, and he advocated early dry season burning as a way for repelling elephants from severely damaged locations.

The findings of this research should be followed up by further research into:

i. Exploring the differences in the extent of *Adansonia digitata* damage in two adjacent, different land uses (National Park and Safari Area);

ii. Assessing other factor(s) that cause tree damage (besides the ones explored in this research);

iii. Assessing the impact of various complex factors, such as the presence of Adansonia digitata damage, altitude, proximity to human settlements, and the availability of supplemental feed and roughage; and

iv. Comparing the use, distribution, and population structure of *Adansonia digitata* inside and outside of protected areas in order to evaluate the possibility of species conservation in these regions.

WORKS OF THE AUTHORS

- Conceptualization, data curation, funding acquisition, research, methodology, project management, writing original draft, writing-review & editing, Done by Mutema Courage
- Conceptualization, research, methodology, supervision, initial draft writing, and writing, review, and editing done by Machinya Johannes, Sai Mercy, and Maravanyika Cuthbert
- Funding acquisition and data curation done by Long Steve.

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STATEMENT OF CONFLICT OF INTEREST

No conflicts of interest are disclosed by the writers.

STATEMENT OF DATA AVAILABILITY

The corresponding author can provide the data used to support the study's conclusions upon request. However, due to ethical and privacy constraints, the data are not publicly available.

ORCID

Courage Mutema https://orcid.org/0000-0002-2380-7179

References

Barnes, F.W. (1980), The decline of the baobab tree in Ruaha National Park, Tanzania. *African Journal of Ecology* 18,243-252.

Barnes, R. F. W., K. L. Barnes & E. B. Kapela (1994), The long-term impact of elephant browsing on baobab trees at Msembe, Ruaha National Park, Tanzania. *African Journal of Ecology* 32: 177-184.

Bax, P. N., & Sheldrick, D. L. W. (1963). Some preliminary observations on the food of elephant in the Tsavo Royal National Park (East) of Kenya. *African Journal of Ecology*, 1(1), 40-51.

Ben-Shahar, R. (1998) Changes in structure of savanna woodlands in northern Botswana following the impacts of elephants and fire. *Plant Ecology* 136: 189-194.

Brits, J, Van Rooyen, M.W. and Van Rooyen, N., (2002), Ecological impact of large herbivores on the woody vegetation at selected watering points on the eastern basaltic soils in the Kruger National Park. *African Journal of Ecology*, 40, pp 53-60.

Biru and Bikele (2012), Food habits of African elephant (Loxodonta Africana) in Babile Elephant Sanctuary, *Ethiopia Tropical Ecology* 53(1) January 2012

Buchmann, C., S. Prehsler, A. Hartl, R. Christian & C. R. Vogl. (2010), The importance of baobab (*Adansonia digitata* L.) in rural West African subsistence suggestion of a cautionary approach to International Market Export of Baobab Fruits. *Ecology of Food and Nutrition* 49: 145-172.

Caughley, G. (1976), Plant-Herbivore Systems. In: May, R.M., Ed., *Theoretical Ecology, Blackwell Scientific Publications, Oxford*, 530 p.

Conybeare, A. M. (2004), Elephant impact on vegetation and other biodiversity. In: AWF Four Corners TBNRM Project: *Reviews of Existing Biodiversity Information*.

De Beer, Y., W. Kilian, W. Versfeld & R. J. Van Aarde. (2006), Elephants and low rainfall alter woody vegetation in Etosha National Park, Namibia. *Journal of Arid Environments* 64: 412-421.

De Smedt, S., A. C. Sanchez, N. Van den Bilcke, D. Simbo, G. Potters & R. Samson. (2012) Functional responses of baobab (*Adansonia digitata* L.) seedlings to drought conditions: Differences between western and south-eastern Africa. *Environment & Experimental Botany* 75: 181-187.

Dunham, K. M. (2012), Trends in populations of elephant and other large herbivores in Gonarezhou National Park, Zimbabwe, as revealed by sample aerial surveys. *African Journal of Ecology* 50: 476-488.

Edkins, M. T., L. M., Kruger, K. Harris & J. J. Midgley. (2008), Baobabs and elephants in Kruger National Park: nowhere to hide. *African Journal of Ecology* 46: 119-125

Gandiwa, E., Magwati, T., Zisadza, P., Chinuwo, T. and Tafangenyasha, C., (2011), The impact of African elephants on Acacia tortilis woodland in northern Gonarezhou National Park, Zimbabwe. *Journal of Arid Environments*, 75, pp 809-814.

Gandiwa, E., Tupulu, N., Zisadza-Gandiwa, P. and Muvengwi, J., (2012), Structure and composition of woody vegetation around permanent-artificial and ephemeral natural water points in northern Gonarezhou National Park, Zimbabwe. *Tropical Ecology*, 53(2), pp 169-175.

Gaugris, J. Y. & M. W. Van Rooyen. (2010), Effects of water dependence on the utilization pattern of woody vegetation by elephants in the Tembe Elephant Park, Maputaland, South Africa. *Africa Journal of Ecology* 48: 126-134.

Hofmeyr .G, Mathan N. Bester, Tambu W. Mulaudzi, Pierre A Pistorious (2007), Median pupping date, pup mortality and sex ratio of fur seals at Marion Island. *African Journal of wildlife Research*

Hayward and Zawadzka (2010), Increasing elephant Loxodonta Africana density is a more important driver of change in vegetation condition than rainfall. *Actatheriological* 55(4):289-298 · October 2010

Hubbard, P. & Haynes, G. (2012), Mtoa Ruins, Hwange National Park, Zimbabwe. *Zimbabwean Prehistory*. 30.

Kupika, O. L., S. Kativu, E. Gandiwa & A. Gumbie. (2014), Impact of African elephants on baobab (*Adansonia digitata* L.) population structure in northern Gonarezhou National Park, Zimbabwe. *Tropical Ecology* 55: 159-166.

Lewis, D. M. (1987). Elephant response to early burning in mopane woodland, Zambia. *South African Journal of Wildlife Research*, *17*(2), 33-40.

Mashapa, C., P. Zisadza-Gandiwa, E. Gandiwa& S. Kativu. (2013) Abundance and structure of baobab (*Adansonia digitata*) across various soil group substrate strata in Gonarezhou National Park, southeast Zimbabwe. *International Journal of Biodiversity*. Volume 2013, Article ID 874713.

Mashapa, C., P. Nyabawa, P. Zisadza-Gandiwa, J. Muvengwi, S. Kativu & E. Gandiwa. (2014) Status of African baobab (*Adansonia digitata*) across Gonarezhou National Park, Zimbabwe. *Journal of Applied Sciences and Environmental Management* 18: 139-143.

Mpofu, E., E. Gandiwa, P. Zisadza-Gandiwa & H. Zinhiva. (2012), Abundance, distribution and status of African baobab (*Adansonia digitata* L.) in dry savanna woodlands in southern Gonarezhou National Park, southeast Zimbabwe. *Tropical Ecology* 53: 119-124.

Mukwashi, K., E. Gandiwa& S. Kativu. (2012), Impact of African elephants on Baikiaea plurijuga woodland around natural and artificial watering points in northern Hwange National Park, Zimbabwe. *International Journal of Environmental Sciences* 2: 1355-1368.

Ndoro, O. Mashapa. C, Kativu, S, & Gandiwa. E. (2016), Impact of African elephant on baobab along a surface water availability gradient in Mana Pools National Park, Zimbabwe. *Tropical Ecology* 57 (2): 333-341.

O'Connor, T. G. & B. M. Campbell. (1986), Classification and condition of the vegetation types of the Nyahungwe area on the Lundi River, Gonarezhou National Park, Zimbabwe. *South African Journal of Botany* 52:117- 123.

O'Connor (2007), Climate change and the African baobab (*Adansonia digitata* L.): The need for better conservation strategies. *African Journal of Ecology* 49 (2): 234 - 245 · February 2011

Owen-Smith, R.N., (1988), Mega herbivores: The influence of very large body size on ecology. *Cambridge University Press*, Cambridge

Robertson, I., Loader, N. J., Froyd, C. A., Zambatis, N., Whyte, I., & Woodborne, S. (2006). The potential of the baobab (*Adansonia digitata* L.) as a proxy climate archive. *Applied Geochemistry*, 21(10), 1674-1680.Rogers, C. (1993), *A woody vegetation survey of Hwange National Park. Department of National Parks and Wildlife Management, Harare, Zimbabwe.*

Sanchez, A. C., P. E. Osborne & N. Haq. (2011), Climate change and African baobab (*Adansonia digitata*): the need for better conservation strategies. *African Journal of Ecology* 49: 234-245.

Schumann, K., R. Wittig, A. Thiombiano, U. Becker & K. Hahn. (2010), Impact of land-use type and bark – and leaf-harvesting on population structure and fruit production of the baobab tree (*Adansonia digitata* L.) in a semi-arid savannah. *Forest Ecology and Management* 260: 2035-2044.

Staub, C. G., M. W. Binford & F. R. Stevens. (2013), Elephant herbivory in Majete Wildlife Reserve, Malawi. *African Journal of Ecology* 51: 536-543.

Swanepoel, C. M. & S. M. Swanepoel. (1986), Baobab damage by elephant in the middle Zambezi valley, Zimbabwe. *African Journal of Ecology* 24: 129-132.

Swanepoel, C. M. (1993), Baobab damage in Mana Pools National Park. *African Journal of Ecology* 31: 220-225.

Symes, C. T. & M. R Perrin. (2004), *Breeding biology of the Grey headed Parrot (Poice phalusfusci collissua helicus) in the wild*. Emu 104: 45-57.

Tafengenyasha, C. (1997), Tree loss in Gonarezhou National Park (Zimbabwe) between 1970 and 1983. *Journal of Environmental Management* 49: 355-366.

Tchamba N. M. (2001), The impact of elephant browsing on the vegetation in Waza National Park, Cameroon. *African Journal of Ecology* Volume 33 Issue 3September1995

Thrash, I. & J. F. Derry. (1999), *The nature and modelling of Biospheres: a review*. Koedoe 42: 73-94.

Wickens, G. E. & P. Lowe. (2008), The Baobabs, Pachycauls of Africa, Madagascar and Australia. Kluwer Academic Publishers Group, Dordrecht, The Netherlands.

Weyerhauser, J. (1985), Survey of elephant damage to baobabs in Tanzania's Lake Manyara National Park. *African Journal of Ecology*. 23,235-243.

Evious Mpofu, Edson Gandiwa, Patience Zisadza-Gandiwa and Hardlife Zinhiva (2012), Abundance, distribution and status of African baobab (*Adansonia digitata* L.) in dry savanna woodlands in southern Gonarezhou National Park, southeast Zimbabwe. Tropical Ecology 53(1): 119-124

Jun-Nan Wan et al, (2020). Modeling impacts of climate change on the potential distribution of six endemic baobab species in Madagascar. Plant diversity 43(2021) 117-124.

Kupika, O. L., S. Kativu, E. Gandiwa & A. Gumbie. 2014. Impact of African elephants on baobab (*Adansonia digitata* L.) population structure in northern Gonarezhou National Park, Zimbabwe. Tropical Ecology 55: 159-166.

Nicholson, S.E. (2017). The EI Nino Southern Oscillation and African climate variability. Journal of Climate, 30(10), 3579-3595.

Onias Ndoro, Clayton Mashapa, Shakkie Kativhu and Edson Gandiwa, (2016). Impact of African elephant on baobab along a surface water availability gradient in Mana Pools National Park, Zimbabwe. Tropical Ecology 57(2): 333-341