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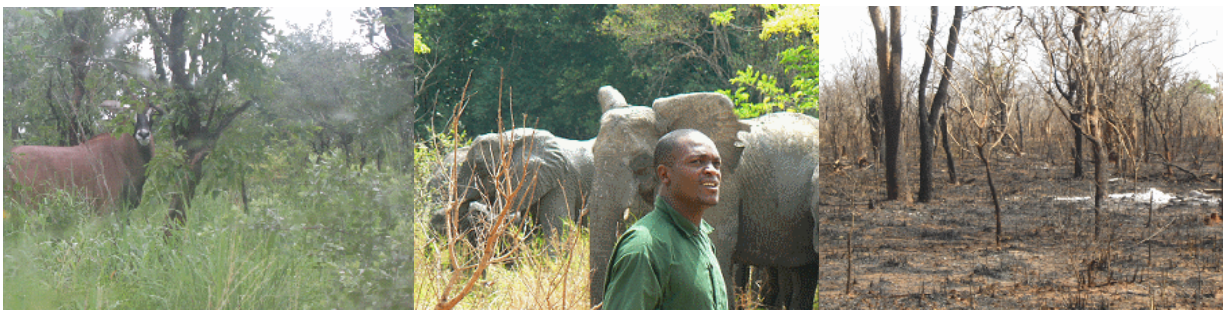

FIRE AND HERBIVORY IMPACTS SAVANNA WOODLAND VEGETATION: SAVING THE LARGEST PROTECTED WOODLAND IN THE GUINEA SAVANNA REGION OF NIGERIA

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Summary of activities

- Impact of fire and its implication on tree species browsed by elephants and other herbivores were investigated including stable fire return interval at the Yankari Game Reserve, Nigeria.
- Yankari Game Reserve is located in Bauchi State, North Eastern region of Nigeria, West Africa.
- Line transect as described by Bibby *et al.* 2000 was employed. Vegetation variables (habitat variables) were measured along a 1000 m transects.
- A total of 80 transects were established and visited in the savanna woodlands.

Summary of key findings

- Fire generally had negative effects on woody plants as compared with herbivory at the Yankari Game Reserve.
- A fire return interval of three to four years was found suitable for the Yankari Game Reserve.
- Few tree species browsed by elephants and other herbivores were negatively affected by fire. *Combretum glutinosum and Combretum fragrans* were adversely affected by fire which are in turn browsed largely by elephants compared with other woody plants.

1.0 Background

Ecosystems are shrinking at an alarming rate, wildlife is disappearing without significant mitigation measures, and man is the most culpable for it. There is a growing trend in the extent to which ecological systems are experiencing human activities and change in function and structure, this phenomenon is critical to the long term sustainable conservation of biological diversity.

Ecosystems such as Savanna woodlands play considerable role in maintaining the integrity of biological diversity across the globe. Savannas are tropical ecosystems made up of grasslands with scattered trees, occupying 20% of the land surface on earth, 40% percent of Africa and 60% of sub-saharan Africa (Canterbury *et al.*, 2000; Eriksen 2007) with rich and fascinating wildlife. The savanna is also characterized by vegetation cover determined to a large degree by disturbances from fire and herbivory compared with rainfall and soil resources.

Fire acts to limit tree cover through demographic bottleneck, limiting the recruitment of tree wildlings to adulthood. Intense fires cause direct decline in the cover of woody vegetation by killing trees or reducing them to smaller sized classes, while herbivores reduce woody vegetation in which trees are either killed or reduced in size (Andy 1993). Many, particularly large herbivores are adversely affected by the reduction in cover and the quality of browse with elephants having most profound effects. Vegetation modification from woodland to grassland have most often been attributed to the joint action of elephants and fire (Napier and Sheldrick 1963, Lawton and Gough 1970, Barnes 1983b, Pellew 1983 and Leuthold 1996). While elephants can impact large or small trees, fire normally acts to suppress re-establishment of the damaged plants to reproductive heights (Guy 1981, Trollope *et al.* 1998, Jacobs & Biggs 2002a), often acting in conjunction with other browsers (Pellew 1983, Ruess and Halter 1990, Jacobs and Biggs 2002a).

The Yankari Game Reserve is the richest in terms of biodiversity and most popular destination for tourists in Nigeria, and as such, plays a crucial role in the development and promotion of ecotourism in Nigeria. Therefore, any effort aimed at boosting research with a

view to effective and sustainable management of the reserve cannot be overemphasized and should be supported by all and sundry. The reserve management gives priority to operational research. This study is cardinal to the sustainability of the biodiversity of the game reserve given that, it is geared towards investigating the fate of the ecosystem at the prevailing circumstances.

1.1 Justification

This project emanates from curious observation on the population dynamics of mammals and primates of the Yankari Game Reserve where the trees supposedly utilize as food by the animals are set on fire indiscriminately. The fire regime seems to be carried out haphazardly, without any specific patterns. A good number of the tree species in the reserve were observed to be dead, wounded or retarded from the adverse effect of the fire. The first Rufford Small Grant addressed part of this concern raised but left more to be desired. This thought provoking area of biodiversity conservation led to interest in studying the effects of fire on trees utilise by large herbivores as food, mainly elephant herbivory on tree survival in particular. Thus far, few studies have consider this area of Conservation Biology and in particular incorporating aspects of the impact of fire and herbivory on the savanna woodlands of Yankari Game Reserve through bio-mathematical tools. This study will therefore assist in understanding the effects of fire on trees utilize as food by large herbivores such as elephants and reveal the impact of fire and herbivory on the general survival of tree species. This will further strengthened and provide evidence based scientific research for this ecosystem, thereby providing a more acceptable fire regime suitable for effective protection and sustenance of games including the unique natural vegetation of the reserve.

1.2 Aim

The aim of this project is to determine the impact of fire on trees utilize by elephants as food and the effects of elephant herbivory on tree survival including fire return interval at the Yankari Game Reserve, Bauchi State, Nigeria.

1.3 Objectives

This research project set out to achieve the following objectives:

1. To determine the impact of fire on trees utilize by large herbivores (elephants) as food.
2. To correlate the impact of elephant herbivory on trees with those of fire in the first RSG.
3. To assess the effects of herbivory and fire on tree survival using mathematical modeling.
4. To present the findings of this project to the management of the Yankari Game Reserve for possible implementation.

2.0 METHODS

2.1 Study Area

This study was carried out at the Yankari Game Reserve (9°45'N 10°30'E), 100 km South east of Bauchi town in Bauchi state. The reserve covers a total area of 2,244 km², in the east-central part of Nigeria. The reserve records an average rainfall of about 1000 mm per year, which occurs between April and October (Crick and Marshall 1981). Yankari Game Reserve lies within the Sudan Savanna Zone (Geerling 1973) of Nigeria with a vegetation made up of swampy flood plain bordered by patches of forest, gallery forest and riparian forest, woodland Savanna (Crick and Marshall 1981). The Game Reserve was designated and opened as Nigeria's biggest National Park in 1991 (but is now a game reserve). It is the most popular destination for tourists in Nigeria and, as such, plays a crucial role in the development and promotion of ecotourism in Nigeria (Odunlami 2000). The Reserve is bisected by the River Gaji. Common woodland tree species include *Afzelia africana, Burkea africana, Pterocarpus erinaceus, Isoberlina doka, Monotes kestingii, Combretum glutinosum, Detarium microcarpum* and *Anogeissus leiocarpus. Gardenia aqualla* and *Dischrostachis glomerata* are frequent in the shrub layer, while *Hyparrhenia involucrate* and *H. bagirmica* are the dominant grasses. In riparian forest *Khaya senegalensis, Vitex doniana, Acacia sieberiana, Tamarindus indica, Borassus aethiopium* and *Daniella oliveri* are common. Characteristics of Yankari are large monodominant stands of *Pteleopsis habeensis,* which grow in some drier areas along riverbanks, the only place in the country where such stands occur. In the seasonally flooded fadamas, *Ficus* spp. and *Mitragyna* sp. are the dominant trees, while tangles of *Mimosa pigra* dominate the shrub stratum. About 337 species of birds have been recorded (Ezealor 2002). Of these, 130 are resident, 50 are palearctic migrants and the rest are intra-African migrants that move locally within Nigeria and/or Africa. The birds in the reserve include the Saddle-billed Stork (*Ephippiorhynchus senegalensis*), Martial Eagle (*Polemaetus bellicosus*), Abyssinina Ground Hornbill (*Bucorvus abyssinicus*), Narina's Trogon (*Apaloderma narina*) among others (Olokesusi 1990).

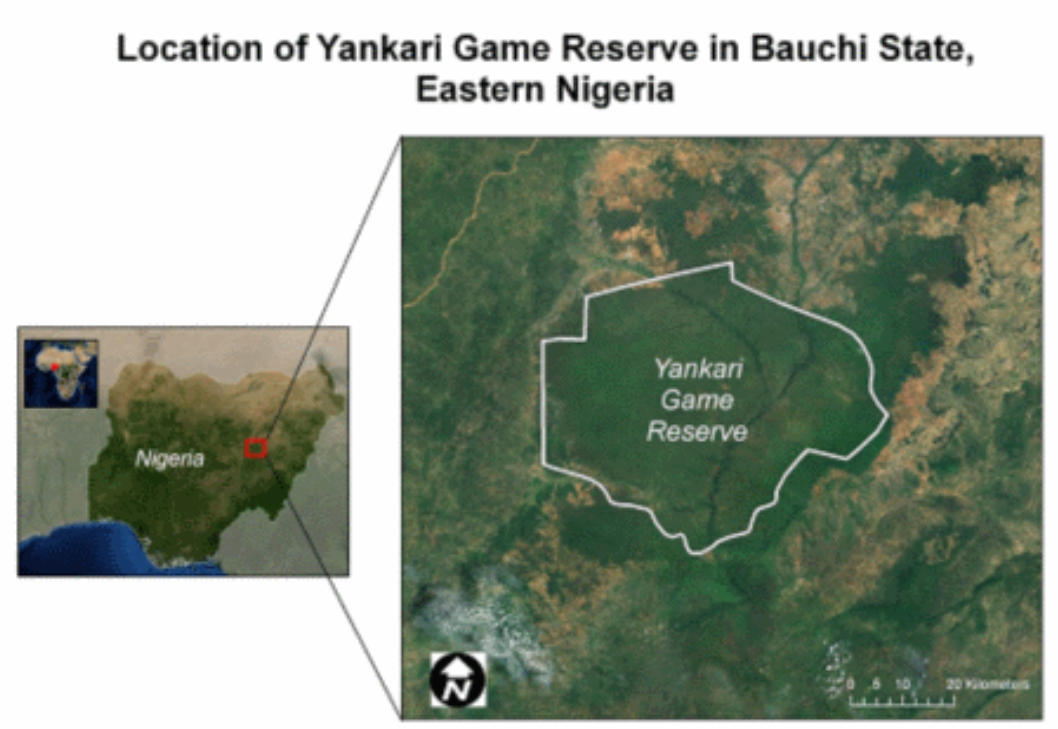


Figure 1. Map of Yankari Game Reserve

2.2 Line Transect

Line transects (Bibby, 2000) was used to record densities of trees and trees utilised as food by elephants. Eighty transects of 1000 m long randomly selected within the reserve used earlier during the first Rufford Small Grant was located in the Savanna woodlands using the GPS.

The following variables were recorded in a 20 x 20m plot at each 100 m section along the transect;

1. size classes of trees base on height,
2. number of stems and DBH,
3. density of browsed trees by Elephants and other herbivores,
4. density of dead trees due to elephant herbivory,

Large herbivores considered in this study alongside Elephant *Loxodonta africana*, include Roan Antelope *Hippotragus equinus*, Bushbuck *Tragelaphus sylvaticus*, Waterbuck *Kobus defassa*, Western Hartebeest *Alcelaphus buselaphus*, African Buffalo *Syncerus caffer*. These large herbivores have a relatively high rate of encounter (Adeiza 2008). While on transect visit, feeding herds of any of the six large herbivores was recorded in order to identify species of trees fed by each group. All the variables were measured within a 20 x 20 m square plot visited during the dry and wet season. Transects were located using GPS to allow for vegetation measurement. Twelve months was used to collect data from the field. Data for the wet season field session began from May 2012 to October 2012 while that of the dry season commenced from November 2012 to April 2013.

2.3 Modeling the Effects of Fire and Herbivory

Preliminary modeling was carried out on aspects of this study. To model the effects of herbivory and fire on the tree community structure, a class structured matrix model was used. Trees were assigned to one of nine size classes based on their height. Trees in the four smallest size classes were assumed to be juveniles and could either grow into the next size class, or die in any given time step. Trees in the five largest size classes were allowed the additional option of remaining in the same size class for more than one time step, and trees in the two largest size classes were considered reproductively mature. For each of these matrices, the probabilities of mortality and survival was changed to include both baseline mortality and mortality from the additional disturbance, either herbivory or herbivory and fire (Baxter and Getz, 2005). All data analyses were carried out using Matlab and Mathematica tools. Findings from this project incorporating elements in the first RSG was presented to the Management and Staff of the Yankari Game Reserve for possible implementation.

Table 1. Height and classification associated with the nine tree size classes (adapted from Baxter and Getz 2005).

Size Class	Classification	Height
1	Seedlings	<15cm
2-5	Saplings	<1m
6	Shrub#1	1-2m
7	Shrub#2	2-3m
8	Tree#1	3-5m
9	Tree#2	>5m

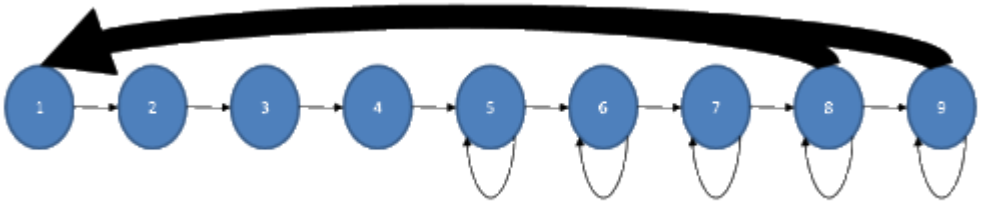


Figure 2. Full matrix with baseline mortality.

Table 2. Diagram of stage structured matrix model showing possible transitions

	Juveniles	Juveniles	Juveniles	Juveniles	Juveniles	Juveniles	Juveniles	Adults	Adults
Size Class	1	2	3	4	5	6	7	8	9
1	0**	0	0	0	0	0	0	f_8	f_9
2	s_1*t_{1-2}	0**	0	0	0	0	0	0	0
3	0	s_2*t_{2-3}	0**	0	0	0	0	0	0
4	0	0	s_3*t_{3-4}	0**	0	0	0	0	0
5	0	0	0	s_4*t_{4-5}	$s_5*(1-t_{5-6})$	0	0	0	0
6	0	0	0	0	s_5*t_{5-6}	$s_6*(1-t_{6-7})$	0	0	0
7	0	0	0	0	0	s_6*t_{6-7}	$s_7*(1-t_{7-8})$	0	0
8	0	0	0	0	0	0	s_7*t_{7-8}	$s_8*(1-t_{8-9})$	0
9	0	0	0	0	0	0	0	s_8*t_{8-9}	s_9

s_x = probability of survival in stage x

f_x = fecundity of adults in stage x

t_{x-x+1} = probability of transitioning from stage x to stage $x+1$

** = zero probability of remaining in size class

2.4 Seasonality

Because Nigeria and particularly the Yankari game reserve experiences two clear seasons (Baxter and Getz 2005), seasonality was incorporated into the model using a six-month time step. It was base on the assumption that during the wet season elephants graze exclusively on grass and that water levels are high enough to prevent fire from occurring. Thus, during the wet season, we include only "natural" mortality (mortality in the absence of herbivory and fire) in the model. During the dry season, it was assumed that the grass is no longer adequate to support the dietary needs of elephants, and that elephants browse exclusively on trees to compensate for the loss of grasses. Fire is also made possible during the dry season by very low moisture levels and high levels of residual dry matter (RDM). Thus, during the dry season, we include either (1) natural mortality and mortality from herbivory, or (2) natural mortality, mortality from herbivory and mortality from fire Appendix 1.

3.0 RESULTS

3.1 Tree species fed by elephants and other large herbivores.

A total of 30 tree species were identified to have been browsed by elephants and other herbivores in this study. Of the 30 tree species, data generally showed that density of the following were browsed more frequently and in high density by elephants and other large herbivores; *Anogeissus leiocarpus (ANLC), Burkea africana(BKAF), Balanites aegyptiaca(BLAG), Combretum fragrans(CMFG), Combretum glutinosum(CMGT) Commiphora pendunculata(CPPD), Detarium microcarpum(DTMC), Feretia apodanthera(FRAD), Grewia erubescens(GRSN), Grewia mollis(GWML), Pteleopsis suberosa(PTSB), Taminalia glaucescens(TMGL)* (Figure 3).

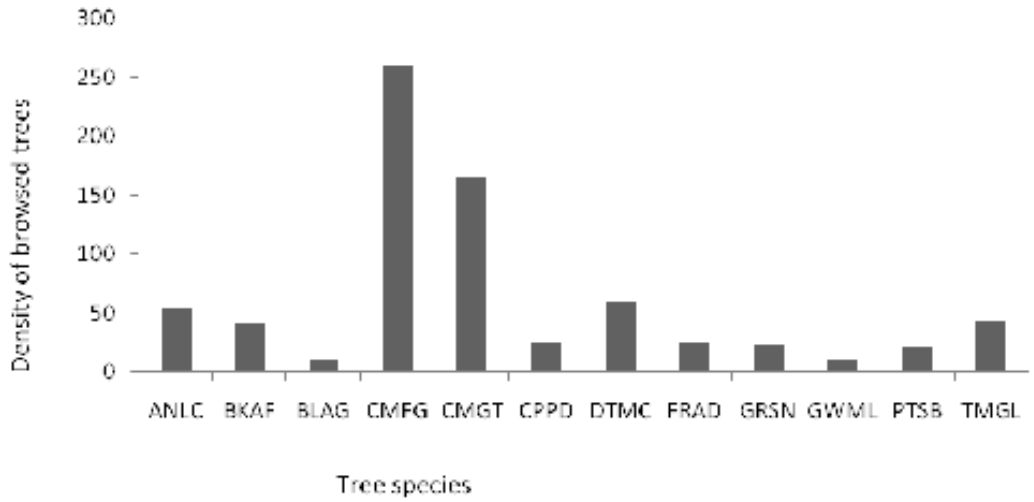


Figure 3. Density of tree species frequently browsed by elephants and other herbivores. *Anogeissus leiocarpus (ANLC), Burkea africana(BKAF), Balanites aegyptiaca(BLAG), Combretum fragrans(CMFG), Combretum glutinosum(CMGT) Commiphora pendunculata(CPPD), Detarium microcarpum(DTMC), Feretia apodanthera(FRAD), Grewia erubescens(GRSN), Grewia mollis(GWML), Pteleopsis suberosa(PTSB), Taminalia glaucescens(TMGL)*

3.2 Impact of elephant herbivory and fire on trees

Few trees utilize as food by elephants were correspondingly affected by fire. Effect of fire mirror the image of few trees browsed by herbivores mainly elephants namely *Anogeissus leiocarpus*(ANLC), *Burkea africana*(BKAF), *Balanites aegyptiaca*(BLAG), *Combretum fragrans*(CMFG), *Combretum glutinosum*(CMGT). Other tree species were not affected by fire but are diet of elephants include *Commiphora pendunculata(CPPD), Detarium microcarpum(DTMC), Feretia apodanthera(FRAD), Grewia erubescens(GRSN), Grewia mollis(GWML), Pteleopsis suberosa(PTSB) and Taminalia glaucescens(TMGL)* (Figure 4).

There was a significantly higher density of dead trees caused by fire compared with elephants herbivory (T-test; t=2.3, df=30, p=0.027) (Figure 5).

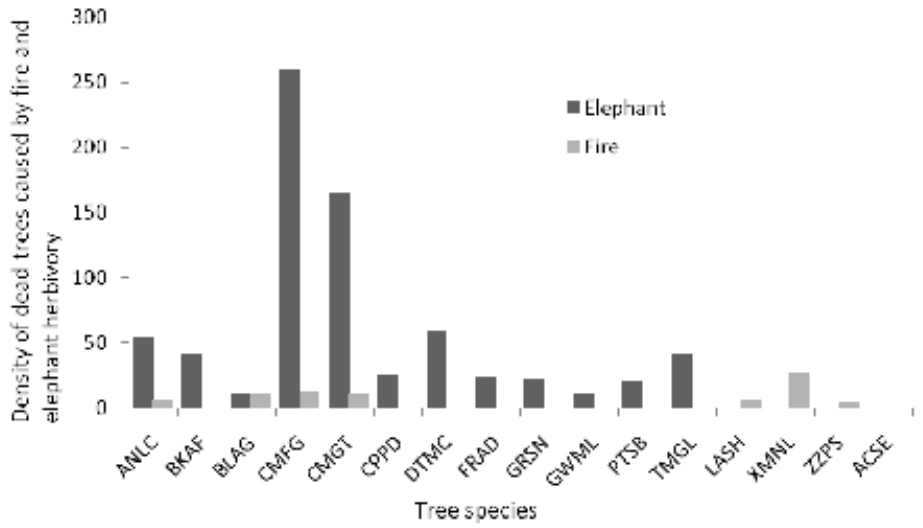


Figure 4. Density of dead trees caused by fire (dark bars) and fed by large herbivores (gray bars). The gray bars also represent dead trees as a result of elephant herbivory.

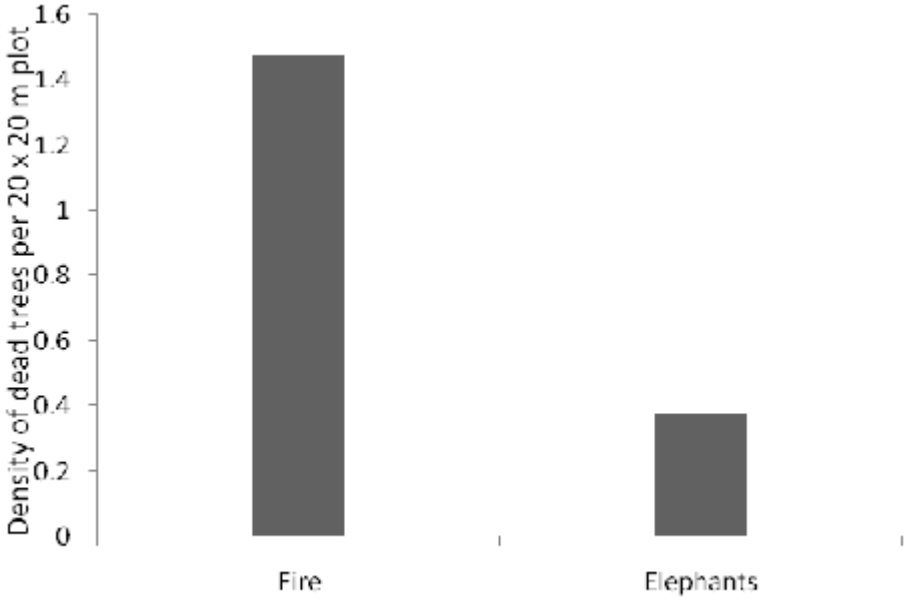


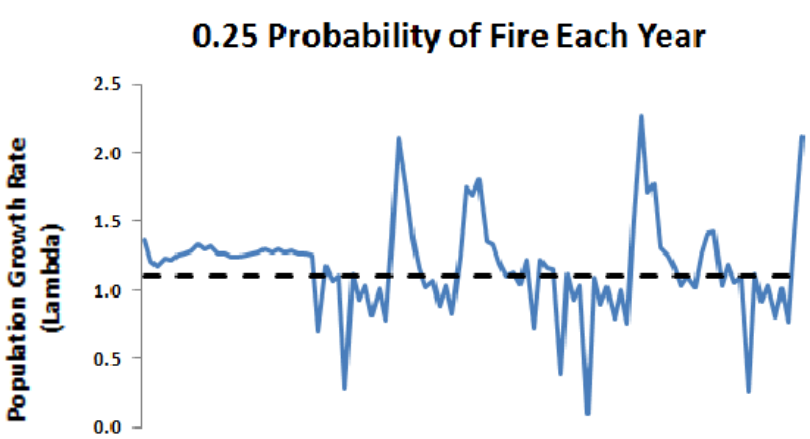
Figure 5. Density of dead trees as a result of fire and elephant herbivory

3.3 Modeling the Impact of Herbivory and Fire on Tree Survival.

3.3.1 Fire Return Interval

This study found out that an average fire return interval of 3-4 years produced an approximately stable population growth rate of 1.0 (Figure 5). Trees in the lower size classes had higher density when compared with higher size classes (Figure 6). Finding from this project has been presented to the management and staff of the Yankari Game Reserve for possible implementation. This collaboration is hoped to be sustained to ensure that this very important game reserve is effectively protected for biodiversity.

5a.



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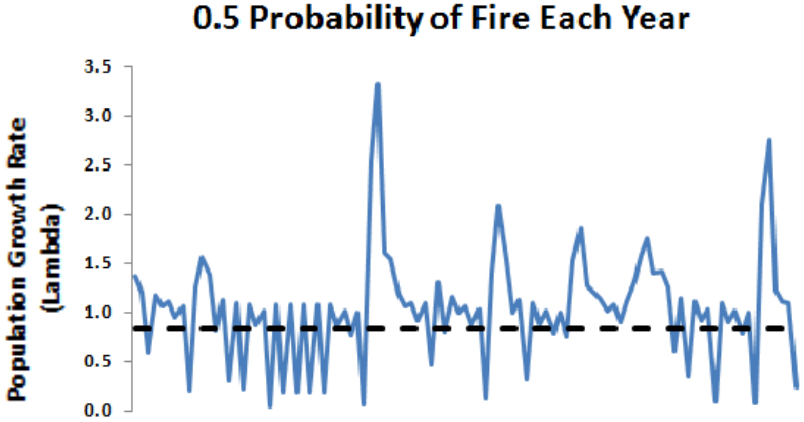

Figure 5. The population growth rate over time for one realization of the model assuming a fire return interval of (a) 4 years and (b) 2 years. Dashed lines show the mean of the population growth rate.

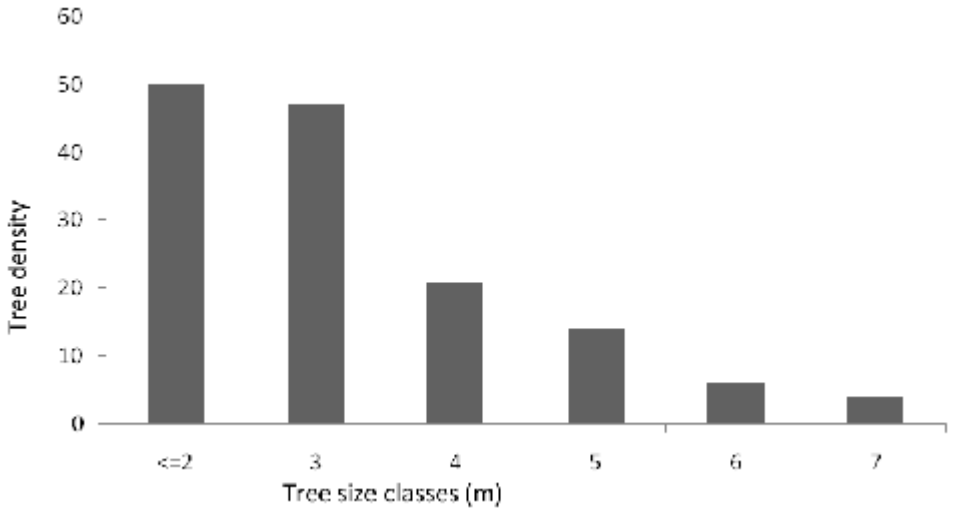

Figure 6. Tree size classes and their corresponding density in a 20 x 20 m plot

3.3.2 Elasticity Analysis

An elasticity analysis showed that survival in the adult size class was the most important factor affecting the average population growth rate.

	Juveniles	Juveniles	Juveniles	Juveniles	Juveniles	Juveniles	Juveniles	Adults	Adults
Size Class									
1	0	0	0	0	0	0	0	0.0630	0.0183
2	0.0815	0	0	0	0	0	0	0	0
3	0	0.0815	0	0	0	0	0	0	0
4	0	0	0.0815	0	0	0	0	0	0
5	0	0	0	0.0815	0.0598	0	0	0	0
6	0	0	0	0	0.0815	0.0693	0	0	0
7	0	0	0	0	0	0.0815	0.0640	0	0
8	0	0	0	0	0	0	0.0815	0.1032	0
9	0	0	0	0	0	0	0	0.0183	0.0349

Figure 4. Elasticity analysis for the parameters

4.0 DISCUSSION AND CONCLUSION

Extensive and frequent fires and herbivory characterized the features of most African savannas (Lawton and Gough 1970, Liedloff 2001, Gandiwa 2011). This study affirms the importance of fire and herbivory as disturbances on the savanna woodland of Yankari Game Reserve, Nigeria. It demonstrates that fire as a phenomenon affects woody vegetation to a large degree in the savanna woodlands when compared with herbivory by elephants and other herbivores. Earlier, fire has been shown to exert adverse effect on trees by reducing their density into different size classes especially for fire in-tolerant species (Gandiwa 2011). Not many tree species are fed by elephants in view of the many species of trees documented for the Yankari Game Reserve (see Geerling 1973, Ezealor 2002). This showed that few tree species are being fed upon by elephants and indeed other herbivores probably due to the effect of fire intensity in reducing or eliminating some tree species browsed by elephants and other herbivores.

Few tree species affected by fire mirror the image of trees fed by elephants and other elephants. Only nearly half of the tree species affected to dead by fire are browsed by elephants and other herbivores. It is possible that the tree species browsed by elephants are shrinking due to effect of fire, considering that this study observed only 30 tree species utilized as food by elephants and other herbivores (appendix 2). Elephants fed more on*, Combretum fragrans*(CMFG)*, Combretum glutinosum* (CMGT) *Anogeissus leiocarpus* (ANLC)*, Burkea africana*(BKAF)*, Detarium microcarpum(DTMC), Taminalia glaucescens(TMGL) and Balanites aegyptica*(BLAG). The two most common tree species recorded as browsed by elephants and other herbivores are *Combretum fragrans and Combretum glutinosum* which happens to be the woody plants affected by fire. Many studies as in this have shown that fire often had greater effect on woody plants than herbivory by elephants and other herbivores (Lawton 1970, Pellew 1983, Ben-Shahar 1998, Gandiwa 2011). Fire intensity restrain the growth and recruitment of small size class trees into larger ones (Turshak *umpublished*, Gandiwa 2011). The Yankari Game Reserve is said to be dominated by the Combrataceous woody plants. This perhaps explains why species of Combretum tops the list of woody plants from the reserve most vulnerable to fire. These results concur with that of Miller & Silander 1999, where fire

also had a significant effect on the vegetation composition and diversity of two species of *Puya* in Paramo, Northern Ecuador, preventing the habitat from attaining its true climax of a forest. The negative effects of fire on woody plants over time could eventually change the vegetation of the reserve, with possible replacement of the present woodlands with alien species (Turshak *Unpublished*).

Although the model used to determine the impact of fire and herbivory was preliminary, some exciting results have been established. Survival of the largest size classes were the most important for population growth rates, which is not surprising given that only these larger classes are able to recruit young plants. The model indicated that fire, in contrast to elephant herbivory, was the most important regulating factor for this ecosystem. Both fires and herbivores can cause mortality and reduce tree size classes (Andy 1993), however fire can suppress the growth of trees to reproductive heights or age (Guy 1981, Trollope et al. 1998, Jacobs & Biggs 2002a). Therefore, the model suggests that this factor appears to be the most important for controlling population growth of savanna trees. This study found out that an average fire return interval of between three and four years produced an approximately stable population growth rate of 1.0. This finding confirm the recommendation made in the earlier first Rufford Small Grant report which recommends a similar fire return for the Yankari Game Reserve. Densities of trees in the smaller size classes were higher perhaps as a result of fire and herbivory disturbances which tends to keep trees perpetually in smaller size classes (Ben-Shahar 1998, Gandiwa 2011).

4.1 Recommendation and conservation action plan

Based on the findings of this study, the following conservation action plans are recommended for possible implementation at the Yankari Game Reserve in order to address conservation issues relating to fire and herbivory on woody plants.

I. Fire return interval may be reviewed. A fire return interval for the Yankari Game Reserve could be reviewed for between three or four years. It is recommended that the early fire regime be practiced as stated earlier in the first rufford grant report. Alternatively, early fire

could be employed to burn parts of the reserve in one season, leaving other parts for another season, this is only necessary for annual burns.

II. The importance of fire breaks throughout the reserve cannot be overempahsised. Creating fire breaks will help to prevent fires set by poachers, hunters and herdsmen that intrude the reserve illegally.

III. A serious attention must be given to patrolling the reserve. Intensifying efforts at patrol will help to ward off illegal activities including illegal fire in the reserve. A close monitoring of the patrolling activities should be carried out to encourage effectiveness.

IV. An educational awareness campaign should be organised for the adjoining communities of the game reserve. This is to inform them of the negative implication of indescriminate setting of fires. Setting up a site support group in the adjoining communiteis may help to put a watchfull eye on illegal activities in the reserve. The importance of local community conservation support group can not be overemphasised.

4.2 Further study

1. Study the effects of fire on woody plants that are utilized by the large herbivores for food and shelter on a long term to predict possible changes that may occur in the future using different models.
2. It may be interesting to study the different macro or micro woodlands within the reserve to determine their role in nutrient cycling as it affects the large herbivores and other animal taxa.

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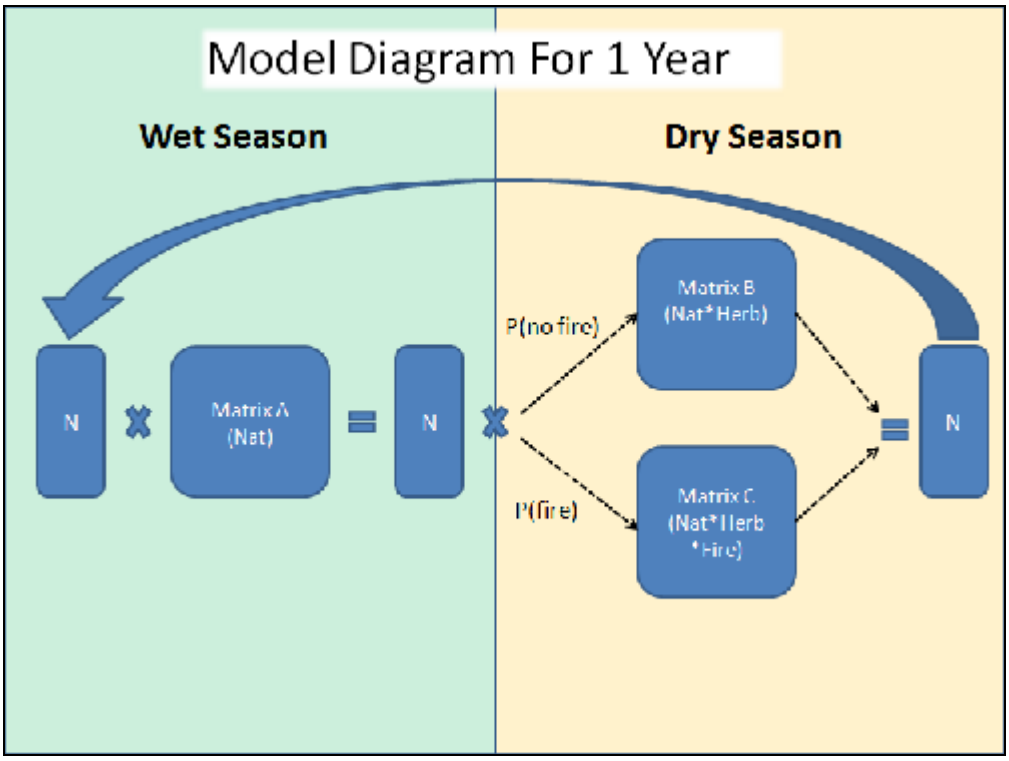
6.0 Appendices

Appendix 1.



Appendix 1. Diagram showing one iteration model. Nat = natural mortality (background mortality with herbivory and fire), Herb = mortality from herbivory by elephants, Fire = mortality from fire, N_0 = starting population size vector, N_W = population size vector during wet season, N_D= population size vector during dry season.

S/N	**Tree species**	**Tree species Code**	**Height**	**DBH**	**Density per 20 x 20 m plot**
1	*Afzelia africana*	AFAF	6	70	8
2	*Anogeissus leiocarpus*	ANLC	6	33	112
3	*Burkea africana*	BKAF	5	31	84
4	*Balanites aegyptiaca*	BLAG	6	48	22
5	*Bombax costatum*	BMCS	8	60	7
6	*Boscia salicifolia*	BSSL	3	21	12
7	*Combretum fragrans*	CMFG	4	18	1070
8	*Combretum glutinosum*	CMGT	4	18	328
9	*combretum molle*	CMML	4	28	6
10	*Commiphora pendunculata*	CPPD	5	30	49
11	*Croton zambezicus*	CTZB	2	7	2
12	*Detarium microcarpum*	DTMC	3	19	131
13	*Feretia apodanthera*	FRAD	3	10	58

Appendix 2. Checklist of tree species commonly utilize by large herbivores at the Yankari game Reserve

14	*Grewia erubescens*	GRSN	3	9	24
15	*Grewia mollis*	GWML	8	11	23
16	*Guira senegalensis*	HXMN	5	26	14
17	*Hymenocardia acida*	HYAC	5	11	10
18	*Lannea schimperi*	LASH	6	52	13
19	*Phyllantus muellerianus*	PHML	3	15	3
20	*Pericopsis laxiflora*	PRLX	3	13	1
21	*Pterocarpus erinaceus*	PTER	5	33	14
22	*Pteleopsis suberosa*	PTSB	3	13	62
23	*Strychnos innocua*	STIN	4	24	2
24	*Strychnos spinosa*	STSP	2	11	1
25	*Sterculia satigera*	STST	4	23	6
26	*Swarzia madagascariensis*	SWMG	4	20	18
27	*Taminalia avicennoides*	TMAV	4	23	7
28	*Taminalia glaucescens*	TMGL	5	24	83
29	*Ximenia americana*	XMAM	3	20	8
30	*Xeromphuis nilotica*	XMNL	5	21	4

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