

ELEPHANT BROWSING IN MAJETE WILDLIFE RESERVE, SOUTH WESTERN
MALAWI

By

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To my parents and my friends in Majete Wildlife Reserve

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The African elephant (*Loxodonta africana*) has a major influence on vegetation structure, composition and ecosystem processes, and is a primary agent of habitat change in Africa. Elephants at moderate to high population densities can damage vegetation, especially when enclosed in protected areas. Knowledge of time- and site-specific factors affecting elephant browsing can be used to forecast future habitat transformations. This study examines the effects of elephant browsing on woody trees with a diameter at breast height of 10 cm and above in Majete Wildlife Reserve (WR), south-western Malawi, where a population of elephants was recently reintroduced after 14 years of absence. The research questions are that given a set of factors known to drive elephant browsing in other areas, which ones have the most influence on browsing at Majete WR, and how are these factors related to browsing in the reserve? Twenty five sampling plots were set up within the three main vegetation types, individual trees with DBH ≥ 10 cm were tagged, browsing was quantified and factors that were potentially associated with browsing were measured. Logistic regression was used to develop a model that identifies factors that influence browsing occurring on trees within the reserve. Twenty four percent of tagged trees had been subject to elephant

browsing. Elephants mostly favored riparian woodlands, followed by *Acacia*-dominated woodland and *Brachystegia*-dominated woodland. Vegetation type, stem diameter and distance from permanent water combined, explained 80% of browsing occurrence. Browsing occurrence was negatively related to distance from permanent water as well as diameter at breast height. Managers should consider these factors to forecast future trajectories of habitat transformation and to manipulate the range of the elephants within the reserve.

CHAPTER 1 INTRODUCTION

Habitat loss and fragmentation are among the most important threats to biodiversity around the world (Myers, 2000, Brooks *et al.*, 2002). The miombo woodlands of south-central Africa are currently experiencing extensive deforestation and land degradation as a result of increased human populations (Walker & Desanker, 2004). Also affected by these changes is the African elephant (*Loxodonta africana* (Blumenbach), whose range in Southern African countries, such as South Africa and Malawi, is now often limited to protected area boundaries (Guldemon & van Aarde, 2008).

Elephants are among the most important agents of vegetation change in African woodlands, especially when their movements are confined (Laws, 1970, Guy, 1976, Cumming *et al.*, 1997, Mapaure & Campbell, 2002, Guldemon & van Aarde, 2008). Elephant activity has a major influence on ecosystem structure and function, primarily on vegetation (Laws, 1970, Barratt & Hall-Martin, 1991, Huntly, 1991, Mapaure & Campbell, 2002, Conybear, 2004). While other herbivores also shape ecosystem structure (van Aarde, 1994), the absolute amount of vegetation consumed per elephant on a daily basis is greater than any other because of their large body size (Owen-Smith, 1988). Elephant's diet is also more varied. They have been found to feed on 146 different plant species in Addo Elephant National Park, South Africa (Kerley *et al.*, 2006). Elephants have also been recorded breaking branches, stripping bark, felling and uprooting trees without consuming them, a phenomenon that has been attributed to social behavior (Hendrichs, 1971).

The effect of elephants on canopy trees is of particular concern (Cumming *et al.*, 1997, Owen-Smith, 1988, Conybeare, 2004). Elephants cause declines and deaths of large trees along with other animal and plant species that depend on the trees (Cumming *et al.*, 1997). Large trees also have important ecosystem functions (Treydte *et al.*, 1997). In semi-arid systems, where water and nutrients often limit vegetation productivity (Scholes, 1990), large trees have better hydraulic lift properties than grasses, thus, shrubs and small trees extract more water and minerals from soils (Ludwig *et al.*, 2003). Their extensive root system stabilizes the soil, preventing soil erosion. Leguminous trees such as *Acacia* species also fix nitrogen, increasing soil fertility (Owen-Smith, 1988). Once felled, mature canopy trees take longer to regenerate than grasses and shrubs and their dominance structure is sometimes altered (Conybeare, 2004). As the canopy layer is thinned, fuel accumulates on the ground, leading to an increase in fire frequency and intensity (van Wyk & Fairall, 1969, Guy, 1989, Mapaure, 2001). This, in turn, may promote the proliferation of browsing-resistant species that may not be favored as much by herbivores (Mapaure, 2001).

A recent rise in elephant densities, coupled with a compression in the size of their home range have made elephants responsible for causing increasing change in associated vegetation structure and composition, and the situation now requires management (Guldemand & van Aarde 2008, Guldemand & van Aarde 2010), especially in South Africa and neighboring Botswana and Zimbabwe, where populations are among the highest in Southern Africa. Long-term population control measures such as translocation and contraception are currently expensive and ethically controversial (Slotow *et al.*, 2008, Lötter *et al.*, 2008, Grobler *et al.*, 2008, Bertschinger *et al.*, 2008).

In Southern Africa, the majority of the budget allocation, donor funding, private investment and other financing mechanisms are directed towards fighting extreme poverty and population density-related issues (UNDP-UNEP, 2010). Under such circumstances, resources for conservation and habitat management are limited, and conservation measures that focus on assessing the risk of habitat conversion, cost of protection and/or biological value are becoming increasingly popular in conservation practice and research (Mills *et al.*, 1993, Pearce *et al.*, 1994, Stephens *et al.*, 2008). Probability-based models are proving especially useful to identify variables that can be used to forecast future trajectories of habitat transformations as well as land use change (Rouget *et al.*, 2003, Newburn *et al.*, 2005, Gude *et al.*, 2007). Identifying the factors associated with elephant browsing in conservation areas could be used to suggest adaptive habitat management options that focus on changing the intensity of landscape use either by preventing access to certain types of vegetation through the use of enclosures (Grant *et al.*, 2008) or by altering the distribution of key resources (e.g. water) both spatially and over time, to direct elephants away from areas that are under too much pressure (Grant *et al.*, 2008).

A number of different site- and time-specific factors, including elevation, proximity to water and vegetation characteristics have been shown to drive the distribution of elephants, and thus their effects on vegetation (Anderson & Walker, 1974, Ben-Shahar, 1993, Campbell *et al.*, 1995, Van de Koppel & Prins, 1998, Chafota, 2007). Elephants are selective feeders and prefer certain plant genera, including *Acacia*, *Colophospermum*, *Brachystegia* and *Adansonia* (Child 1968, Anderson & Walker, 1974, Guy, 1989). The pattern of species distribution, the vegetation type, as well as the

species richness and diversity in an area may therefore potentially have an important influence on elephant browsing characteristics in an area. Vegetation characteristics such as tree density and stem diameter have been reported to influence browsing. In Ruaha National Park, browsing intensity on *Faidherbia albida* decreased with a corresponding decline in tree density (Barnes, 1982). Although elephants have been observed to push over trees up of to 60 cm diameter (Chafota, 2007), they have the tendency to utilize trees that have a diameter of 30 cm or smaller (Laws, 1970). The proximity of certain vegetation types to permanent water has also been associated with an increased susceptibility to elephant browsing, especially in areas where palatable species are present (van Wyk & Fairall, 1969, Conybeare, 1991, Ben-Shahar, 1993, Fullman, 2009). Riparian woodlands tend to be favored for these reasons (Child, 1968, Anderson & Walker, 1974). Finally, elephants tend to avoid climbing and prefer areas where topography is flat, presumably to conserve energy (Whyte *et al.*, 1996).

In Majete Wildlife Reserve, the study site used in this study, elephant browsing is expected to vary according to a number of factors including vegetation characteristics, tree stem diameter, and distance from roads as well as from permanent water. Majete's dominant tree genera such as *Acacia*, *Brachystegia* and *Combretum* have been favored by elephants in different areas (Anderson & Walker, 1974, Barnes, 1982). However, browsing is expected to be highest in riparian woodland, followed by *Acacia*-dominated woodland and *Brachystegia*-dominated woodland, mostly due to water accessibility and topographic differences. Both riparian and *Acacia*-woodland grow at low altitude, riparian vegetation grows along rivers and streams, while *Brachystegia*-woodland grows in the higher, wetter parts of the reserve. Whether elephant browsing varies according

to vegetation species richness and diversity in an area is unclear. However, species richness was expected to be positively associated with browsing, since a higher number of plant species was likely to result in the occurrence of a higher number of favored species. Similarly an increase in species diversity in an area featuring favored species was expected to be subject to more browsing than others. Elephants seek water daily therefore browsing tends to be higher in areas located close to water sources. However, vegetation utilization by elephants does not always decrease with distance from water (Fullman, 2009, Holdo, 2006). Also unclear is whether there is a significant relationship between browsing, distance from the road and tree density. Areas where tree density is low were expected to be more favored than others, since these are presumably easier to navigate through. Elephants were often seen walking along and browsing vegetation along vehicle tracks, particularly during the rainy season, when the vegetation is densest, presumably for the same reason. Browsing was therefore expected to be higher near vehicle tracks than further away. Finally, we assumed that increasing stem diameter would be negatively associated with browsing. Holdo (2006) observed that in Hwange National Park, Zimbabwe, stem diameter was the single strongest predictor of browsing presence. Tall, large trees tend to be hard to break or push over, and their canopy harder to reach by elephants. Although all the above factors have been extensively studied in different areas over the years, research focusing on the relative importance of key variables and their interactions with elephant browsing in different areas is relatively scarce (Holdo, 2006).

The objective of this study is to quantify elephant browsing within a sample of medium to large trees in Majete Wildlife Reserve (hereafter referred to as Majete), in

southwestern Malawi, and examine the occurrence of browsing as a function of key environmental variables known to influence browsing in other areas. The Lower Shire valley at the southern end of the African Rift Valley and where Majete is located is poorly documented in terms of habitat change (Timberlake *et al.*, 2000). Mammal populations in Majete were intensely poached in the 1970's and almost completely wiped out, with elephants disappearing between 1986 and 1992 (Sherry, 1995), but reintroduced beginning in 2003. As part of a joint effort to rehabilitate the area, the African Parks Network and the Department of National Parks of Malawi improved law enforcement, constructed an elephant-proof fence around the reserve and brought animals back from surrounding parks. Two thousand five hundred and fifty of animals including elephants had been reintroduced by 2008. Majete offered an opportunity to analyze and monitor the impact of this new elephant population at the early stage of two years after reintroduction, with a view to identifying the drivers of elephant damage, and managing habitat transformation within the reserve by manipulating the range of the elephants, until an acceptable long-term population control method becomes implemented.

CHAPTER 2 MATERIALS AND METHODS

Study Area

Majete Wildlife Reserve is a 691 km² protected area in the Lower Shire Valley, the southern tip of the African Great Rift Valley in the south-west of Malawi (Figure 1). The Lower Shire Valley is characterized by a semi-arid climate, where annual rainfall (~700 mm per annum), is seasonal and mostly occurs between November and May and average temperature is moderate (~23°C). Altitude in Majete varies from 150 m on the Shire in the East, to 900 m in the West. The soils are Lithosols, shallow, stony, ferruginous and of low fertility, with limited areas of more fertile alluvial soil occurring along some of the rivers (Clarke, 1983). There are two permanent water sources within the reserve; the Shire and Mkurumadzi Rivers, located on the north-eastern border. Five artificial waterholes were constructed between 2003 and 2009, and their locations, along with the major vegetation types, permanent water sources, and sampling plots are shown in Figure 1 (map adapted from Sherry, 1989).

The western part of the reserve, where a series of hills form the western escarpment of the African Rift Valley, is covered by tall, closed Miombo woodland dominated by *Brachystegia* and *Julbernardia* spp. Altitude decreases toward the east, where the vegetation changes into open *Acacia*-dominated mixed woodland, and strips of riparian woodland/thicket association, dominated by *Markhamia obtusifolia*, *Cleistochlamys kirkii* and *Dichrostachys cinerea* growing along the seasonal and permanent water sources. Detailed descriptions of the vegetation were given by Dowsett-Lemaire & Dowsett, (2002). The average elephant density at the time of this study was 0.2 km⁻² (total: 144

elephants, 82 within and 62 outside the sanctuary located in the north east of the reserve).

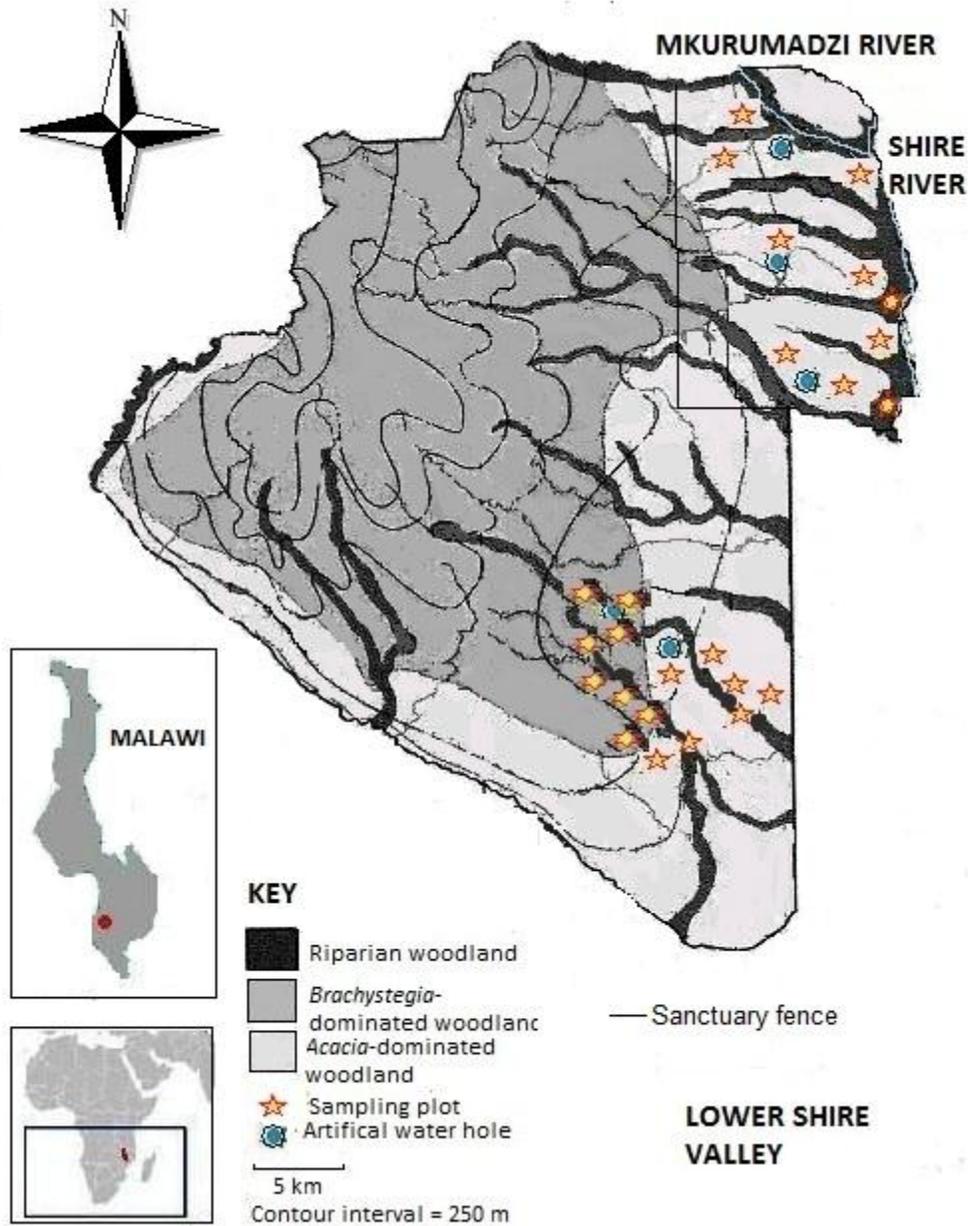


Figure 2-1. Location of Majete Wildlife Reserve and simplified topographic map, showing the location of major vegetation types, permanent water sources, and sampling plots (map adapted from Sherry, 1989).

Measurement of Parameter Variables

Twenty-five 0.1-hectare rectangular plots (20 m x 50 m) were established within the reserve, and measurements (adapted from Dudley, 1993) were taken between June 2008 and May 2009. Plots were distributed within the three major vegetation types and in areas that were accessible from the road. Plot locations were recorded using a hand-held global positioning system (GPS) receiver. Woody trees (DBH \geq 10 cm) were marked with aluminum tags and identified to species. A sketch was produced to show the location of tagged trees within the plots to ensure the same trees could be measured over time. Presence or absence of elephant browsing was determined by inspection. Elephant browsing is distinguished from that caused by other herbivores by the appearance of torn branches (Nellemann *et al.*, 2002, Holdo, 2003).

Major vegetation types were separated into Riparian woodland, *Acacia*-dominated and *Brachystegia*-dominated dry woodland (Dowsett-Lemaire & Dowsett, 2002). The distance from roads and water sources was measured from the center of the plot to the nearest dirt track or the two rivers and the five artificial waterholes. Tree density was measured as the number of live trees (DBH \geq 10 cm) present on the plot. Diameter at breast height (DBH) was the measured circumference at 1.3 m divided by π . Species richness was taken as the total number of woody tree species (DBH \geq 10 cm) within the plot, and species diversity was calculated using the Shannon-Wiener Diversity Index ($H' = -\sum p_i \ln p_i$), where p_i is the proportion of individuals of tree species i to the total number of individuals in the community (Wiener, 1949). Interactions between vegetation types and distance from water were considered to be potentially important factors of elephant browsing and were included in the model.

Statistical Procedure

Stepwise binary logistic regression (SPSS® ver. 17.0) was conducted to identify factors that are related to elephant browsing within the reserve. In this study, the logistic regression model evaluates the influence of a set of independent (predictor) variables on the probability of browsing occurring on trees in Majete. Logistic regression takes the following form:

$$\text{Logit}(p) = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + \dots + b_k X_k$$

Where p represents the probability of browsing presence, b_0 is the intercept, and $b_1, b_2 \dots b_k$ are the coefficients estimated for each independent variable, X_1, X_2, \dots, X_k . First, Pearson's Correlation was used to test independent variables for multicollinearity. High correlation between covariates may potentially inflate standard errors and bias the estimates of logistic regression coefficients, justifying the removal of one of the highly correlated variables from the model (Field, 2005). A threshold level of 0.8 was selected, above which one of the correlated variables was excluded. All predictors were continuous, with the exception of vegetation type which consisted of three categories and was converted into 0-1 dummy variables. Riparian woodland, being the category where most of the browsing was expected to come from, was assigned the non-coded category, while *Brachystegia* woodland (BW) and *Acacia* woodland (AW) were coded dummies 1 and 2 respectively. A two-stage stepwise regression procedure was used to first select model main effects and then to select interactions of those main effects (Meents *et al.*, 1983). A variable was selected if it was statistically significant at $p < 0.05$.

A threshold for the final model was selected to maximize true positives and minimize false negatives. Sensitivity (true positives) is the percentage of trees correctly classified by the model as being browsed while specificity is the percentage of

observations correctly predicted as not being browsed. From the conservation management perspective used in this study, which was to protect habitats from excessive transformation by elephants, the consequences of classifying a tree as 'non browsed' when it had actually been browsed were more serious than those that resulted from classifying a non-browsed tree as 'browsed.' Finally, the model was cross-validated using randomly selected equal size subsets of 'browsed' (170) and 'non-browsed' (170) observations. This was done to ensure that the difference between the number of browsed and non-browsed observations would not bias the coefficient estimates and model predictions (Noon, 1986, Field, 2005).

Model Assessment and Interpretation

We used the model chi-square statistic to determine whether there was a significant improvement in the explanatory power of the model upon the addition of the independent variables, while the log-likelihood statistic provided an estimate of the variance unaccounted for after the model had been fitted (Field, 2005). The Nagelkerke R^2 , a Pseudo Pseudo- R^2 value, was used to assess how well the model fit the data (Field, 2005). A Nagelkerke R^2 value larger than 0.2, which is equivalent to a regular R^2 value of 0.5 suggests a satisfactory model fit R^2 (Domencich & McFadden, 1975, Serneels & Lambin, 2001, Peterson *et al.*, 2009). The presence of potential outliers or influential observations was investigated using standardized residuals, Cook's distance and leverage statistics.

From the resulting model, estimated coefficients provided by the estimated model were used to measure the association of independent variables with browsing (Field 2005). Negative exponential Beta values were inverted to produce values larger than one, which are easier to interpret. Sensitivity, specificity and overall classification

accuracy were used to evaluate the predictive value of the model (Lindenmayer *et al.*, 1992).

CHAPTER 3 RESULTS

Six hundred and ninety-six woody trees with DBH (≥ 10 cm) were measured on 25 plots. 53.5% of browsing was concentrated within Riparian woodland, followed by 39.4% in *Acacia* woodland and 7.06% in *Brachystegia* woodland (Table 2-1).

Table 2-1. Browsing measured in Majete according to vegetation type.

		<i>Acacia</i> woodland	Riparian woodland	<i>Brachystegia</i> woodland	Total
No. of plots		13	6	6	25
Browsing	Absent (0)	195	125	206	526
	Present (1)	67	91	12	170
Total		262	216	218	696

The mean and standard deviation of the numerical independent variables are shown in Table 2-2. All variables were measured for each plot except for diameter at breast height, which was measured on individual trees. All the independent variables displayed multicollinearity, but there were no significant correlations of 0.8 or higher at the 0.05 level of statistical significance (Appendix A).

Table 2-2. Numerical independent variables measured in Majete Wildlife Reserve.

Variable	Mean	S.D
Distance from the road (m)	80.020	6.750
Distance from permanent water (km)	2.129	1.486
Tree density	31.110	1.106
Diameter at breast height (cm)	22.400	1.343
Species richness	10.740	3.567
Species diversity	0.7623	1.809

The model selected vegetation type, distance from water and DBH as significant browsing factors in the reserve (Table 2-3). The interaction between distance to water and both dummy variables were significant but their addition resulted in poorer model fit

and classification (Appendix B, Tables B6-B8). Interaction terms were therefore left out of the final model. The classification probability threshold or cutoff point was manipulated to obtain the highest sensitivity and overall classification accuracy values, and was set to $p=0.25$. Regression diagnostics revealed that 1.9% of observations in the data were potentially influential. These extreme cases were part of the same population as the other cases, so their removal could not be justified and they were left in the final model, which is displayed in Table 2-3.

Table 2-3. Results of the logistic regression.

	Odds	S.E.	$p <$	Exponential Beta	95% C.I. for EXP(B)	
					Lower	Upper
<i>Brachystegia</i> woodland	-2.313	.339	0.0001	.099	.051	.192
DBH_cm	-.026	.008	.001	.975	.959	.990
<i>Acacia</i> Woodland	-.921	.209	0.0001	.398	.264	.600
Dist_fm_water	-.439	.083	.001	.645	.548	.758
Constant	1.075	.274	.002	2.929		

Log likelihood statistic = 640.078, Nagelkerke $R^2 = 0.26$

Classification cutoff value = 0.25. Sensitivity = 80%, specificity = 63.9%, overall model accuracy = 67.8%

Brachystegia woodland (BW), *Acacia* woodland (AW), DBH and distance from water are statistically significant independent variables at $p < 0.05$. The odds are negative for all independent variables, indicating that the likelihood of browsing decreased with a corresponding increase in the selected independent variables. The odds ratio indicates that the odds of browsing increased by 1.5 times per unit in distance from water (1/.645) (Figure 2-2 A). DBH had the smallest effect on the odds, with every unit increase resulting in a drop by a factor of 1.02 (Figure 2-2 B). BW and AW, being dummy variables, are interpreted in comparison with the reference category (Riparian woodland). At the time of the study, a tree was 10.10 times (1/0.099) more likely to be

browsed in Riparian woodland than in *Brachystegia* Woodland. The odds of browsing were also higher for Riparian woodland trees than for those located in *Acacia* woodland, but only by a factor of 2.5 (1/.398).

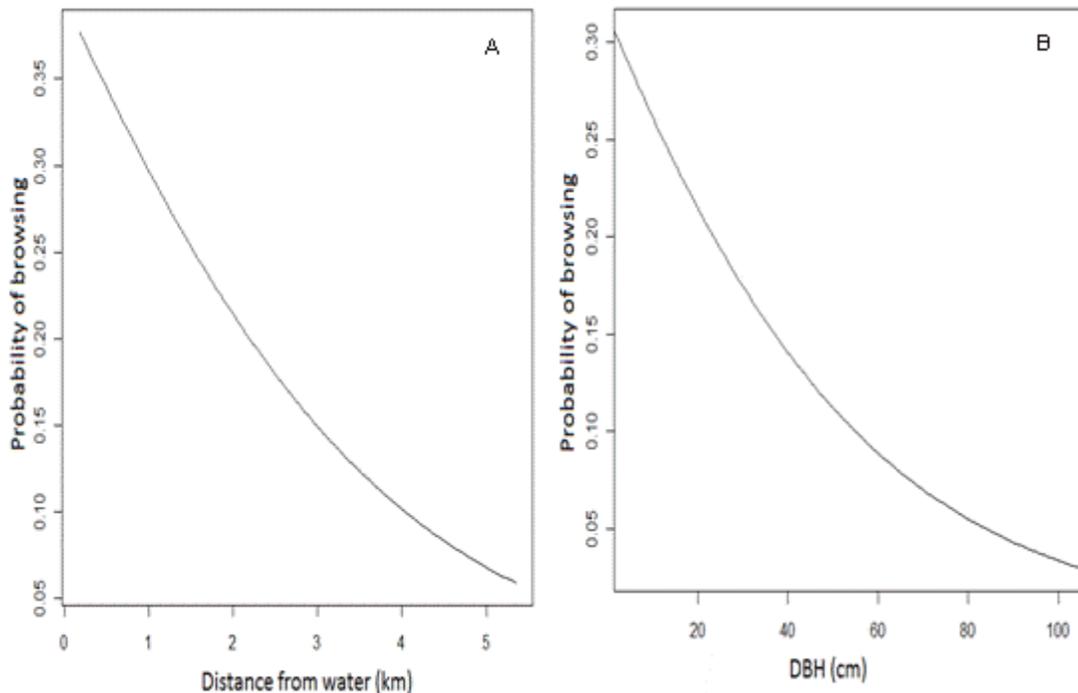


Figure 2-2. Probability of the presence of browsing as a function of distance from permanent water (A), and DBH (B), with all other variables being held constant.

A cross validation operation using randomly selected equal size subsets of 'browsed' and 'non-browsed' observations resulted in model fit values that were similar to the ones produced using the full sample (Nagelkerke $R^2 = 0.278$), and the same four variables were selected (Appendix C, Tables C1-C3), which confirmed the reliability of the model.

CHAPTER 4 DISCUSSION

Two years following their reintroduction, elephant browsing was already high, and probably has an effect on vegetation structure and composition in Majete WR, as has been reported to occur in other areas (Kerley *et al.*, 2008, Anderson & Walker, 1974, Barnes, 1985). The model helped identify and characterize a number of factors that influence the spatial heterogeneity of browsing in the reserve.

An association between browsing and vegetation type within the reserve was clear. Browsing was most concentrated in riparian woodland, where over 50% of the browsing recorded in this study occurred, and least concentrated in *Brachystegia* woodland (7.06%). This was also shown by the logistic regression model, where the addition of vegetation type improved the model by reducing unexplained variance. Numerous studies acknowledge that riparian woodlands, in addition to being located in the proximity of water, are favored for their combination of shade, palatable species and nutrient levels (Child, 1968, Conybeare, 2004, Anderson & Walker, 1974). Second to riparian woodlands, elephants show a preference for *Acacia*- over *Brachystegia*-dominated woodlands. Elephants have been attracted to both these vegetation types in different areas (Anderson & Walker, 1974, Barnes, 1982). This finding may therefore be attributed to species composition, but it may also partly be attributed to topographic relief, which is known to be negatively associated with browsing (Jachmann & Bell, 1985, Whyte *et al.*, 1996, Conybeare, 2004), and/or to the location of permanent water sources, most of which are located within low altitude *Acacia*-dominated woodlands. There was no need for elephants to travel uphill, to *Brachystegia*-dominated woodland in search for water.

My findings also showed that browsing increases with proximity to water, which was already known to be the case, since these animals are water dependent (van Wyk & Fairall, 1969, Conybeare 1991, Ben-Shahar 1993). However, Fullman (2009) reported that in Chobe National Park, Botswana, only one form of utilization (debarking) decreased with distance from Chobe river, while total utilization did not. Furthermore, Holdo (2006) showed that distance to water may not be statistically significant when sampled trees are too far from water. This suggests that in Majete, the sampling plots are located close enough to permanent water sources for water to have an important effect on elephant browsing.

DBH was the fourth and last variable to be selected as having a significant influence on browsing in Majete WR. The model suggests that it has a smaller effect on browsing than the other variables, which is opposite to what occurred in Hwange National Park, Zimbabwe, where stem diameter was found to be the single strongest predictor of browsing presence (Holdo 2006). That result may be due to the difference in the DBH range considered in both studies. Holdo (2006) considered trees with a DBH of 5 cm and below, while we considered a DBH of 10 cm and above. A smaller DBH range may have made a different contribution to the final model. Our study also reports a negative relationship between browsing and stem diameter, which concurs with findings from Laws (1970), but not with Holdo (2006) who found that with trees with DBH (≤ 5 cm), browsing and stem diameter were positively correlated. This suggests that elephants do favor a certain diameter range, and that trees may be rejected for being too small or too large.

The -2 log likelihood value produced in the final model indicated the presence of unexplained variance in the model. This may be explained by the absence of other important variables and/or interactions, and also the presence of the outliers (Holdo 2006). Individual species such as *Acacia tortillis* and *Lonchocarpus bussei*, which appeared to be browsed more than others, should be included in the model to determine whether their relationship with browsing is significant. Elephants are selective feeders and prefer certain plant genera, including *Acacia*, *Colophospermum*, *Brachystegia* and *Adansonia* (Child 1968, Anderson & Walker, 1974, Barnes 1982)

The amount of elephant activity on the plots is also likely to be a significant factor. Another likely contributing factor is prior disturbance (e.g. fire or disease), which has the potential to affect plant palatability, hence their attractiveness to elephants (Bergstrom *et al.*, 2000; Du Toit *et al.*, 1990). In this study, variable interactions caused a decrease in model fit and classification accuracy, which may be due to the tradeoff that sometimes occurs between model complexity and the addition of potentially important variables (Bozdogan, 1987). Other interactions may have resulted in model improvement. For example, an interaction between plot location and the past fire events may have resulted in variations in elephant browsing.

CHAPTER 5 MANAGEMENT APPLICATIONS

Now that we know some of the factors that influence elephant browsing in Majete, it may be possible to alter the intensity at which elephants use the landscape. One way to do that is to modify the scale of vegetation availability. In the 1970's, the home range of the elephants that lived in Majete was reported to be larger than the area now enclosed within the protected area boundaries (Sherry, 1989). As of 2009, up to 130,000 people lived on the perimeter of the reserve¹, therefore extending the elephants range outside the park boundary is not justified because of the risk of human-elephant conflict. However, the Northern part of Majete contains a sanctuary fence that is supposed to be taken down in the future. As a result, elephants will be able to disperse further during the wet season and the sanctuary area would be under less pressure from elephants.

Managers should also consider altering the elephants' access to resources (e.g. vegetation) in certain areas. Since elephant reintroduction is relatively recent, parts of the reserve still experience low levels of browsing relative to others. Elephant-proof vegetation enclosures could be constructed to protect areas of higher biological and or economic value, and act as benchmark sites against which to compare the vegetation in elephant-browsed areas, as was done in Addo Elephant National Park in the 1970s (Moolman & Cowling 1994 cited in Johnson *et al.*, 1999). The third option, which is currently being implemented both in Kruger National Park and Addo Elephant National Park in South Africa, involves altering the distribution of water both spatially and over time, to direct elephants away from areas that are under too much pressure (Grant *et*

¹ Mzumara per. comm., 2009

al., 2008). The Shire River will remain the main source of water for elephants within Majete, but the manipulation of artificial waterholes may prove effective in directing elephants towards certain areas and away from others (more vulnerable) ones, especially during the dry season.

Management should ensure that both quantitative and qualitative measures of elephant browsing are collected over time. Vegetation change should be monitored using a combination of spatial (GIS and remote sensing) and ground vegetation monitoring techniques to obtain results that are representative of browsing in the reserve as a whole, and to identify spatial patterns in landscape use by elephants.

CHAPTER 6 CONCLUSION

Two years after the reintroduction of African elephants in Majete Wildlife reserve, certain areas already show much evidence of browsing on woody trees. Among factors that influence the spatial heterogeneity of browsing within the reserve are vegetation type, distance from permanent water and stem diameter. Elephants show strong preference for riparian woodlands and *Acacia*-dominated woodlands, while *Brachystegia*-dominated woodlands were relatively unaffected. Browsing increased with proximity to water and decreased as a function of stem diameter. A larger number of trees, sampled at random and covering a larger portion of the reserve would provide more reliable estimates of browsing and related factors. A potential association between browsing, individual plant species, prior disturbance and levels of elephant activity may improve our understanding of elephant browsing patterns in Majete. A short term management strategy that this study could be used to develop involves manipulating the intensity of landscape use by elephants, either by preventing access to certain types of vegetation through the use of enclosures or by altering the distribution of key resources both spatially and over time.

APPENDIX A
CORRELATION MATRIX

Table A-1. Pearson correlation matrix.

	DBH (cm)	Sp_rich	Sp_div	Dist_fm_water (km)	Tree density	Dist_fm_rd (m)	BW	AW
DBH (cm)	1	.003	.089*	-.045	-.133**	-.048	-.168**	.084*
		.934	.020	.240	.000	.203	.000	.027
Sp_rich	.003	1	.339**	.194**	.360**	.009	-.142**	-.424**
			.000	.000	.000	.811	.000	.000
Sp_div	.089*	.339**	1	.305**	-.170**	-.121**	-.258**	.208**
		.020	.000	.000	.000	.001	.000	.000
Dist_fm_water (km)	-.045	.194**	.305**	1	-.020	.072	.392**	-.273**
		.240	.000	.000	.605	.056	.000	.000
Tree density	-.133**	.360**	-.170**	-.020	1	.279**	.293**	-.575**
		.000	.000	.605		.000	.000	.000
Dist_fm_rd (m)	-.048	.009	-.121**	.072	.279**	1	.426**	-.297**
		.203	.811	.001	.000		.000	.000
BW	-.168**	-.142**	-.258**	.392**	.293**	.426**	1	-.525**
		.000	.000	.000	.000	.000		.000
AW	.084*	-.424**	.208**	-.273**	-.575**	-.297**	-.525**	1
		.027	.000	.000	.000	.000	.000	

** . Correlation is significant at the 0.05 level (2-tailed)

* . Correlation is significant at the 0.01 level (1 tailed)

APPENDIX B
LOGISTIC REGRESSION

Table B-1. Logistic regression: data summary.

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	696	100.0
	Missing Cases	0	.0
	Total	696	100.0
Unselected Cases		0	.0
Total		696	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table B-2. Baseline model (intercept only)

			Coefficients	
Iteration		-2 Log likelihood	Constant	
Step 0	1	775.342	-1.023	
	2	773.859	-1.127	
	3	773.858	-1.130	
	4	773.858	-1.130	

a. Constant is included in the model.

b. Initial -2 Log Likelihood: 773.858

c. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Table B-3: Baseline classification table

			Predicted		Percentage Correct
Observed			Browsing		
			.00	1.00	
Step 0	Browsing	.00	526	0	100.0
		1.00	170	0	.0
Overall Percentage					75.6

a. Constant is included in the model.

b. The cut value is .500

Table B-4. Forward stepwise regression including independent variables

		B	S.E.	Df	Sig.	Exp(B)	95% C.I. for EXP(B)	
							Lower	Upper
Step 1 ^a	BW	-2.137	.312	1	.000	.118	.064	.218
	Constant	-.706	.097	1	.000	.494		
Step 2 ^b	Dist_fm_water (km)	-.391	.079	1	.000	.676	.579	.790
	BW	-1.735	.322	1	.000	.176	.094	.332
	Constant	-.077	.154	1	.617	.926		
Step 3 ^c	Dist_fm_water (km)	-.441	.082	1	.000	.643	.548	.756
	BW	-2.182	.335	1	.000	.113	.058	.217
	AW	-.919	.207	1	.000	.399	.266	.598
	Constant	.483	.202	1	.017	1.620		
Step 4 ^d	DBH (cm)	-.026	.008	1	.001	.975	.959	.990
	Dist_fm_water (km)	-.439	.083	1	.000	.645	.548	.758
	BW	-2.313	.339	1	.000	.099	.051	.192
	AW	-.921	.209	1	.000	.398	.264	.600
	Constant	1.075	.274	1	.000	2.929		

a. Variable(s) entered on step 1: Brachystegia.

b. Variable(s) entered on step 2: Dist_fm_water.

c. Variable(s) entered on step 3: LowAltitude.

d. Variable(s) entered on step 4: DBH_cm.

Table B-5. Stepwise regression including variables: model summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	699.559 ^a	.101	.151
2	672.166 ^b	.136	.203
3	651.868 ^b	.161	.240
4	640.078 ^b	.175	.261

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

b. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Table B-6. Forward stepwise regression classification table

	Observed		Predicted		Percentage Correct
			Browsing		
			.00	1.00	
Step 1	Browsing	.00	526	0	100.0
		1.00	170	0	.0
	Overall Percentage				75.6
Step 2	Browsing	.00	526	0	100.0
		1.00	170	0	.0
	Overall Percentage				75.6
Step 3	Browsing	.00	494	32	93.9
		1.00	128	42	24.7
	Overall Percentage				77.0
Step 4	Browsing	.00	482	44	91.6
		1.00	123	47	27.6
	Overall Percentage				76.0

a. The cut value is .500

Table B-7. Model fit statistics following the addition of interaction terms

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	694.818 ^a	.107	.160
2	659.870 ^a	.151	.225
3	646.062 ^a	.168	.250
4	641.792 ^a	.173	.258

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Table B-8. Stepwise logistic regression including interaction terms: classification table

	Observed		Predicted		Percentage Correct
			.00	1.00	
Step 1	Browsing	.00	526	0	100.0
		1.00	170	0	.0
	Overall Percentage				75.6
Step 2	Browsing	.00	526	0	100.0
		1.00	170	0	.0
	Overall Percentage				75.6
Step 3	Browsing	.00	514	12	97.7
		1.00	158	12	7.1
	Overall Percentage				75.6
Step 4	Browsing	.00	505	21	96.0
		1.00	149	21	12.4
	Overall Percentage				75.6

a. The cut value is .500

Table B-9. Stepwise logistic regression including interaction terms: variable selection

		B	S.E.	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
							Lower	Upper
Step 1 ^a	BW by Dist_fm_water (km)	-.836	.144	1	.000	.433	.327	.575
	Constant	-.728	.096	1	.000	.483		
Step 2 ^b	BW by Dist_fm_water (km)	-1.014	.157	1	.000	.363	.267	.494
	Dist_fm_water (km) by AW	-.597	.120	1	.000	.550	.435	.696
	Constant	-.322	.117	1	.006	.725		
Step 3 ^c	DBH (cm)	-.027	.008	1	.001	.973	.958	.988
	BW by Dist_fm_water (km)	-1.083	.163	1	.000	.339	.246	.466
	Dist_fm_water (km) by AW	-.620	.121	1	.000	.538	.425	.681
	Constant	.318	.215	1	.138	1.375		
Step 4 ^d	DBH (cm)	-.026	.008	1	.001	.974	.959	.989
	BW by Dist_fm_water (km)	-1.020	.172	1	.000	.361	.257	.506
	Dist_fm_water (km)	-.176	.086	1	.041	.839	.709	.993
	Dist_fm_water (km) by AW	-.575	.129	1	.000	.563	.437	.725
	Constant	.535	.241	1	.026	1.708		

APPENDIX C
CROSS VALIDATION

Table C-1. Cross validation model summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	391.973 ^a	.208	.278

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Table C-2. Cross validation model classification table

Observed		Predicted Selected Cases ^a Browsing			Unselected Cases ^b Browsing			
				Percentage Correct			Percentage Correct	
Step 1	Browsing	.00	105	65	61.8	233	123	65.4
		1.00	36	134	78.8	0	0	.
Overall Percentage					70.3			65.4

a. Selected cases Filter_0 EQ 1

b. Unselected cases Filter_0 NE 1

c. The cut value is .500

Table C-3. Cross validation model variable selection

							95% C.I. for EXP(B)		
	B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper	
Step 1 ^a	DBH_cm	-.027	.009	8.331	1	.004	.973	.955	.991
	Dist_fm_wate	-.428	.097	19.404	1	.000	.652	.539	.789
	r								
	Brachystegia	-2.006	.382	27.576	1	.000	.134	.064	.284
	LowAltitude	-.632	.271	5.451	1	.020	.532	.313	.904
	Constant	2.001	.349	32.792	1	.000	7.394		

a. Variable(s) entered on step 1: DBH_cm, Dist_fm_wate, Brachystegia, LowAltitude.

APPENDIX D
REGRESSION DIAGNOSTICS

Table D-1. Regression diagnostics: model fit statistics

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	620.207 ^a	.189	.282

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Table D-2. Regression diagnostics: classification table

Observed		Predicted		Percentage Correct
		Browsing	1.00	
Step 1	Browsing	.00	336	64.0
	1.00	31	136	81.4
Overall Percentage				68.2

a. The cut value is .250

Table D-3. Regression diagnostics: variable selection

						95% C.I. for EXP(B)		
	B	S.E.	Df	Sig.	Exp(B)	Lower	Upper	
Step 1 ^a	DBH (cm)	-.027	.008	1	.001	.974	.958	.990
	Dist_fm_water (km)	-.446	.084	1	.000	.640	.542	.755
	BW	-2.616	.378	1	.000	.073	.035	.153
	AW	-.931	.210	1	.000	.394	.261	.595
	Constant	1.117	.278	1	.000	3.056		

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BIOGRAPHICAL SKETCH

Caroline G. Staub received a Bachelor of Science degree in Environmental Biology from Curtin University of Technology, Perth, Western Australia in 2005 and a Master of Science degree in Geography from the University of Florida in the spring of 2011. Her work focuses on the ecological aspects of landscape change in Southern Africa. Prior to pursuing her master's degree, Caroline worked as a wildlife monitoring officer for the African Parks Network (Majete) in Chikwawa, Malawi from 2008 to 2009.