DOCTOR OF PHILOSOPHY

Process and drivers of vegetation change in African drylands : a case study of Yankari Game Reserve

Fada, Salamatu

Award date:
2015

Awarding institution:
Bangor University

Processes and drivers of vegetation change in African drylands: a case study of Yankari Game Reserve, Nigeria

PRIFYSGOL BANGOR UNIVERSITY

A thesis submitted for the degree of Doctor of Philosophy to

Bangor University

By

Salamatu J Fada

PGCert HE. (2014) Bangor University, M.Sc. (Hons). Environmental and resource planning (2005), B.Sc. Geography (Hons) – University of Jos, Nigeria.

School of Environmental, Natural Resources and Geography, Bangor University,

United Kingdom.

April, 2015

Declaration

Details of the Work

I hereby agree to deposit the following item in the digital repository maintained by Bangor University and/or in any other repository authorized for use by Bangor University.

Author Name:……………………………………………………………………………

Title:………………………………………………………………………………………

Supervisor/Department:..

Funding body (if any):...

Qualification/Degree obtained:……………………………………………………….

This item is a product of my own research endeavours and is covered by the agreement below in which the item is referred to as “the Work”. It is identical in content to that deposited in the Library, subject to point 4 below.

Non-exclusive Rights

Rights granted to the digital repository through this agreement are entirely non-exclusive. I am free to publish the Work in its present version or future versions elsewhere.

I agree that Bangor University may electronically store, copy or translate the Work to any approved medium or format for the purpose of future preservation and accessibility. Bangor University is not under any obligation to reproduce or display the Work in the same formats or resolutions in which it was originally deposited.

Bangor University Digital Repository

I understand that work deposited in the digital repository will be accessible to a wide variety of people and institutions, including automated agents and search engines via the World Wide Web.

I understand that once the Work is deposited, the item and its metadata may be incorporated into public access catalogues or services, national databases of electronic theses and dissertations such as the British Library's EThOS or any service provided by the National Library of Wales.

I understand that the Work may be made available via the National Library of Wales Online Electronic Theses Service under the declared terms and conditions of use (http://www.llgc.org.uk/index.php?id=4676). I agree that as part of this service the National Library of Wales may electronically store, copy or convert the Work to any approved medium or format for the purpose of future preservation and accessibility. The National Library of Wales is not under any obligation to reproduce or display the Work in the same formats or resolutions in which it was originally deposited.

Statement 1:

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless as agreed by the University for approved dual awards.

Signed ………………………………………….. (Candidate)

Date ……………………………………………..

Statement 2:

This thesis is the result of my own investigations, except where otherwise stated. Where correction services have been used, the extent and nature of the correction is clearly marked in a footnote(s).

All other sources are acknowledged by footnotes and/or a bibliography.

Signed ………………………………………… (Candidate)

Date ……………………………………………

Statement 3:

I hereby give consent for my thesis, if accepted, to be available for photocopying, for inter-library loan and for electronic storage (subject to any constraints as defined in statement 4), and for the title and summary to be made available to outside organisations.

Signed ………………………………………… (Candidate)

Date ……………………………………………

NB: Candidates on whose behalf a bar on access has been approved by the Academic Registry should use the following version of **Statement 3:**

Statement 3 (bar):

I hereby give consent for my thesis, if accepted, to be available for photocopying, for inter-library loans and for electronic storage (subject to any constraints as defined in statement 4), after expiry of a bar on access.

Signed …………………………………………… (Candidate)

Date ………………………………………………

Statement 4:

Choose **<u>one</u>** of the following options

a) I agree to deposit an electronic copy of my thesis (the Work) in the Bangor University (BU) Institutional Digital Repository, the British Library ETHOS system, and/or in any other repository authorized for use by Bangor University and where necessary have gained the required permissions for the use of third party material.	
b) I agree to deposit an electronic copy of my thesis (the Work) in the Bangor University (BU) Institutional Digital Repository, the British Library ETHOS system, and/or in any other repository authorized for use by Bangor University when the approved **bar on access** has been lifted.	
c) I agree to submit my thesis (the Work) electronically via Bangor University's e-submission system, however I **opt-out** of the electronic deposit to the Bangor University (BU) Institutional Digital Repository, the British Library ETHOS system, and/or in any other repository authorized for use by Bangor University, due to lack of permissions for use of third party material.	

Options B should only be used if a bar on access has been approved by the University.

In addition to the above I also agree to the following:

1. That I am the author or have the authority of the author(s) to make this agreement and do hereby give Bangor University the right to make available the Work in the way described above.

2. That the electronic copy of the Work deposited in the digital repository and covered by this agreement, is identical in content to the paper copy of the Work deposited in the Bangor University Library, subject to point 4 below.

3. That I have exercised reasonable care to ensure that the Work is original and, to the best of my knowledge, does not breach any laws – including those relating to defamation, libel and copyright.

4. That I have, in instances where the intellectual property of other authors or copyright holders is included in the Work, and where appropriate, gained explicit permission for the inclusion of that material in the Work, and in the electronic form of the Work as accessed through the open access digital repository, *or* that I have identified and removed that material for which adequate and appropriate permission has not been obtained and which will be inaccessible via the digital repository.

5. That Bangor University does not hold any obligation to take legal action on behalf of the Depositor, or other rights holders, in the event of a breach of intellectual property rights, or any other right, in the material deposited.

6. That I will indemnify and keep indemnified Bangor University and the National Library of Wales from and against any loss, liability, claim or damage, including without limitation any related legal fees and court costs (on a full indemnity bases), related to any breach by myself of any term of this agreement.

Signature: ………………………………………………………… Date:

Dedication

To my mum, Leah Audu Nunghe

To my Dad, Late Abdulrahman Jidda

To my children, Vanessa, Jamin, Jabal and Jahleel.

Acknowledgement

I would like to thank the Federal Government of Nigeria; specifically the Tertiary Education Trust Fund (TETFund) and the A.P. Leventis Ornithological Research Institute (APLORI) for funding this study.

Secondly, I want to appreciate the tireless efforts of my supervisors Professor Andrew S. Pullin and Dr James M. Gibbons, for invaluable advice and perseverance during this study. I am also grateful for the GIS manager Andrew J. Packwood for his assistance and support during the course of this study.

During my field trips to Yankari to collect data for this study, I benefitted from tremendous support of Messrs Steven Haruna, Naziru, Yankasta, Musa, Afang, the rangers and staff of Wildlife Conservation Society. I also enjoyed the support and cooperation from the heads of the local communities I worked in. I want to say 'thank you' to all these people.

I will like to thank Prof Julia Jones, Dr Eifiona Thomas-Lane, Dr Anthony Nyong, Dr S.A Manu, Late Dr Tiseer, Dr Matt Hayward, Dr Sophie Williams, Dr Amin Kamate, Dr Joseph Onoja, Dr Mahesh Poudgal, Dr Magnus Uju Amajirionwu and Mr Ian Harris who also advised and supported me during the study.

I am particularly thankful to Rev. Pauline Edwards and the entire AoG church members for being a solid support and prayer partners during this study. Thank you: Enid, Amanda, George, Chukwudi, Bally, Carol, Paulet and Andrew, Steve and Ani, Henri and Kitty, Barbara, Tameka and others that supported me and the children here in Bangor. Thank you to ECWA family in Nigeria who supported me in prayers throughout the study. My daddy, Rev Isaac Laudarji for tirelessly checking on me.

I am heartily grateful to my siblings for their love, support and encouragement during the study. I want to particularly thank three families: Dr, Mrs Jimeta and their beloved children; Group Captain (rtd) Mrs Oyerinde and their lovely children and Dr Hassan Ahmadu Haruna and family, who are the some of the best people I know.

This study also gave me an opportunity of meeting and relating with some amazing people: Haruna and Sarah Moda, Linda Chinangwa, Bilyana Macura, Shereefa Al-salam and Dr Ama Eyo. Thank you for your friendships. I want to say thank you also to Richard and his family, Mrs Inusa and family, Grace, Nate, Malame, Gambo, Victor, Yomi, Nengi, Wale, Monalisa, Moses, and Usman for their friendships.

I am also thankful to my MSL family for their love and prayers, my big brother John Dangwaram for constantly checking on me and for to everyone collectively for being a part of this journey.

Lastly, I want to say thank you especially to Miss Talatu Simon for being there for me and the children, for her love, support, understanding, encouragement. I pray the Lord rewards you abundantly.

Abstract

Despite the large quantity of research on the projected impacts of environmental drivers of change, relatively little is known about the changes in the West African savannah woody vegetation and their drivers. Understanding processes that operate and long term impact of drivers of vegetation change, acting individually or in combination, is vital to enable future mitigation through conservation practices to be successful. This thesis assessed the processes and drivers of vegetation change in the West African savannah, (with particular focus on the role of herders and their livestock) aiming to develop mitigation strategies to increase ecological resilience of the region, using the Yankari Game Reserve of Nigeria (Yankari) as a case study. This study is interdisciplinary, drawing on ecological (tree and shrubs inventories), geospatial (GIS and remote sensing techniques) and social – cultural (focus group discussions, questionnaires, and observations) approaches to collect and analyse relevant data to explore the study questions. Overall, it was found that the woody vegetation of Yankari has changed over time, showing general increase in species of Combretacaea family and decline in fodder species. Additionally, it was found that high variability in annual rainfall, prevalence of droughts, fire scars, prevalence of, and increase in human activities at the boundary of Yankari and 2013 satellite image showed that encroachment has extended into Yankari. Fodder s are harvested in Yankari but the extent of harvest varies by species. (Afzelia africana and Balanites aegyptiaca are severely harvested). Statistically significant relationships were found between core - boundary distance and the harvest rates of A. africana (P = 0.0001), and also, distance impacts significantly on recruitment of fodder treess in Yankari. The herders in Yankari inconsistently reported on the trends in their livestock but had clear knowledge of the preference and availability of fodder trees in their surroundings. Additionally, the study found out that many Fulani and their livestock undertook major migrations to the local communities in the 1980s and 1990s. Herders are aware of the decline in the abundance of fodder trees and have devised temporary migration as a strategy to cope with the situation. This study has provided quantitative evidence of current threats to West African savannah systems. It has also highlighted areas for further investigation as well as showed the need to initiate conservation strategies that will be beneficial for both the local communities as well as the conservation goals for Yankari.

Table of Contents

List of Tables

List of Figures

Abbreviations and acronyms

APLORI	A.P. Leventis Ornithological Research Institute
DBH	Diameter at breast height
CITES	Convention on International Trade in Endangered Species
FAO	Food Agricultural Organization
FGD	Focus group discussion
GIS	Geographic Information System
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
PET	Potential evapotranspiration
PCQM	Point Centre Quarter Method
NIMET	Nigerian Meteorological Agency
NDVI	Normalized Difference Vegetation Index
NWFPS	Non-Wood Forest Products and Services
MEA	Millennium Ecosystem Assessment
MIKE	Monitoring the Illegal Killing of Elephants
MODIS	Moderate Resolution Imaging Spectroradiometer
SLC	Scan line corrector
SCD	Size class distribution
TETFund	Tertiary Education Trust Fund
UNEP	United Nations Environmental Programme
USGS	United States Geologic Survey
WCPA	World Commission on Protected Areas
WCMC	World Conservation Monitoring Centre
WCS	Wildlife Conservation Society

Introduction

1.1 Background to study, aim and research questions

Human interactions with the environment that supports them have had profound impacts in many ways. In the last fifty years, ecosystems have changed more rapidly and extensively compared to any period in human history, with more than 60% of the world's ecosystems degraded (MEA, 2005). Habitat loss and degradation, over-exploitation of natural resources, pollution and disease, introduction of invasive alien species and human-induced climate change have been recognized and reported as the five major threats to global biodiversity (Sala *et al.,* 2000; MEA 2005; Lopoukhine *et al.,* 2012; IUCN, 2014). Humans have modified soils (Tolba *et al.,* 1992; Meyer and Turner 1994), influenced climates (Chase *et al.,* 1999; Houghton *et al.,* 1999; Lambin *et al.,* 2001; Lambin *et al.,* 2003; Foley *et al.,* 2005), have also affected geomorphic processes and changed water quality and quantities (Moore *et., al,* 2009; Goudie 2013).

The inabilities of humans to protect the natural systems have heightened the threats to biodiversity (Secretariat of the Convention on Biological Diversity, 2010). Additionally, in the last century, the global population has quadrupled, unsustainable consumption patterns and rates of natural resources and waste emissions have increased to a point where human consumption is at a faster pace than the Earth can regenerate (Haberl *et al.,* 2007; Wackernagel *et al.,* 2002; WWF, 2010). Furthermore, climate change in the last decade has emerged as the key environmental and developmental concern of the new millennium. Consequently, climate change will exacerbate the other sources of environmental degradation and may generate new threats with devastating consequences for both biodiversity and human welfare, especially for the poorest and most vulnerable communities and nations (Lopoukhine *et al.,* 2012)

Plant life, more than any other component of the environment has suffered the severest impacts from human activities (Goudie, 2013). The structure and functioning of semi-natural and natural ecosystems are negatively impacted, posing danger to diversity of plant and animal species (Bobbink *et al.,* 1998). The nature of land-use and land-cover changes are so pervasive, when summed globally, they have profound impacts on the functioning of key components of the Earth System. Thus human-induced vegetation changes have transformed the very nature of landscapes that support them (Hannah *et al.,* 1994; Goudie, 2013).

The environmental impact of human-induced pressures is dissimilar in both its nature (Behrens *et al.,* 2007; Krausmann *et al.,* 2009; Galli, *et al.,* 2012) and geographic location (Erb *et al.*, 2009; Halpern *et al.*, 2008; Hertwich and Peters, 2009). Consequently the changes may determine, in part, the vulnerability of places and people to climatic, economic or socio-political disturbance (Kasperson *et al.,* 1995; Lambin *et al.,* 2001).

The West African Sudan like other ecological zones in the West African savannah, has suffered from different types of vegetation changes. These changes are probably the result of both natural long-term climatic changes (Nicholson, *et al.,* 1998; Karl 2009) and short-term changes such as high inter-annual rainfall variability (Nicholson, 1981) and the droughts of the early 1970s and the mid-1980s (Wiggins, 1995; Nicolson 2001; Dai *et al.,* 2004). Additionally, the West African Sudan has a long tradition of human use and dependence on natural resources; the effects and influence of humans on natural resources is linked to their agro-pastoral activities. The natural vegetation is often removed partly or completely to give way to cultivation, cattle rearing and wood cutting (Wezel, 2006). Numerous studies have reported the decline in tree cover caused by human activities such as mentioned above (Scholes and Archer 1997; Hoffman, 1999). More recently, the vegetation changes have been documented as a more serious consequence of human activities (Nilsson, 2000; Lambin, 2003; MEA, 2005; Parry, 2007; Goudie, 2013; IPCC, 2014). Nevertheless climatic impacts also pose serious threats to vegetation (Anderson *et al.,* 2004; Veron *et al.,* 2006; Goudie *et al.,* 2013). In turn, vegetation change has profound impacts on the rural livelihoods in many ways (plants have important role as medicinal, food, firewood, local crafts, fodder, Guinko and Pasgo, 1992; Lykke, 1998 Sankaran *et al.,* 2008; Staver *et al.,* 2011). Consequently, the negative impacts in vegetation change are evident in the day-to-day survival of rural people in the West African Sudan Region.

More recently, many studies (for example, Herrmann and Hutchinson, 2005; Lykke 2006; Gaoue and Ticktin, 2009) have explored the perception and indigenous knowledge of rural people to understand the threats and solutions to vegetation changes in the West African savannah. This method has proved beneficial as it provides quick and reliable information at a scale that can range from individual species level (which can be directly used for local resource management (Wezel, 2004)) to habitat information. However most of these studies have been concentrated in the Sahelian West African savannah. Nonetheless in the West African savannah generally, the direct (resource extraction) and indirect (climate warming) anthropogenic activities and the interactions between these threats are complex and poorly understood. The study was therefore necessary and timely for this region.

African nations have established an extensive network of protected areas (WCMC, 2004; Newmark, 2008; Lambi *et al.,* 2012) to minimise threatening human activities. Protected areas are still known to conserve biodiversity especially in West Africa where most of the natural habitats have been converted to farmlands for crop cultivation, urbanization and other uses. Additionally, other common challenges facing West African protected areas are linked to small isolated wildlife populations surrounded by growing human populations, such as human-elephant conflict and human encroachment into the protected areas (IUCN, 2014). Protected areas, if designed appropriately and managed effectively, can make a valuable contribution to overall efforts to address these challenges (Lopoukhine *et al.,* 2012).

The Yankari Game Reserve (Yankari), Nigeria is used as a case study. It is representative of West African savannah. The availability of baseline data collected in Yankari over 26 years ago presents the opportunity to carry out this research. The current study is aimed at assessing the processes and drivers of vegetation change in the West African savannah (with particular focus on the role of herders and their livestock), aiming to develop mitigation strategies to increase ecological resilience of the region. The thesis examines the following key questions:

- What are the ecological changes in woody vegetation of Yankari, Nigeria since 1986?
- What are the trends in drivers of woody vegetation change in Yankari Game Reserve, from the 1980s to 2011?
- To what degree are the observed changes in the fodder plants likely to have been driven by herders 'activities in Yankari?
- What are the experiences and perceptions of herders in the local communities surrounding the reserve, with regards to trends in their herds and abundance of fodder plants?

This study is interdisciplinary. It draws on a combination of the following approaches: ecological (trees and shrubs inventories); geospatial (GIS and remote sensing techniques) and socio – cultural (focus group discussions, questionnaires, and observations). Data collected was analysed using appropriate statistical tools.

1.2 Study area

1.2.1 Brief description of the West African savannah

Savannahs cover up to 20 per cent of the earth's land surface; support an estimated one-fifth of the world's human population and most of its rangeland, livestock and wild herbivore biomass (Scholes and Archer, 1997). The savannah ecosystem is known for its high diversity of large mammals such as elephants, giraffes and many species of antelopes (de Bie, 1991). Both the wild and domestic herbivores are heavily dependent on the woody vegetation as an important source of food (de Bie, 1991; de Bie 1998), but there are seasonal variations in food supply for both grazing and browsing herbivores in the West African savannah.

Furthermore, because, savannahs are defined as having a continuous herbaceous layer, with a discontinuous stratum of disturbance-tolerant woody species (Ratnam *et al.,* 2011), the availability of resources such as water and nutrients, and disturbance regimes such as fire and herbivory (wild and domesticated) are important in regulating the woody cover (Scholes and Archer, 1997; House, *et al.,* 2003; Sankaran *et al.,* 2004).

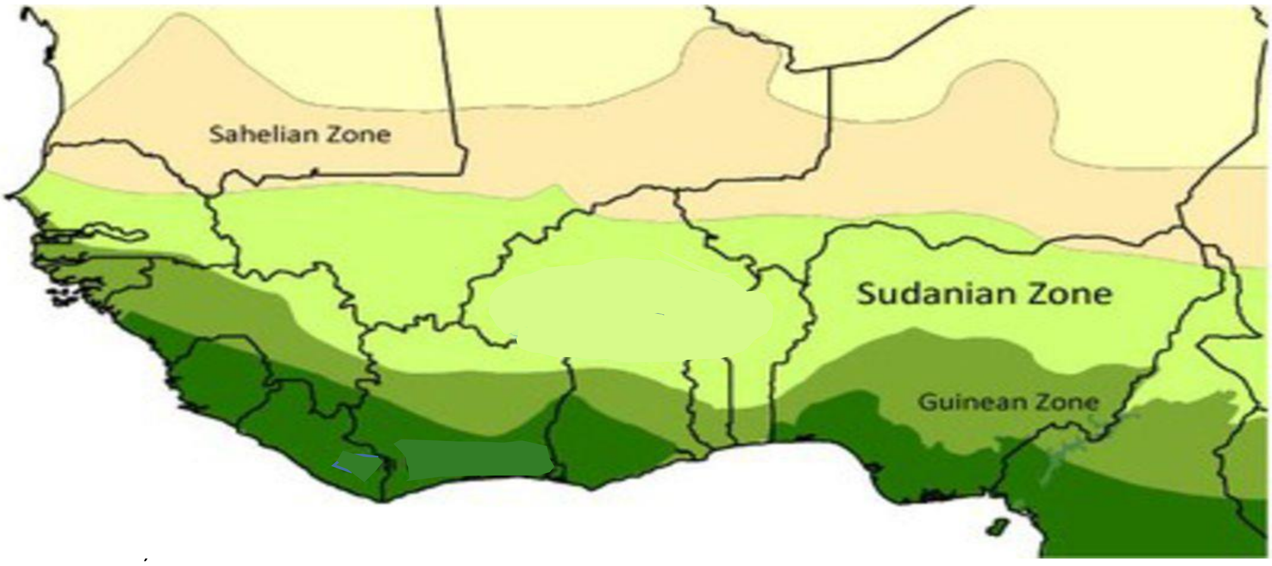


Figure 1.1: Ecological map of West Africa, showing the three savannah zones. Source: Adapted from White, 1983.

The Sahel savannah is characterized by shrubs and thorny tree species with bipinnately compound leaves. The Sudan savannah has tropical woodland of trees with pinnately compound leaves and dry fruits, while the Guinea savannah is characterized by tropical deciduous broadleaf closed-canopy forest of trees with simple broad leaves and moist fruit (Gonzalez, 2001).

There are two contrasting seasons: the wet and dry season that mainly determine and influence plant growth throughout the year. Consequently, savannah ecosystems are characterized by the co-dominance of trees and grasses with woody cover as a chief determinant of ecosystem properties (Scholes and Archer, 1997; House *et al.*, 2003). The growth of woody plants occurs throughout the year with highest growth levels during the wet season, and growth of grasses is confined to the wet season (Bourlière and Hadley, 1983), with a rapid growth response to the first rains. On the other hand, unlike the grasses, woody trees and shrubs produce new leaves before the first rains (Owen-Smith, 1982; Sarmiento and Monasterio, 1983). The West African savannah, like other savannahs, is a habitat with a luxuriant vegetation growth throughout the wet season but as the dry season sets in the vegetation becomes dry, poor and bare in some areas, with attendant impacts such as: reduced cover and food scarcity for domestic and wild herbivores (Bourlière and Hadley, 1983).

The West African savannah ecosystem came under considerable pressure after a severe drought period in the early 1970s and in the mid-1980s, with attendant negative impacts such as the changes of phenology of the plants, to high numbers in livestock as a result of migration from the Sahel zone and to expansion in areas used for cultivation (de Bie, 1998). These combined factors, resulted in a process of landscape degradation (Petit, 2003; Gaoue and Ticktin, 2007). These changes were particularly damaging because in the West African savannah there existed limited local experience with sedentary livestock and hence with potential stocking rates, management of grazing systems, their control, and grazing rights, compared to the traditional pastoral zone - the Sahel, as the savannah was mainly inhabited by sedentary crop farmers and visited by transhumant livestock.

1.2.2 Brief description of Yankari

This study was carried out in Yankari North-eastern Nigeria (9°45’16”N, 10°30’37”E; 9°75′44”N, 10°51′03”E). It is a large wildlife reserve with an area of 2,244 km². Yankari is a premier game reserve in Nigeria (Sikes, 1964). It is a very popular eco-touristic destination in West Africa (Olokesusi, 1990 and Odunlami, 2000). It was established in 1956 and opened to public use in 1962.

Figure 1.2: Map of Yankari Game Reserve, Nigeria.

Yankari is a region of rolling hills, mostly between 250m and 450m above sea level. Gaji River is the lowest point at 200m and the highest point is Kariyo Hill, at 640m. (Tende *et al.,* 2009).

Rainfall in Yankari climate is characterized by the influence of two wind systems; the south-west monsoonal wind which prevails during the rainy season (May to September) and the north-east trade wind during the dry season (November to February). Like most parts of the region, annual rainfall averages 900 to 1000 mm, (the 950 mm isohyet passes through Yankari) and August is the wettest month with rainfall averaging 160 days per year (Green and Amance, 1987). Temperatures are generally high all year round but there exists variations between seasonal temperatures; the annual average minimum temperature is 18°C and annual average maximum temperature is 33°C during the rainy season. In the dry season, night temperatures are between 12°C and 18°C while day temperatures range from 30°C and 36°C. March and April are the hottest months in the year, having night temperatures range between 25°C and 30°C and day temperatures between 38°C and 42°C.

Yankari lies in the Sudan Savannah zone of Nigeria with the vegetation made up of swampy flood plain bordered by patches of gallery forest and riparian forests, and woodland savannah (Crick and Marshall, 1981). Geerling (1973) described the Yankari vegetation as belonging to a complex *Combretum – Burkea africana* woodland. This is characterised by trees and shrubs with an open canopy and a matrix of tall annual and tussock forming perennial grasses. He also notes the presence of a mosaic of riparian vegetation around the river valleys. The vegetation of Yankari can be categorized as thus: to the east of the Gaji River the vegetation is classically Sudan type (tropical xerophyte woodland) while to the west of the river, the vegetation is a transitional type of the Guinea savannah (dry deciduous woodland). Previous studies on the vegetation of Yankari recognized and characterized six vegetation types (Sikes, 1964); twelve habitat types (Geerling, 1973) and fifteen habitat types (Green, 1987). These studies have remained the standard reference documents on the vegetation of Yankari for both research and management purposes. Yankari also has a large and diverse freshwater ecosystem around its freshwater springs as well as the Gaji River. The numerous natural springs and the Gaji river valley support a far more lush vegetation than normally found in the Sudan savannah zone. The major woodland species are *Combretum nigricans, Combretum glutinosum, Combretum molle, Afzelia africana, Burkea africana, Pterocarpus erinaceus, Pterocarpus suberosa, Isoberlina doka, Monotes kestingii, Detarium microcarpus* and *Anogeissus leiocarpus*. *Hyparrhenia involucrate* and *H. bagirmica* are the dominant grasses. In the riparian forest, *Khaya senegalensis, Vitex doniana, Acacia sieberiana, Tamarindus indica, Borassus aethiopium* and *Daniella oliveri* dominate. Large monodominant stands of *Pteleopsis habeensis* occur uniquely in Yankari. In the seasonally flooded fadamas, *Ficus spp.* and *Mitragyna spp*. are the dominant trees, while tangles of *Mimosa pigra* dominate the shrub stratum.

Yankari is known for its diverse and charismatic wildlife including elephants (*Loxodonta africana*), lions (*Plantshera leo*), hippopotamus (*Hippopotamus amphibious*), African buffalo (*Syncerus caffer*), a wide variety and number of antelopes like waterbuck (*Kobus defassa*), western hartebeest (*Alcelaphus buselaphus*), spotted hyena (*Crocuta crocuta*), olive baboon (*Papio Anubis*), warthog (*Phacochoerus africanus*) and mongoose (*Herpestes spp*) (Odunlami, 2000; Odunlami, 2003). Yankari has the largest viable number (estimated as 350 individuals) of elephants in Nigeria (Omondi *et al.*, 2006; Bergl *et al.*, 2011) and one of the largest remaining in West Africa (Bergl *et al.*, 2011). Yankari has been designated an important bird area (IBA) in Nigeria with over 337 bird species (Ezealor, 2002). Saddle-billed Stork (*Ephippiorhynchus senegalensis*), martial eagle (*Polemaetus bellicosus*), Abyssinina ground hornbill (*Bucorvus abyssinicus*), Narina's trogon (*Apaloderma narina*) (Olokesusi, 1990), are some of the species. In addition, several species of fish (26), amphibians (7) and reptiles (17) have so far been identified in Yankari. The African rock python (*Pythons. Sebae*), the Nile crocodile (*Crocodylus niloticus*) and the Nile monitor lizard (*Varanus niloticus*) are quite common (Geerling, 1973; Green and Anadu, 1987).

Apart from its large biological diversity, Yankari has many interesting archaeologic and geographic features such as the Dukkey Wells, Marshall Caves, Tunga Iron Smelting, Kalban Hill, Kariyo Hill, Paliyaram Hill and the Tonlong Gorge. Yankari is also famous for the "Wikki warm spring". The Wikki spring has a daily flow of 21,000,000 litres of clear, spring water into the Gaji River and has a constant temperature of 31.1°C throughout the year and has been developed for recreation (Nihotours, 2000).

Yankari is an 'island' without a buffer zone and surrounded by many villages. There has not been any habitation in Yankari for over a century, but from inception it has been traversed by game viewing tracks that link communities across the reserve and by which local communities access and utilize natural resources within the reserve. Farmers and herders populate the local communities that surround Yankari, other inhabitants engage in hunting and small-scale trading. The local communities rely on the natural resources in the reserve for their sustenance, directly or indirectly (Tende *et al.*, 2011)

Previous studies have described the nature of the interaction and have recommended that urgent actions should be taken to minimize the illegal activities from the local communities (see Green, 1987), but nothing was done. A recent study has highlighted the frequency of human utilization (lopping) of tree species in the reserve; coincidentally these species are also evidently browsed by wild stock (Tiseer, 2009). The threats to Yankari are many: poaching remains a major threat to large mammals in the reserve - illegal fishing occurs in the rivers and numerous ponds and pools during the dry season – as well as grazing of livestock in the reserve by Fulani herdsmen (WCS, 2013; 2014).

Yankari is a traditional game reserve strictly under government control and has been, since its inception in 1962. First it was managed by the Northeast Government and the Bauchi State government. In 1991, it went under the Federal government of Nigeria as the largest National Park. Yankari was returned to the Bauchi State Government in 2006. However, the Wildlife Conservation Society (WCS) has signed a memorandum of understanding with the Bauchi state Government and has taken over the management of Yankari for a period of 4 years - from 2014 to 2018. Throughout these years from inception till now, Yankari has remained a strict government reserve and culprits caught trespassing in Yankari are arrested and fined depending on the level of activity and offence committed.

Yankari is an ideal case study for this research because it is a significantly protected area both for Nigeria and West Africa. It is situated in one of only five countries in West Africa with lion populations (Henschel *et al.*, 2010; BBC, 2014). Yankari serves as a choice venue for government retreats and field trips for students of all levels of education. Additionally, various studies have been conducted and documented on various aspects of Yankari ranging from the floral, faunal and eco-tourist facilities, one of which serves as the baseline for the present study. Yankari, like many protected areas in West Africa is faced with poaching, illegal wildlife trade, over-grazing, human-elephant conflicts, effects of climate change, shortage of funds for effective management, etc. (Agbelusi,1994; Newmark, 2008; Meduna *et al.,* 2009). Some plant and animal species in Yankari have been recognised by the International Union for the Conservation of Nature (IUCN) as threatened. Historically, records show that eight species of large mammals (African hunting dog, leopard, cheetah, giraffe, western kob, Korrigum, red fronted gazelle and bohor reedbuck) have become locally extinct in Yankari.

Yankari can serve as a model and as an example if managed effectively, because the threats she faces are similar to many of the protected areas in the West African savannah. A study done in Kainji National Park, Nigeria (see, Meduna *et al.,* 2009), revealed that livestock grazing, farming on parkland, fishing, fuelwood collection, fodder collection and logging are the main threats the park faces from the villages surrounding it. In a related study on the W-Arly-Pendjari WAP complex which straddles the borders between Benin, Burkina Faso, Niger and Togo, in West Africa (Clerici *et al.,* 2007), the study found that despite the effectiveness of the park conservation programme, the WAP complex is decreasing its potential capacity to conserve species richness this is as a result of rapid and extended agricultural expansion taking place around the complex.

1.3 Thesis outline

This thesis is split into four result chapters excluding an introduction and a general discussion. The chapters, whilst standing alone, provide evidence for the processes and main drivers of woody vegetation in Yankari. The thesis begins with a general introduction (background and rationale, description of study site). The next chapter details general findings from the resurveyed vegetation transects and additional plots in Yankari 26 years after the initial study was done (Chapter 2). As a continuation of further investigations on causes (drivers) of the changes highlighted by Geerling (1973) and Green (1986) and evident from Chapter 2, the third chapter focuses on exploring the trends in potential drivers of woody vegetation change in Yankari. The fourth chapter focuses on the impacts of herder harvests on the fodder plants in Yankari, looking at the pattern and extent of herder's harvest. The fifth chapter, explores the perception of the settled/migrant herders in Yankari on trends in their herds and availability of fodder plants in their surroundings. The sixth chapter describes the implications of the study. It details recommendations for further research, and outlines strategies for conservation in Yankari.

Ecological changes in woody vegetation of Yankari Game Reserve, Nigeria (1986 to 2011)

Abstract.

An ecological study to investigate changes in the woody vegetation of West African Savannah was done. The Yankari Game Reserve, Nigeria was used as a case study. The study investigates spatio-temporal changes in woody vegetation of Yankari, Nigeria since 1986. Green (1986) established five permanent vegetation transects in Yankari Game Reserve to collect baseline data and for long term ecological monitoring. However no surveys have been conducted since then. In Oct – Nov. 2011, a resurvey of the original transects Green established in 1986 was conducted. Additional transects (replicates) were established also in the reserve. Point centre Quarter method and the plot methods were used to estimate key tree and shrub species and to compare their current distribution and abundance with those reported by the previous study. Parameters for data collection included species identification, trees diameter and tree heights. Comparison of results for both surveys (1985, 2011) were done using the R software and Excel tools. Relative densities and basal areas were calculated between the two periods (1985, 2011). Additionally, the study also characterized the current species composition using size class distribution, species accumulation curves and the non-metric multidimensional scaling (nMDS). Furthermore the study assessed changes in vegetation cover from four Landsat images of Yankari using remote sensing techniques (The Normalized Difference Vegetation Index = NDVI). The results show an overall increase in mean basal area in most of the species belonging to the family of Combretacaea and high reductions in mean basal area in the species highly utilize as fodder to feed livestock. The sub habitats in Yankari are similar in species composition. Combertum nigricans and Combretum glutinosum are wide spread in Yankari. The results from the ANOVA test run, reveal adifferences across the four years, even at 0.001 interval level (p = 0.0001). TukeyHSD's pairwise comparison showedsignificant difference between the mean NDVI values of the Year 2012/2009 and Year 2012/2000. It will be beneficial to further investigate the causes of the changes in the composition and structure of the woody vegetation of the Yankari.

2. 1 Introduction

Change in tree cover directly affects the global carbon budget, biodiversity and ecosystem function. Many studies have reported extensive deforestation worldwide (Carr, 2009; Aide *et al.,* 2013), yet other studies have documented local forest recovery (Chazdon, 2008, Walker, 2012; Aide *et al.,* 2013). These contrasting dynamics have been largely connected to human population, and social and economic changes. Humans have interacted with and altered the vegetation structure more than any other components of the landscape. Vegetation changes have been widely recorded for different ecosystems throughout the world (Ucla ioes Senior Practicum, 2012; Mitchard and Flintrop, 2013; Brandt *et al.*, 2014). While some studies report declining and disappearing species at different scales (Wezel and Lykke, 2006; Luz *et al.*, 2009; Spiekerman *et al.*, 2015), others suggest that species are increasing in abundance (Lykke, 1998; Mitchard and Flintrop, 2013). Effects of these declines/increases manifest in all aspects of their livelihoods: in food, medicine, fodder, construction; and ultimately altering ecosystem function and causing habitat loss. Whether species are decreasing or increasing, acquiring an understanding of the most important drivers and their interactions in the environment, can potentially inform conservation strategies for ecological resilience.

The forest resource assessment (FAO, 2010) report, stated that on average, 49 countries in sub-Saharan Africa lost 0.5% of their forest cover from 1990 – 2000 (FAO, 2010). Similarly, in the period 2005 – 2010, only seven of the 49 countries reported forest area gain. These forest-gain countries are small in size, and represent only 0.45% of the total area of sub-Saharan Africa (FAO, 2010). Other studies also recorded evidence of recent deforestation and land cover reduction in this region (Mitchard and Flintrop, 2013). Although the global rate of deforestation has slowed down in the last decade, the reported global figures are still alarming (FAO, 2014). For example, the deforestation rate in Africa is four times the world's average, an estimated 18 million acres (7.3 million hectares) are lost each year, according to the United Nations Food and Agriculture Organization (FAO, 2014).

Forest resources play a vital role in maintaining the ecological balance and environmental setup. Over-utilization of these resources has resulted in their depletion, and consequently in the loss of overall environmental conditions (Kumar, 2011). This challenge is made all the more urgent by ongoing and escalating loss of biodiversity (Kumar *et al.,* 2010). The changes in forest cover are a matter of global concern due to its ability to promote the role it plays in the carbon cycle (Kumar, 2011).

In the West African savannah, agro-ecological systems form the basis of sustenance for humans and livestock. Savannahs in West Africa flourish during the wet season when there is abundant vegetation, and lose their leaves or reduce productivity in the long, dry months with associated food scarcity for domestic and wild herbivores (Bourlière, 1983). Woody vegetation in the savannah zone provides an important source of food for these herbivore species (De Bie, 1991). Therefore, the West African savannah shows great seasonal variations in food supply for both grazing and browsing herbivores.

The West African savannah ecosystem has come under considerable pressure after severe drought periods in the 1970s and 1980s (Wand *et al.,* 2000; Sinclair 1979; Barnes *et al.,*1982; Gandah *et al.*, 2003; Lykke, 2006). This has resulted in a combined process of degradation, where droughts have induced the replacement of perennial plant species by annual species and of species with high water requirements by drought-tolerant species (de Bie, *et al.*, 1999). Following the drought, there has been an increase in livestock numbers, mainly cattle and sheep, as a result of increased migration from the Sahel zone. This, coupled with the eradication of diseases (Trypanosomiasis and river-blindness) and more effective medication, has resulted in increased grazing pressure by livestock in areas not historically available for grazing and an expansion of the area used for cropping (de Bie *et al.*, 2002). Most previous studies on droughts have concentrated on the Sahel ecosystem (LeHouérou, 1980; Cissé, 1988; Wezel and Lykke 2006, Gonzales *et al.*, 2012 and Spierkerman *et al.*, 2015).

Previous vegetation studies in the Yankari (see Sikes, 1964; Afolayan, 1980; Geerling 1973; Green, 1987; Abdullahi *et al.*, 2009) have focussed on vegetation classification and description of the general threats facing the vegetation. Increase in the magnitude of indicators of these threats have been described (Longtong, 2008; Omondi *et al.*, 2006; Bergl *et al.,* 2011; Nyanganji *et al.,* 2012). The author also observed that Yankari is still under many threats, mostly from poaching and grazing of cattle, and seasonal nomads heighten these threats. There is a lack of recent evidence about the status of the park vegetation and changes since the previous period of study. There are patrols by the WCS, but they do not provide reliable quantitative evidence. Although Landsat imageries have been available since the late 1970s, the previous vegetation studies did not use them for the surveys at the time.

The classification of the woody vegetation of Yankari as shown in Table 2.1.

Table 2.1: Previous studies on woody vegetation classification of Yankari Game Reserve, Nigeria. The classification are described by numbers 1-5. 1 represents the same vegetation type in all four studies, likewise 2, 3, 4, 5 and 6. PCQM = Point Centre Quarter Method.

Study	Survey method	Parameters Recorded	Vegetation Description
Keay 1961	Unknown	Unknown	1 Vegetation main Type 1 2 Vegetation main Type 2 3 Shrub savannah of sub-sudan Zone 4 Sub sudan zone
Tuley 1970	Unknown	Unknown	Afrormosia -Detarium savannah woodland
Geerling 1973	Step wise method	Presence/absence of canopy cover, height of canopy and plant species were identified	1 *Afzelia* savannah woodland 2 Combretaceous savannah woodland 3 Combretaceous shrub savannah 4 Detarium savannah woodland 5 Riparian vegetation
Green 1986	PCQM	Plant species were identified, DBH measured and the distance of plants from the pointer were recorded	1 *Afzelia* savannah woodland 2 Combretaceous savannah woodland 3 Combretaceous shrub savannah 4 *Detarium* shrub and tree savannah 5 Gaji River complex 6 Tonglong Gorge complex

The works of Geerling (1973) and Green (1986) remain the standard reference documents on the vegetation of Yankari, but these studies are about 38 and 25 years old respectively, and no longer provide reliable information on the current situation. Additionally, the management plan for Yankari (Green and Amanche, 1987) is about 30 years old and has neither been updated nor reviewed.

Furthermore, the reports of both Geerling (1973) and Green (1986) have also highlighted some concerns: Geerling (1973) noted that although *Acacia ataxacantha* was heavily browsed by elephants during the dry season, the vegetation was able to regenerate during the wet season. Green and Amance (1987) noted that the main concern at the time was that elephants were killing *Borassus aethiopum* and *Adansonia digitata* faster than they were regenerating. Additionally, the authors also reported on the extensive die-off of trees and shrubs in the savannah woodland as a consequence of the droughts, and added that even though the vegetation was vulnerable to frequent fires, drought was a key factor in the die-off of the trees. This is evident by some drought-resistant species (*Balanites aegyptiaca* and *Sterculia satigera*) surviving at the time (Green and Amance, 1987).

Green (1986) established five permanent vegetation transects at Yankari in order to collect baseline data, as well as for long term ecological monitoring. However, no comprehensive surveys have been conducted since 1986. The baseline data collected by Green (1986) therefore provides the background to this research. This study investigates spatio-temporal changes in woody vegetation of Yankari, Nigeria since 1986. The following objectives guide this investigation.

The present study focuses on Sudan savannah in the West African an important droughts prone area to investigate changes in the woody vegetation species. The rationale behind the study choice is based on the limited assessments in the West African savannah. This study investigates and quantifies the processes of woody vegetation change by combining direct measurements of trees and shrubs and also satellite images. The study will further aid regular monitoring of climatic and ecological changes as well as the dynamics of other stressors in order to determine effective response strategies that can help to better protect ecosystems and ensure greater species survival.

- To measure and estimate abundance of the most abundant tree and shrub species in Yankari.
- To re-survey and compare the current distribution and abundance of key species (across the sub habitats) with those reported by Green (1986).
- To investigate changes in vegetation cover for Yankari using remote sensing.

2.2 Methods

2.2.1 Study design: Yankari woody vegetation composition and distribution

Sixteen most dominant (Dominance is the degree of predominance of one or few species compared to its competitors in an ecological community. The species are numerous to form the bulk of the biomass. It also implies that the species not only make a major contribution to the total biomass of the plant community but also tends to impact the environment as well as influence the quantity, distribution of the associated flora and fauna (Grime *et al.,* 2014). Dominance can be measured as either counting individuals of seedlings or estimating biomass / basal area is for of large trees). woody plants were reported by Green (1986): *Afzelia africana, Combretum glutinosum, Combretum nigricans, Bossia salicifolia, Ptericarpus erinaceus, Detarium microcarpum, Strychnos spinosa, Combretum molle, Terminalia laxiflora, Khaya senegalensis, Balanites aegyptiaca, Ptericarpus suberosa, Anoggessius leiocarpus, Crossopteryx febrifuga, Tamarindus indica* and *Burkea africana*. Additionally, this study identified six main vegetation types in Yankari at the time: Combretaceous tree savannah, *Afzelia* savannah woodland and Combretaceous shrub savannah, *Detarium* shrub and tree savannah, Gaji river complex and Tonglong gorge complex, which are largely defined by the abundant species. However, the resurvey measurements in this study focused on only four out of the six vegetation types (Combretaceous tree savannah, *Afzelia* savannah woodland, Combretaceous shrub savannah, Gaji river complex). Furthermore, the dominant woody plants mentioned earlier are classified into the following ecological types: herder and elephant preferred (HE), prone to fire and drought (DF) and others, neither belonging to HE or DF (O) (see Table 2.2). The assigned codes (HE, DF and O) to these classes are for ease of identification and discussion. This classification is based on intensive literature search (Le Houerou, 1980; Cooper *et al.,* 1988; Bayer, 1990; de Bie 1998; Swaine, 1992; Lykke, 2000; Bond and Midgley 2003; O'Connor *et al.*, 2007; Ouédraogo-Koné, 2008), providing the basis that these species can be considered under these ecological groups in this study.

Table 2.2: Categories of dominant plants in Yankari designed for this study

S/No	Elephant + Herder pref.(HE)	Drought + Fire (DF)	Others (O)
1	*A. africana*	*C. glutinosum*	*B. salicifolia*
2	*P. erinaceus*	*C. fragrans*	*D. microcarpum*
3	*S. spinosa*	*C. molle*	*T. glaucescens*
4	*K. senegalensis*	*B. aegyptiaca*	*P. suberosa*
5	*B. aegyptiaca*	*A. leiocarpus*	*G.senegalensis*
6	*T. indica*	*C. febrifuga*	
7		*B. africana*	

2.2.2 Survey plan

Data was collected using vegetation surveys and remote sensing imageries. An inventory of woody vegetation was carried out in the two main habitats (see, chapter 1) of Yankari. To reduce bias, the author used the same methods and the same locations as Green's 1986 survey, for the point centre quarter method (PCQM) survey (see, 2.2.2.1). Additionally, a plot method was used to give a more robust sampling, and extended the sampling to cover the riparian forest. To supplement the data from the field survey, remote sensing images were downloaded from the United States Geologic Survey (USGS) website. Image classification and processing were duly carried out and procedure is discussed in greater detail in Section 2.2.2.4.

2.2.2.1 Green's survey (1986)

Green (1986) reported that PCQM (Cottam and Curtis, 1956; Muller-Dombois and Ellenberg, 1974), was chosen for its rapidity, simplicity and relative accuracy. Contrary to the plot method, plot-less methods, such as PCQM, involve measuring distances for a random sample of trees, typically along a transect, and recording the characteristics of interest for the sample (Michell, 2007). The PCQM is perhaps the most popular of the plot-less sampling techniques. Each point represents the centre of a measurement. From the centre (pointer) a compass is used to define four quadrants. The closest plant from the pointer in each quadrant is determined, and distance between the plant and the centre is measured, along with the diameter at breast height (DBH) which is used to estimate the area covered by the plant. Typically, four plants are measured at each sample point. Figure 2.1 is an illustration of the PCQM.

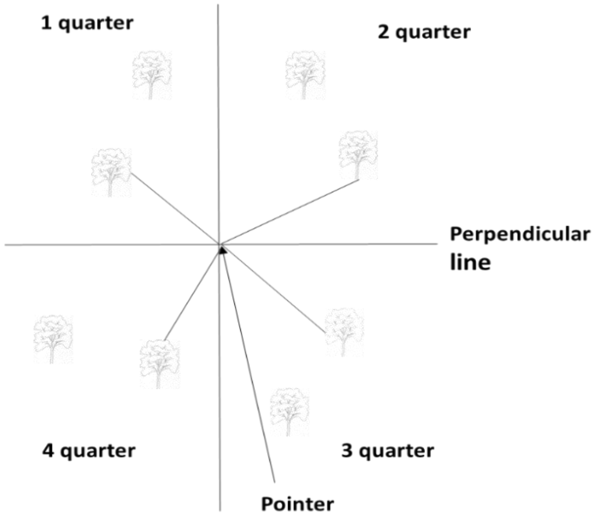


Figure 2.1: Typical point centre quarter method

In August five transects were erected (Green, 1986) to collect baseline data for future monitoring of the vegetation in Yankari .The baseline data were collected in September and October 1986. This period marks the end of the wet season, and the vegetation is easy to identify. Green's choice of transect locations may have been influenced by the different sub-habitats in the Yankari. Samples were collected at only five locations in Yankari at the time. However, the author reported to have had logistical limitations, and the plan was that the survey would be repeated every four/five years. All five transects were located adjacent to game viewing tracks. Sampling points occurred along the compass traverse at ten pace intervals. This was chosen to satisfy the requirement that 'an individual plant must be located within each quarter of each sampling point and an individual plant must not be measured more than once (Green, 1986). Seventy five points were surveyed per transect. The first four transects were divided into four segments (25, 25, 13 and 12). Transect 5 had six segments of 13 and 12 sampling points; this was to avoid extending into a different vegetation type, Figure 2.2.

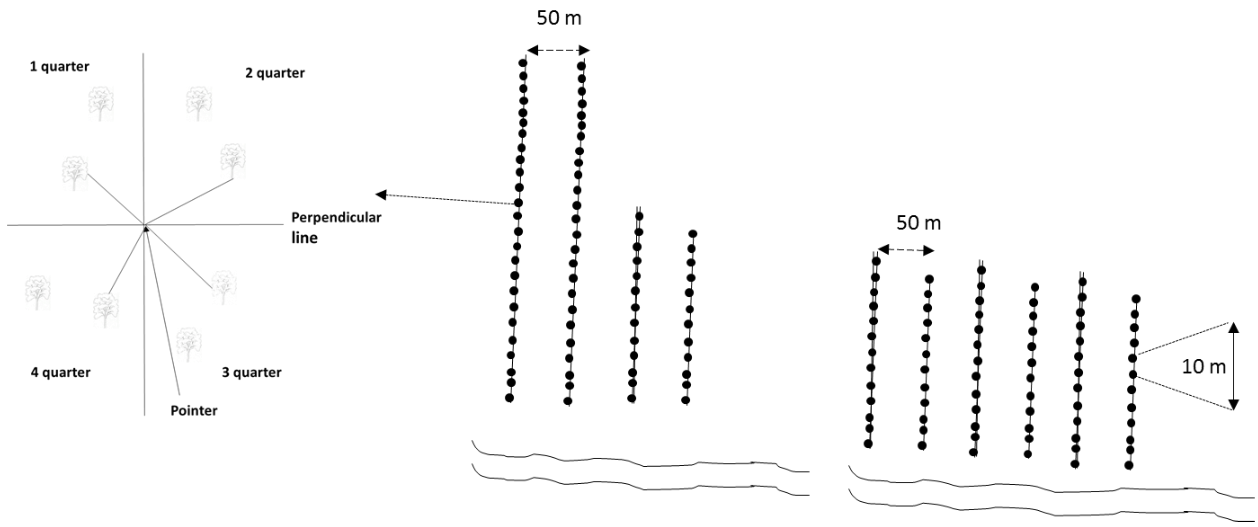


Figure 2.2: Point centre quarter method sampling design for woody vegetation baseline survey of Yankari Game Reserve, Nigeria (Green, 1986).

300 woody plants (four samples per measurement point) were measured per transect (> 10.0 cm DBH are considered mature plants <10.0 cm DBH are saplings and 2 m in height). Plant species were identified, DBH measured and the distance of plants from the pointer were recorded. Breast height (DBH) is generally measured in estimation of trees as stem diameter 1.30 m above the ground (Kankare *et al.,* 2013 and Castaño-Santamaría, Javier, *et al.,* 2013). In the context of this study, the same estimation was used to sample adult trees and saplings. However only saplings starting from 2 m height were included in the measurement of breast height.

2.2.2.2 Authors' survey (2011)

Field measurements were carried out between 6th October and 9th November 2011 in Yankari, Nigeria. The expectation was that the state of the vegetation would be relatively comparable with Green's (1986) survey, which was conducted between September and October 1986. The transects that Green originally laid were re-surveyed, and additional measurements were taken within the same sub-habitats. A topographic map and the infrastructure map of Yankari (Geerling, 1973 and Green, 1987) served as guides to trace the original transects. GPS co-ordinates and elevation were recorded at each point. In transect five, the pole which Green (1986) reported as having been erected, was discovered; this further assured the author on precision on Green's transect locations. Same measurements and procedures were used in each transect, as shown in figure 3.

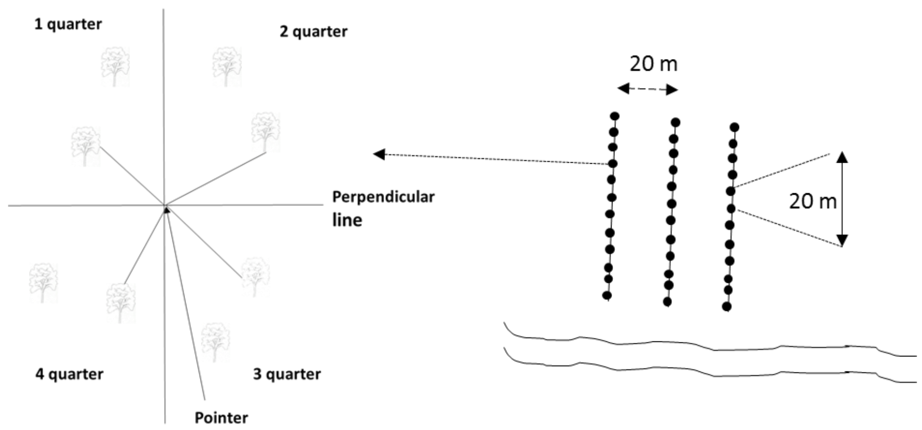


Figure 2.3: Point centre quarter method sampling design for woody vegetation re-survey of Yankari Game Reserve, Nigeria

Sample units were measured and four points were marked and re-surveyed with the PCQM (Figure 2.3). The major difference between the two surveys, was the interval between sampling points. Green (1986) used 10 m, whilst the recent survey used 20 m. During the re-measurements, the author encountered many plants overlapping between points, possibly as a consequence of structural habitat change (Noss, 1990). As a result, the measurements were adjusted to 20 m intervals. The same parameters as Green's (1986) were measured: species identification, tree diameter, tree height, and distance from the pointer. Indicators of human activities (lopping, logging, and stumps) were also recorded, photographed and mapped (Figure 2.4). Thirty six points were recorded in each transect, covering a total surveyed area of 720 m^2. All sampled plants species were confirmed and identified by the late Dr Tiseer, a plant taxonomist in Ahmadu Bello University Zaria – Nigeria.

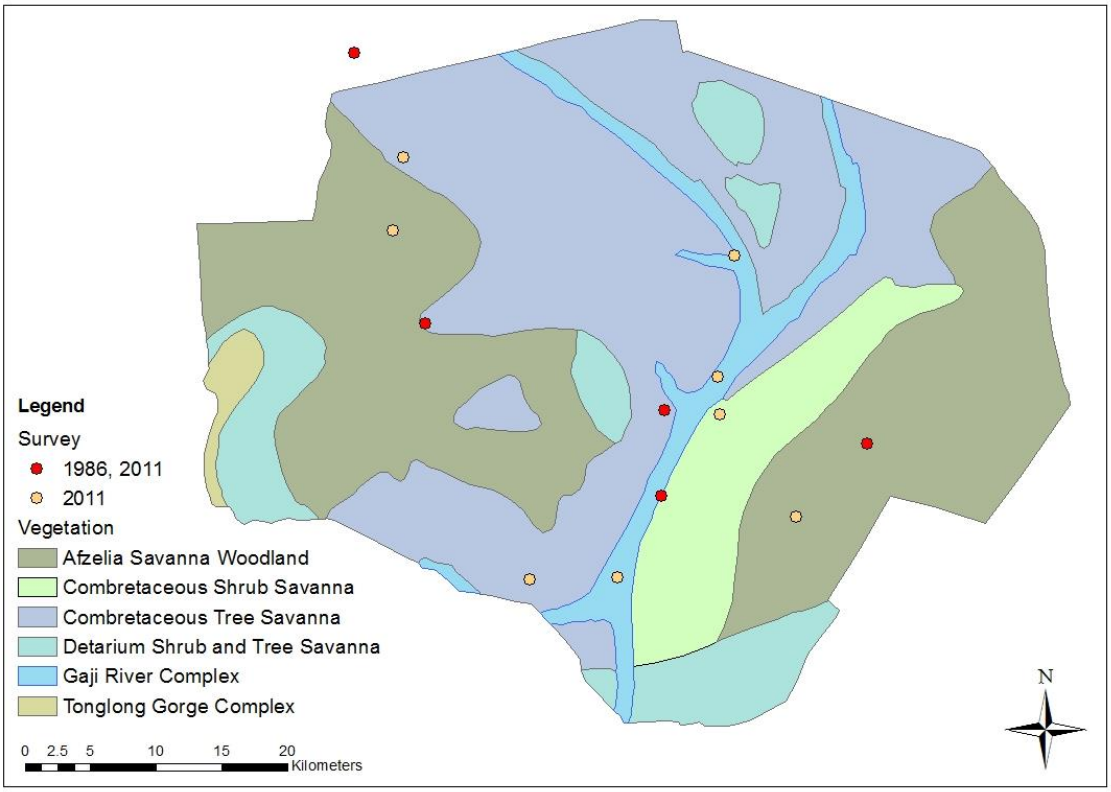


Figure 2.4: Vegetation map of Yankari showing sample point locations. The sketch map from Geerling (1973) and Green (1986) served as base map, while the sample points were from the surveys of Green (1986) and author (2011). Red dots are baseline survey points taken in 1986, and resurveyed in 2011, while the orange dots show additional survey points (2011).

2.2.2.3 Plot methods

Plots were laid adjacent to the original transects established by Green (1986); the purpose of this was to examine within-vegetation type variations. Samples were taken 50 m from the surveyed track to avoid any biases that may affect the habitat as a result of the track. In each transect, 10 plots (20 x 20 m), of five plots each separated by 200 m distance were surveyed (see, figure 2.5).

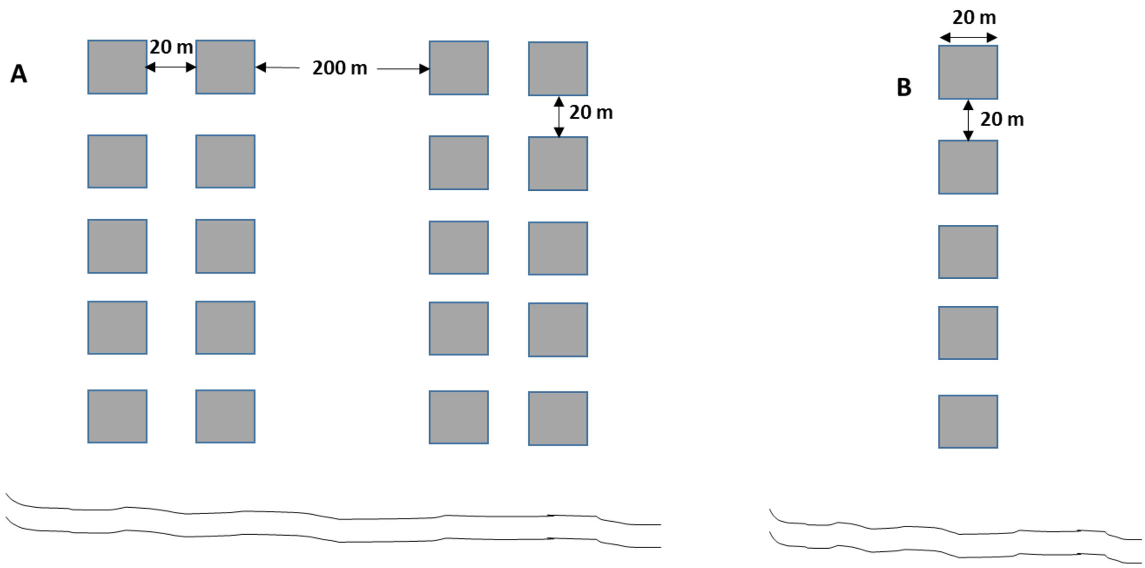


Figure 2.5. Plots sampling design for woody vegetation of Yankari Game Reserve, Nigeria. Each grey square represents a 20 X 20 m plot. A = sample design for *Combretum* tree savannah; *Afzelia* tree savannah; *Combretum* shrub savannah and B = Riparian vegetation

The interval between any two plots was 20 m. Stratified random sampling (two transect locations within a sub habitat) was employed to establish more sampling units; this was to ensure a good representation of the total area of the sub habitat. A total number of 115 plots were surveyed; 100 (10 plots per transect) plots in the savannah vegetation and 15 (5 plots per transect) plots in the riparian vegetation. The reason for fewer plots in the riparian plot was because the riparian forest is only a strip and therefore could not accommodate 10 plots. In each plot, all tree species were identified, tree diameters and heights were measured and recorded. Most plants were identified by Dr Onoja Joseph, a research associate with APLORI, and Mallam Yankasta, who supplied the Hausa names of some tree and shrub species. Both men have extensive experience working with the late Dr. Tiseer on the vegetation in Yankari. Dr Tiseer confirmed the identification done by the duo before his demise.

2.2.2.4 Image classification and processing

Ecologists recognize the need to understand ecosystems based on assessing their functioning over long time scales (Oldfield *et al.,* 2000). Remote sensing tools offer the important means to enhance change detection in ecosystems (Jensen *et al.*, 2004). However, the need to incorporate spatial and temporal information, relationships, and quantifications of physical habitats are critical components of any study that analyses a changing landscape. Past studies have demonstrated the potential of using Normalized Differential Vegetation Index (NDVI) The NDVI is used to simply and quickly identify vegetated areas and their condition, and is the most used index to detect live green plant canopies in multispectral remote sensing data.

The NDVI is calculated with the formula: $\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{VIS})}{(\mathrm{NIR} + \mathrm{VIS})}$

Where VIS and NIR stand for the spectral reflectance measurements acquired in the visible (red) and near-infrared regions, respectively to study vegetation dynamics (Townshend and Justice, 1986; Verhoef *et al.,* 1996).

The previous authors illustrate the value of using high temporal resolution Multispectral Scanner System (MSS) imagery to monitor changes in wetland vegetation and document the importance of image temporal frequency for accurately detecting forest changes in the south-eastern United States (Elvidge *et al.*, 1999 and Lunetta *et al.*, 2004). With the advent of MODIS NDVI 250 m data, time series data analysis can be adapted for higher (moderate) resolution applications. However, the utility of the MODIS NDVI data products are limited by the availability of high quality (e.g., cloud free) data (Jin and Sader, 2005).

The author downloaded Landsat images from the United States Geological Survey (USGS) website. Four Landsat 7 (EMT+) images for years 2000, 2004, 2009 and 2012 were selected based on the time of year, cloud cover and avoidance of censor calibration problems. These images were unzipped and stacked using ERDAS IMAGINE 2013 to produce the image (.img) that was read in ArcGIS 10.1. The Normalized Differential Vegetation Index (NDVI) were created using ERDAS IMAGINE for each of the selected images, and displayed in ArcGIS 10.1. The fishnet tool in the ArcGIS 10.1 was used to create sample points at X–Y (2 X 2 km). The position of the points were adjusted, to avoid the missing data caused by the scan line corrector failure (SLC). A comparison of point locations across four images and manually moving/repositioning those occurring over clouds or cloud shadows was carried out. The NDVI pixel values from each image at the point location were extracted. The abnormalities in values were checked and corrected (modified their location) while others were excluded from analysis

2.2.3 Data analysis:

The author used ArcGIS 10.1, ERDAS IMAGINE 2013, R version 3.0.1, Microsoft EXCEL 2013 software packages to analyse both the remote sensing data and field data collected for this chapter.

Characterization of biodiversity through inventories can be useful in the planning of operations that aim to conserve biodiversity (Belbin and Collins 1995; Faith and Walker, 1996; Kelema, 2010). Species richness is an important index in characterizing the number of species in a community (Whittaker, 1972; Hubbell, 2001). A change in species diversity is often used as an indicator of anthropogenic or natural disturbances in an ecosystem (Liu and Brakenhielm, 1996; Kalema, 2010). Therefore, the species accumulation curves were used to determine the alpha and beta diversity (Whittaker, 1972) of the 115 sampled plots across the sub-habitats that were studied.

The size class distribution (SCD) of 16 top (most abundant) species were analysed, based on the dataset from the 2011 re-survey of Yankari. SCD analysis followed the method used by previous authors (Condit *et al.,* 1998; Lykke, 1998). Plant diameter at breast height (DBH) was used as an indicator of the growth potentials of the top species. DBH was calculated for individual species, and the sum across all plots were used to plot the bar graph for each species. The DBH were grouped into seven classes ranging from 0 to 61cm: 0-10 class describes saplings with DBH = >10 cm/2 cm height and 11-20cm to 61& above are trees with DBH is < 10cm). Bar graphs were plotted for each species to allow visual comparison. The shape of the population structure of each was interpreted following Everard *et al.,* (1995); Obiri *et al.,* (2002), Mwavu and Witkowski, (2009).

Non-metric Multi-dimensional Scaling (nMDS) (see, Gauch, 1982) was used to visualise the relationships (dissimilarities and similarities) across the four sub-habitats of Yankari. Data collected from the riparian forest was included to this analysis. The vegan ordination package was used to plot the graphs. Mean basal area (BA) was used to compare the current distribution and abundance of key species with those reported by Green (1986). The baseline did not give room for robust statistical analysis as the absolute figures of the survey were not available to the author during the time of this study. Therefore the best comparison between the mean BA for the two studies relied on a basic estimation.

The relative basal area could not be compared, as the baseline did not provide absolute values to work with. The baseline study provided summaries of the data collected in 1986 (relative densities, relative BA, total counts of trees, etc.), therefore, options of data analyses were limited and comparison were made only between the mean basal area and standard errors. The BA of individual species were multiplied by the number of plants recorded by Green (300), the figures were divided by the number of plants earlier recorded by the author (144). X * 300/144. This was to enable the author calculate the mean BA for each sub habitat per period (1986, 2011) and work out the standard errors. Bar graphs were plotted in Excel. The same standard errors were used for the two periods, because they were not available for the Green (1986) data.

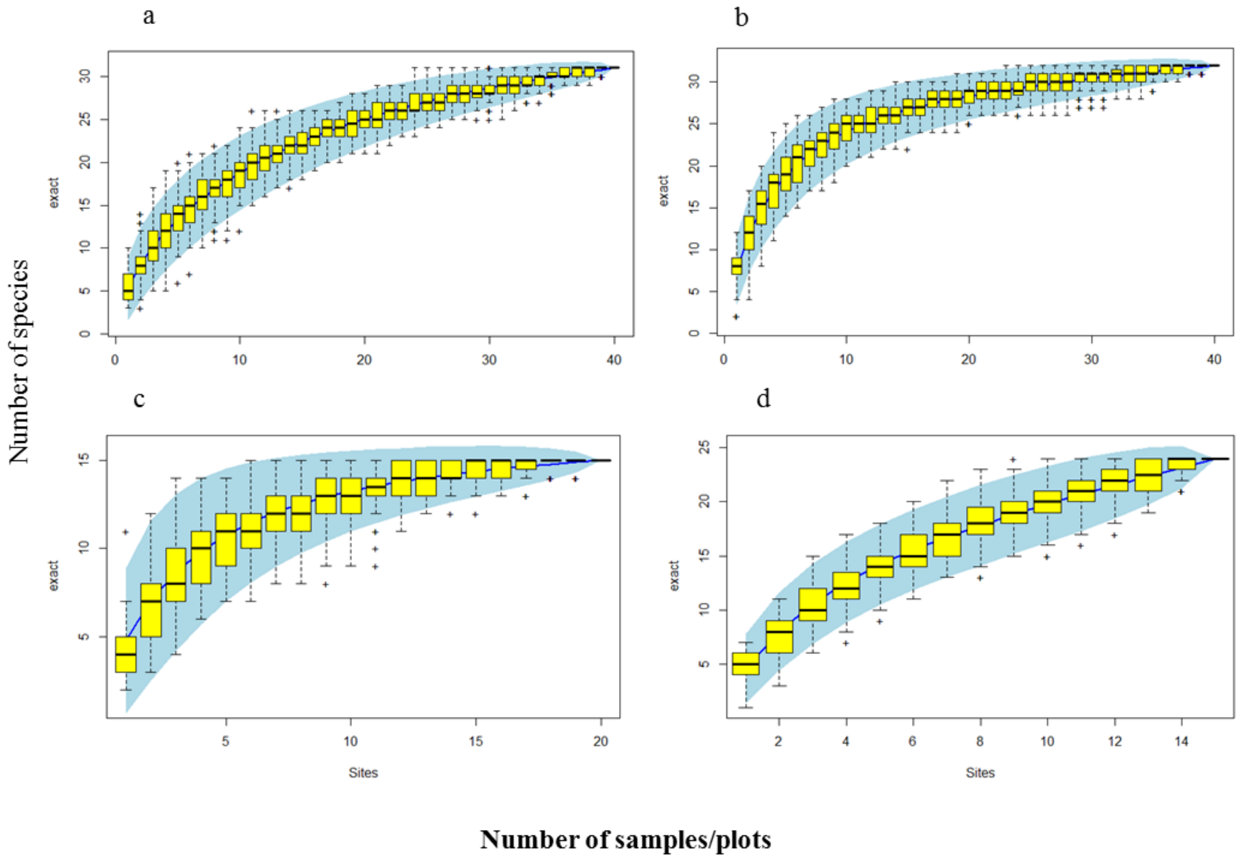
Finally, to investigate the spectral changes in the vegetation cover in Yankari from Landsat remote sensing images, the NDVI values of four years were created (2000, 2004, 2009 & 2012) from Landsat 7 (+EMT). The NDVI values were used as indicators of temporal changes. ANOVA was used to test the variation between years. A pairwise comparison using TukeyHSD was used to detect where the difference lay. The Tukey confidence interval was plotted to show the significance level.

2.3. Results:

2.3.1 Spatial and temporal comparisons of field surveys (1986 and 2011)

2.3.1.1 Species richness for 2011 plot survey

Figures 2.6 (a – d) show estimates of species richness in each sub-habitat. *Combretum* tree savannah and *Afzelia* tree savannah show higher beta diversity, Riparian Forest show moderate beta diversity and *Combretum* shrub savannah show very low beta diversity and on the contrary high alpha diversity.



Figures 2.6 (a - d): Figure: Comparison of Species – accumulation curves of four sub – habitats in Yankari Game Reserve, Nigeria. y – axis represents the number of species sampled while the x – axis represents the sub - habitats sampling was carried out. a = *Combretum* tree savannah; b =*Afzelia* tree savannah; c = *Combretum* shrub savannah; d = Riparian vegetation. Yellow boxplots: species richness by stratified random sampling. Light blue polygon: 95% confidence interval of species richness

2.3.1.2 Size class distribution of sixteen of the dominant woody plants species

SCD of the 115 plots surveyed are presented in figure 2.7. DBH of 0 – 10 cm is the dominant class; this shows that more shrub species than tree species dominate the habitats of Yankari, Nigeria. Nevertheless some species (*A. africana*, *K. senegalensis*, B. *aegytiaca* and A. *leiocarpus)* have some trees in larger size classes but show abnormal structures.

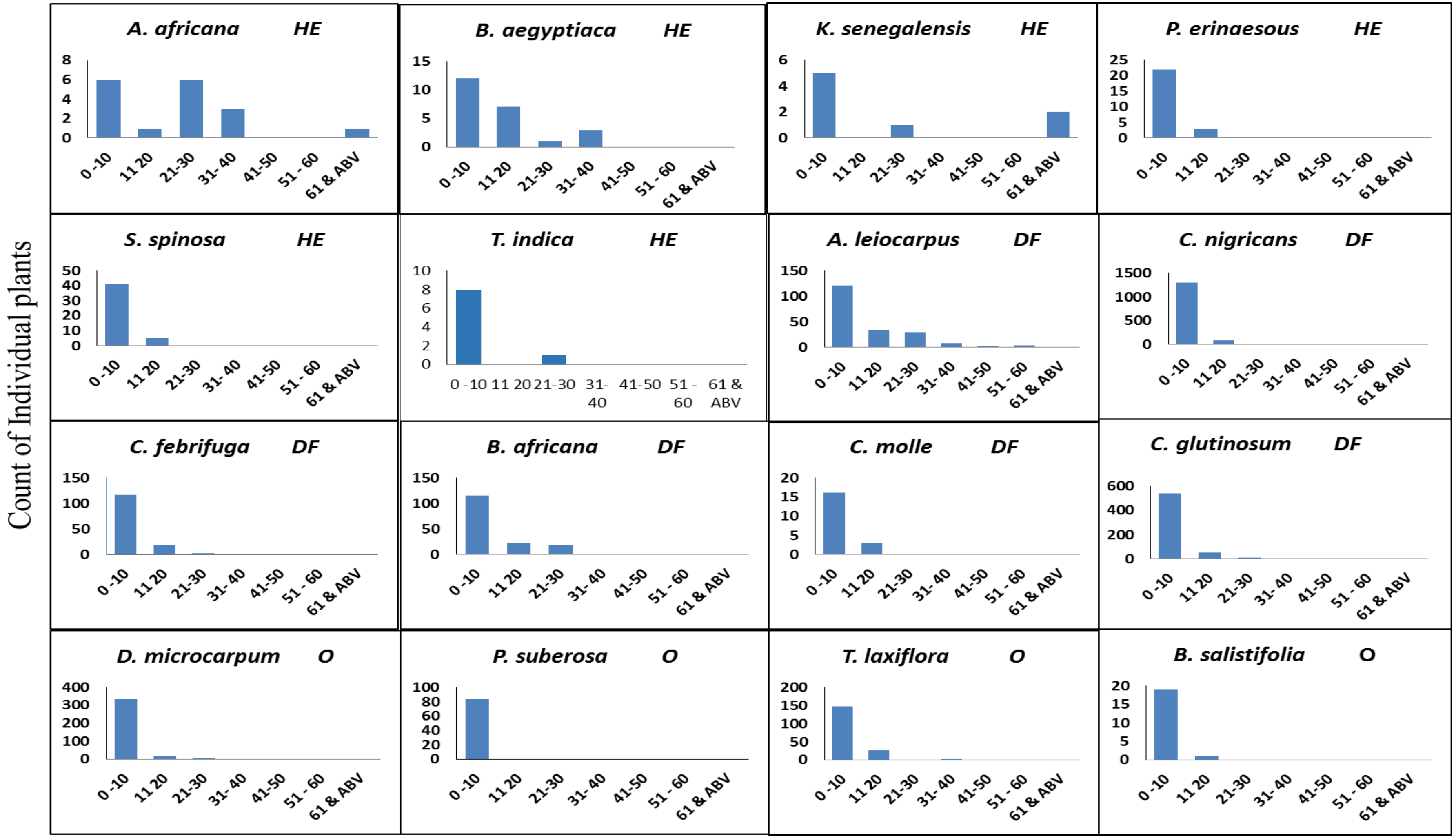


Figure 2.7: Size-class-distribution of sixteen dominant woody plants as suggested by baseline study (see, Green 1986) in Yankari Game Reserve Nigeria. These dominant species were categorized according to threat groups: HE = herders and elephants preferred species; DF = drought and fire prone species; O = neither. DBH was calculated for individual species and the sum across all plots was used to plot the bar graph for each plants. Size-classes are shown on the x-axis and number of individuals on the y axis.

Comparison of BA per hectare across the sub habitats for 1986 and 2011, show an increase of species abundance in two (*Combretum* tree savannah and *Combretum* shrub savannah) of the three habitats and a reduction in *Afzelia* tree savannah, Figures: 2.8

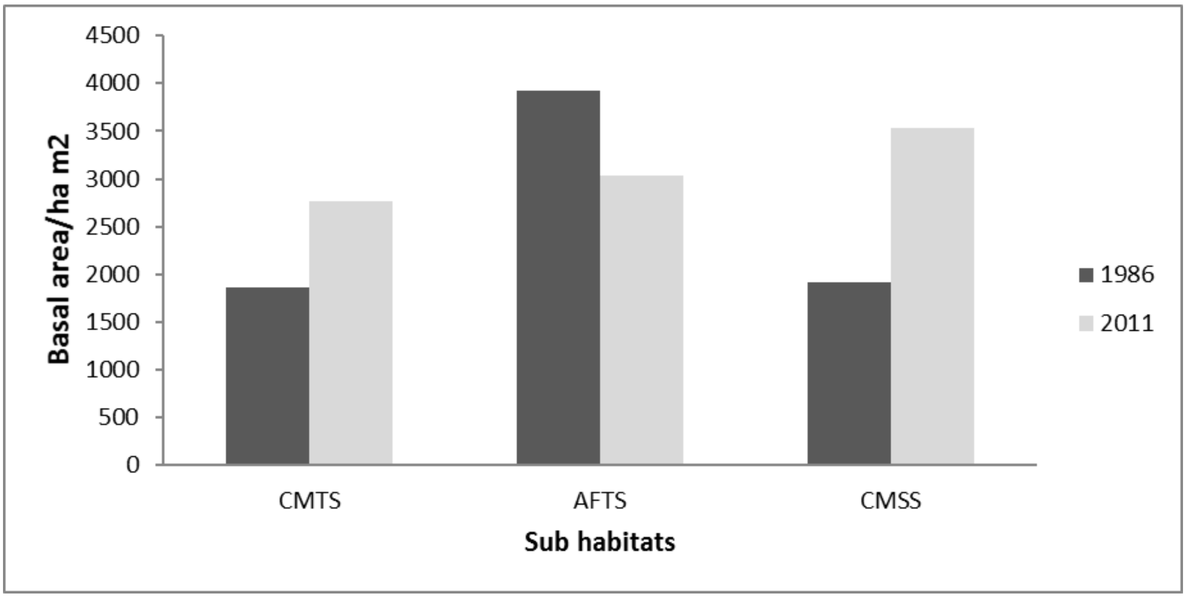


Figure 2.8: Comparison of Basal Area per sample area (per hectare) for vegetation surveys in Yankari (1986 and 2011). Results from the two way paired t-test shows no significant reduction in basal area between the two surveys ($p > 0.05$). Data represent mean values of BA per total sample area on Y axis and for the two periods across sub habitats (CMTS, AFTS and CMSS) locations on the x-axis. CMTS = *Combretum* tree savannah, AFTS = *Afzelia* tree savannah and CMSS = *Combretum* shrub savannah.

Results of the comparison of basal area per sample area for species of category HE (species used as fodder) across the sub-habitats shows clearly, the changes that occurred between the two periods. However, the results from the two way paired t-test shows no significant reduction in basal area between the two surveys.

Only *A. africana* and *S. spinosa* were recorded for the two periods. *B. aegyptiaca, P. erinaceous* and *T. indica* were not recorded in the locations Green (1986) surveyed (Figure 2.9)

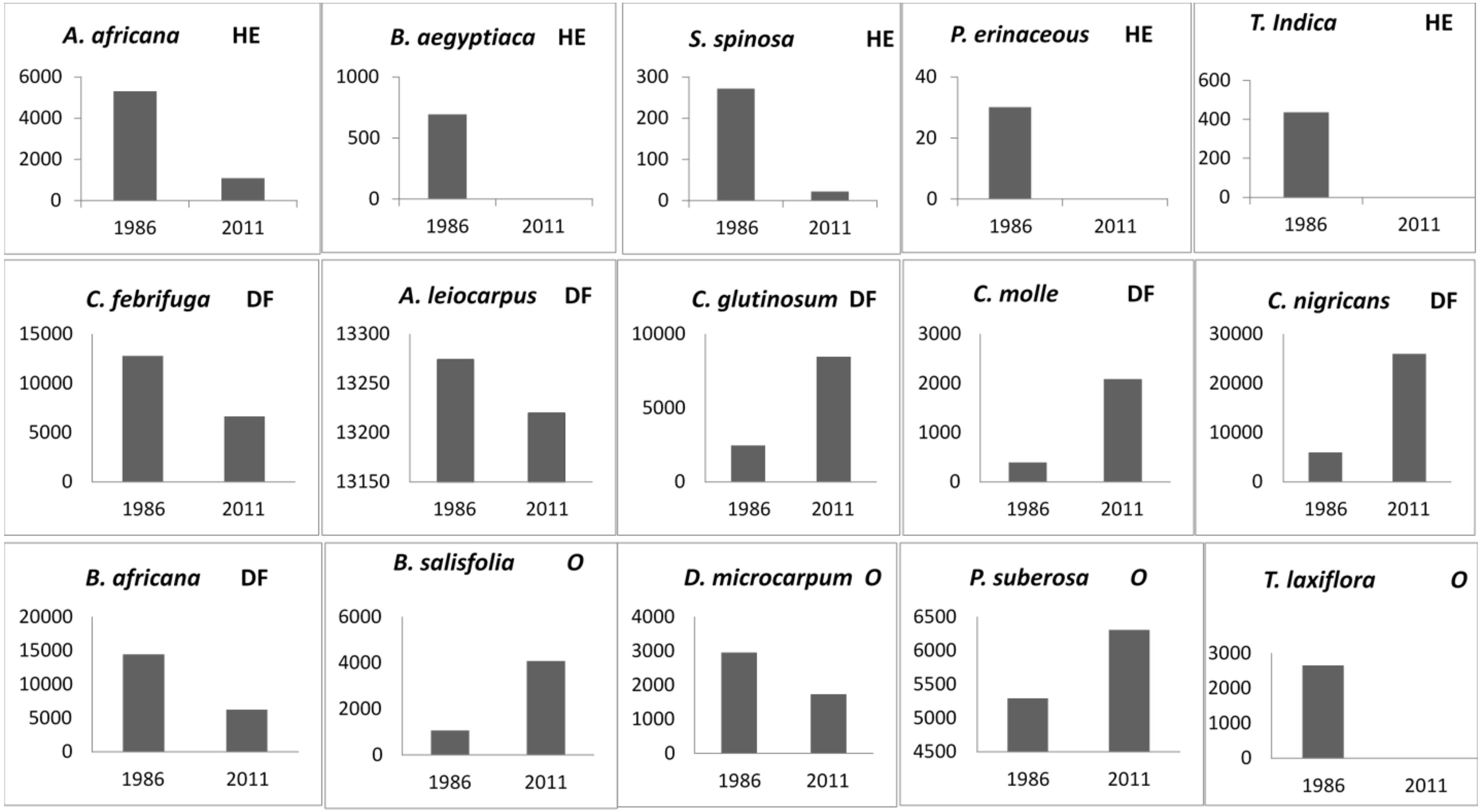


Figure 2.9: Comparison of Basal Area per sample area (m^2) of the 16 dominant woody plants (minus *Khaya senegalensis*) in Yankari (1986 and 2011). Data represent mean values of BA per total sample area for the two periods across sub habitats (CMTS, AFTS and CMSS). CMTS = *Combretum* tree savannah, AFTS = *Afzelia* tree savannah and CMSS = *Combretum* shrub savannah. HE = species preferred by herders and elephants: DF = species that are prone to drought and fire: o = other species not belonging to either of the two groups.

2.3.1.3 Non-metric multi-dimensional scaling of 16 top species

The nMDS indicated clear vegetation dominance by one vegetation type, characterized by *Combretum* species. This was revealed in general terms by the overlapping of the sub habitats (Figure 2.7). Results for spatial comparison of sub-habitats revealed the composition of the species, together with a significant similarity for the savannah sub-habitats. It also showed that some species were common to both savannah and riparian forest, as seen in the overlaps in figure 2.10. CMTS and CMSS are the closest in similarity, as approximately 75% of the total area of CMSS overlap with CMTS. The AFTS sub-group also shows an almost 50% similarity to the CMTS. The most dissimilar habitats are the RP and the AFTS, as they do not overlap at any point and are the farthest from each other.

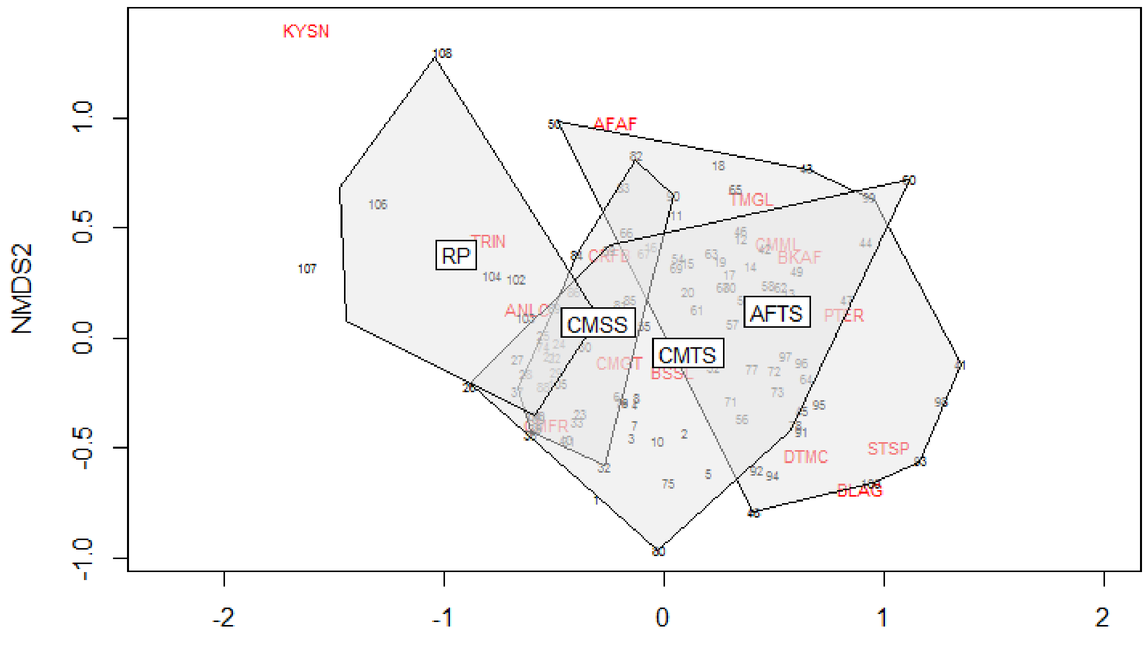


Figure 2.10: Non-metric multidimensional scaling (nMDS plot, Stress = 0.24) on the basis of the Bray-Curtis dissimilarity measure calculated count data of the sub habitats in Yankari Game Reserve, Nigeria. RP: riparian forest, CMTS*:* *Combretum* tree savannah*;* AFTS represents *Afzelia* tree savannah and CMSS represents *Combretum* shrub savannah. Species are in red letters: KYSN = *Khaya senegalensis; AFAF= Afzelia Africana;* TRIN = *Tamarindus indica;* ANCL =*Annogasius leiocarpus*; CRFB = *Crossopteryx febrifuga*; = TMGL = *Taminelia glausecence:* CMML = *Combretum mole:* BKAF = *Burkea africana:* PTER= *Ptericarpus erinacous:* CMGT = *Combretum glutinosum:* BSSL: *Boscia salicifolia:* CMFR = *Combretum fragrans*; DTMC= *Detarium microcarpum;* STSP= *Strychnos spinose;* BLAG = *Balanite aegyptiaca*

2.3.2 Spatial and temporal changes from remote sensing images

The variation in the distribution of the NDVI values between the years, is shown in Figure 2.11. Years 2004 and 2012 show high median values of 0.45 and 0.42 respectively, while years 2000 and 2009 show values as low as 0.26 and 0.30. This suggests more greenness in the years 2004 and 2012 compared to the latter years mentioned.

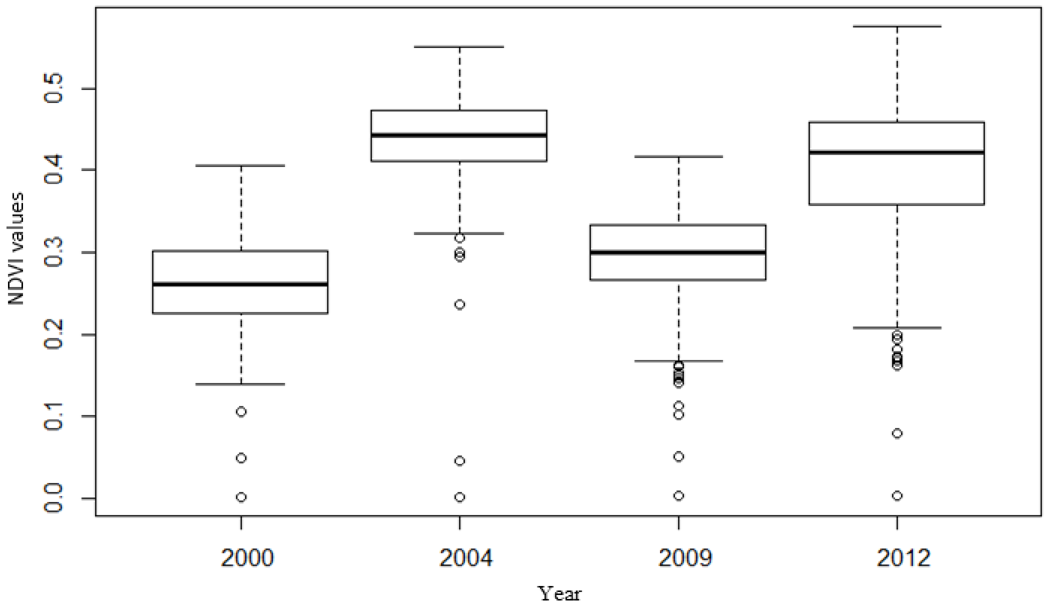


Figure 2.11: Box and whisker plots showing NDVI values on the y- axis and years sampled on the x-axis. Plots represent data of the summaries of NDVI values of years 2000, 2004, 2009 and 2012.

The mean NDVI values across the four periods were compared using ANOVA. Results show differences occur in the four years ($p = 0.0001$). Furthermore, a pairwise comparison using TukeyHSD was carried out to verify where the differences occurred in the four observations. The output indicates differences between 2012/2004 and 2009/2000 as significant. . Figure 2.12 shows the confidence interval of the comparison.

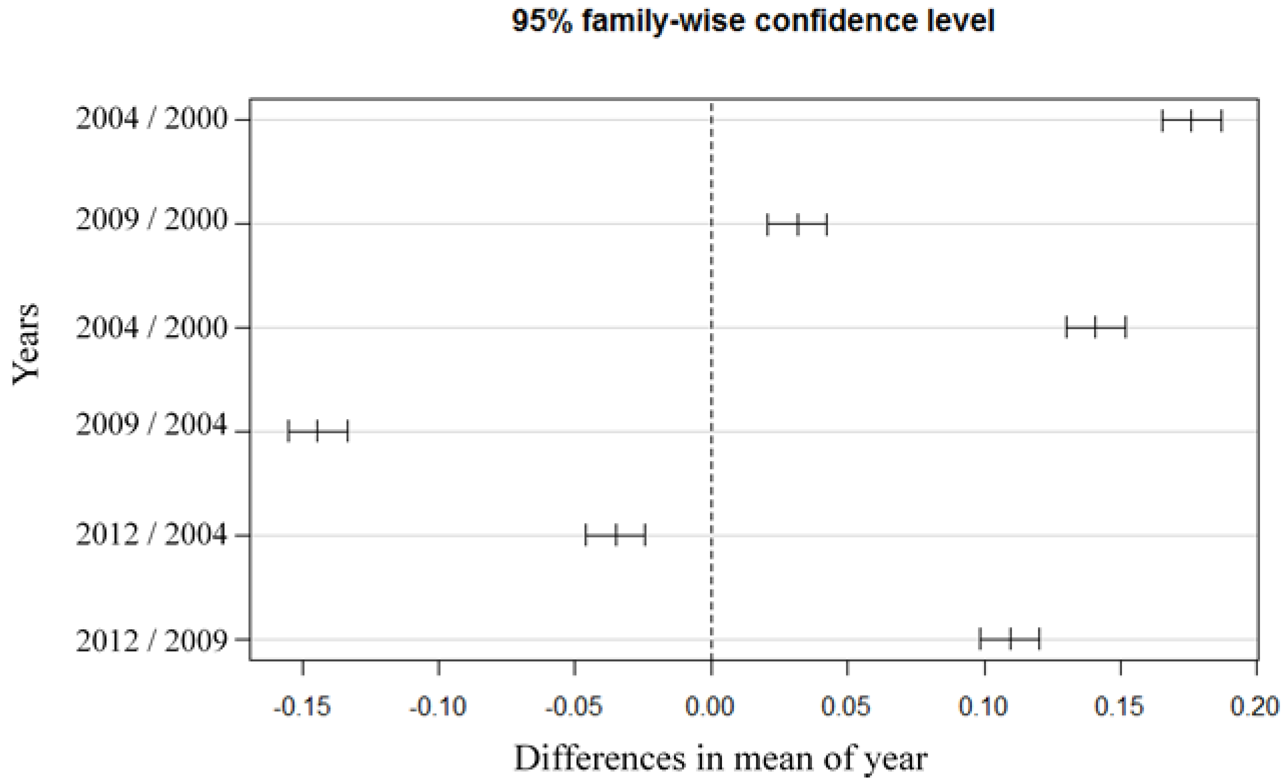


Figure 2.12: Confidence interval of TukeyHSD multiple comparison of means at 95% family-wise confidence level. Y - axis = comparison between years and x – axis = differences in means of the years compared.

2.4. Discussion

2.4.1 Overview of findings

In this study, our findings demonstrate that the woody vegetation of Yankari had changed over time, and that the direction of the change is not the same for all woody species. Most species belonging to Combretacaea family, have increased in abundance, while other species suggest a decline in abundance. The species that have declined are multipurpose species, but commonly used as livestock fodder in the West African region. This study is in line with the study of woody encroachment in sub-Saharan woodland (Mitchard and Flintrop, 2013). The study found evidence that both forest loss and gain are occurring widely throughout Africa. They concluded that the size of land undergoing woody encroachment can be comparable, or can even be larger than that undergoing forest loss. Most of the increase is in the woodland and savannah of sub-Saharan Africa north of the equator, whereas in the Miombo woodland regions (Tanzania), south of the equator, forest loss appears to be dominating. However, this conclusion contains a high degree of uncertainties, owing to potential artefacts in the GIMMS dataset, and regional variation in the relationship between NDVI and woody cover (Mitchard and Flintrop, 2013).

2.4.2 Characterization of 16 dominant woody plants of Yankari

The species accumulation models have provided a visual assessment of the four habitats sampled. The *Combretum* tree savannah and *Afzelia* tree savannah have more species diversity than either of *Combretum* shrub savannah and the riparian forests. Moreno and Halffter (2000) have used the same method to evaluate the completeness of inventories of bats, and to provide valid comparisons among inventories. They argued that the species accumulation curves can be used to assess the inventories of any other group. However, Willott (2001) is concerned that the measure that was used to estimate their sample effort is not the appropriate one to compare species accumulation curves among different habitats. Nevertheless, our results is in line with the baseline result, where Green (1986) found lower diversity in the *Combretum* Shrub savannah compared to others. With the riparian forest curve, it may not be possible to rule out the fact that the results may be biased based on the premise that fewer plots were surveyed.

Historically, the woody vegetation of Yankari is characterized mainly by shrubs but with big trees in the riparian forests. Size class distribution (SCDs) of the 16 most-abundant woody plantss tilted towards typical saplings distribution as SCDs show dominance of class 0-10 cm DBH of the six size classes for the 16 key species analysed. The two most-dominant woody plants being C. *nigricans* (1, 300 individuals) and the *C. glutinosum* (about 600 individuals) belong to this class (see, Figure 2.4). The high proportion of stems in the smallest size classes of 0 to < 10 cm implies that most *C. nigricans* individuals and *C. glutinosum* have the natural ability to regenerate (Hennenberg *et al.,* 2005). However, the larger tree species i.e. *A. africana, K. senegalensis, P. erinaceus, B. africana, B. aegytiaca, T. indica* and *A. leiocarpus* showed irregular distributions. Although *B. africana* and A. leiocarpus had many individuals, the saplings classes dominate with 30 and less individuals in few other classes. *A. africana, K. senegalensis, P. erinaceus* and *T. indica* had few individual species. This made it difficult to draw conclusions on their distribution at this point.

In a similar study, Neelo *et al.,* (2013) reported SCDs in five groups: species in his first grouping exhibited reverse J-shaped distribution, which indicated stable population structures as also reported by Lykke, (1998) Conduit *et al.,* (1998). Species in the second group showed relatively good recruitment but the regeneration was negatively affected and his third grouping was a combination 3, 4 and 5 of his initial groups and he reported that this group exhibited hampered regeneration, as a result of disturbances caused by humans, domestic animals and annual fires. Additionally, Lykke (1998), observed in her study that many species, particularly large trees, have few young individuals, and therefore flat SCDs that deviate from the reverse-J shape SCDs characterizing species with abundant and constant rejuvenation. She concluded that most of the flat distributions analysed were the effects of the decline in population sizes caused by human impact, particularly fire. The findings of these authors give an insight into the possible irregular distribution of the SCDs found in this study and suggests that a more extensive research to investigate the abundance and population structure of these species will be beneficial.

Vegetation community ordination and dissimilarity analysis gave the opportunity to visualize the abundance and composition of the species over the habitats of the reserve. The overlaps suggest that there is a significant similarity in species composition across the habitats. The dominance and spread of *C. nigricans* and *C. glutinosum* are likely to be responsible for this. The Geerling (1973) and Green (1986) classification of six separate classes therefore, is not reliable. As *C. nigricans* and *C. glutinosum* are now widely spread in the savannah habitat and extend to the riparian habitat, it can be inferred that there has been a major change in woody vegetation composition.

2.4.3 Spatio-temporal comparison between 1986 and 2011 results.

2.4.3.1 Increasing populations of some woody species

Combretum tree savannah and *Combretum* shrub savannah showed increase in mean basal area between 1986 and 2011. Most of the species belonging to these habitats are of Combretacaea family occurring predominantly in the savannah habitats and extending to the riparian forest. *C. nigricans* and *C. glutinosum* are the two most dominant woody plants in Yankari. Both plant species are widely spread extending to the riparian forest. Although the species have been reported to be both fire and drought prone in some related studies (Keay, 1950; Green, 1986), yet, other studies reported these species as drought tolerant, fast growing and profuse (Sakandé and Sanon, 2007) and recommended that *C. nigricans,* among other species, are potentially usable for vegetation recovery programs. Furthermore, the findings of this study are consistent with research from East Africa, where *Combretum* and *Terminalia* species dominated savannah woodland (Lewis and Berry, 2011). Lastly, *C. molle, B. salistifolia and P. suberosa* also showed increases in mean DBH between the years (Figure

2.6), amongst the three species, *C. molle* showed a more than twofold increase in DBH. This follows the trends of the other Combretacaea species previously mentioned as dominants in Yankari.

2.4.3.2 Decreasing populations of some woody species

Afzelia tree savannah is the only one of the three *(Afzelia* tree savannah, *Combretum* tree savannah, *Combretum* shrub savannah) that showed a decline in species basal area for the periods of 1986 and 2011. This sub-habitat contains species that are highly utilized as cattle fodder. These species (*A. africana, T. indica, B. aegyptiaca* and *K. senegalensis*) are also preferred species for elephants and other wild herbivores (Geerling, 1973; Tchamba and Mahamat, 1992; O'Connor *et al.,* 2006). All individuals of *A. africana* encountered showed evidence of harvest. Similarly, many individuals of *S. spinosa* and *P. erinaceous* showed evidence of harvest that is similar to patterns of harvesting in African dry lands. Individuals of *S. spinosa* were cut into halves so that the upper leafy part falls to the ground to enable the smaller animals (sheep and goats) to feed.

Geerling, (1973) and Green and Amance, (1987) reported the pressures that elephants inflicted on *B. aethiopium* and *A. digitata*, and feared they may not survive the destruction in the riparian forest because of elephant activities. Their observations are in agreement with the findings of this study. The author observed that there were very few individuals of *A. digitata* and *B. aethiopum* remaining in Yankari. A probable reason for this may be that the fruits constitute the main diet of the baboons and the elephants during the dry season.

The results from the plot survey also corroborated that *C. pendunculata* had greatly declined in Yankari. There is no basis to conclude that these plants have totally disappeared from Yankari, but rarity has clearly increased. *A. africana, K. senegalensis, B. aegyptiaca, T. indica* are important species in the Yankari and surrounding local communities, and these are heavily utilized by people and wild and domestic herbivores (Geerling, 1973; Green, 1986; Tiseer, 2009). The reduction in these trees could therefore have consequences for large wild herbivores through a change in forage quality (Ludwig *et al.,* 2008), habitat loss and possible reduction in species (Jan van Wagtendonk, 2009). Fewer large trees will ultimately slow forest regeneration after fires, as large trees are known to be more fire-tolerant than smaller trees (Jan van Wagtendonk, 2009).

Furthermore, other species (*C. febrifuga, A. leicarpus, T. Laxiflora, D. Microcarpum* and *B. Africana*), that were not classified as fodder in this study, also reduced in mean DBH between the two periods. *A. leicarpus*, though belonging to the Combretacaea family, has been reported to be used, to a great degree, for both domestic and commercial purposes and is a browse species in Sudano-sahelian regions (Tézenas du Montcel, 1994). It is a species very sensitive to fire, but recommended also for reforestation (Andary *et al.,* 2005).

2.4.4. NDVI analysis of vegetation cover

NDVI analysis indicated a fluctuating trend; this is cyclical for the vegetation of Yankari, and may be as a result of the short period of study. The year 2012 particularly showed an increase in abundance of vegetation cover compared to the previous years. The spectral analysis could not go beyond a general assumption of increase. Whether or not the increase was limited to particular species, was not easily detected as the Landsat images assessed were of low resolution and lacked the capacity to show clear features. Ground truthing would have served as a tool to verify and validate some of the suggested findings, but that is beyond the scope of this study.

The Post-hoc TukeyHSD tests revealed significant difference between the mean NDVI values of 2012; 2004, and 2000; 2009. This implies that significant changes in vegetal cover have occurred between the periods. The patterns and extent of changes will be interesting to further investigate in this study and that should be able to give pointers to inform monitoring or initiate relevant management initiatives (see chapter 4).

2.4.5 Implication for conservation and management

There is clearly a change in the structure and composition of the woody vegetation of Yankari between the baseline survey and our study. The decline of trees used as fodder is also evidenced by the comparison between the two surveys. Overall, if fodder plants populations continue to decline, local extinctions are possible. Given the trends of decline, further investigation to assess the current abundance and population structure of the fodder plants, and also investigate the harvest patterns and extent is necessary and urgent.

The sensitivity of the response of semi-drylands and drylands to the adverse impacts of climate change cannot be over-emphasized. Climate change compounds the impacts of drivers of vegetation changes, besides, other factors as warmer conditions are said to increase the length of the summer dry season (Boko *et al.,* 2007), which may affect the phenology of some of these fodder plants. A longer dry season in the summer, can also reduce tree growth and vigour, and can reduce the ability of trees ability to resist insects and pathogens, according to Jan van Wagtendonk (2009) and Lutz *et al.*, 2009). Therefore, a study of climate impacts should be considered as it will be beneficial for Yankari and similar protected areas within the Savannah systems.

This study is the first extensive woody vegetation study since the baseline survey. The period between the two studies is 25 years. This is a long time considering the threats to vegetation and habitats of Yankari. More regular surveys and vegetation monitoring should be introduced and should now be straightforward as this study has georeferenced the survey plots which makes repeatability easy.

2.5. Conclusion

This study found that the woody vegetation of Yankari has changed over time. The change is two dimensional, while there is a general increase in most species belonging to Combretacaea family, there is evidence of decline in species commonly used as livestock fodder in Yankari. The scope of the study did not include the investigation of the causes of increase or decline in the woody vegetation, although the previous studies (Geerling, 1973; Green and Amance 1986; Green, 1987), have highlighted threats (elephant numbers, climate, fire activities and human activities) to the woody vegetation in Yankari at the time of their studies. Rainfall, for example, is the greatest influence on vegetation in the tropics (Pielke, 2001; Zelazowski, 2011; Gereve *et al.*, 2011; Swann *et al.,* 2012), yet there have not been any climate-related studies done in Yankari. Wildfires, as well as early annual burning undertaken by the rangers in Yankari have been reported as greatly influencing the woody vegetation, yet no quantitative studies have been carried out on trends in fires.

It will be interesting to investigate the trends in the drivers, particularly from the period the baseline study covers. Therefore in chapter 3, assesses the trends in the drivers of woody vegetation change in Yankari (elephant numbers, climate, fire activities and human activities) from the 1980s to present time. The evidence of change in the drivers (increase or decrease), should provide some quantitative basis for conservation initiative, for patrols and monitoring.

Yankari is a heterogeneous landscape where many things are taking place simultaneously e.g. ecotourism, research, field excursions for pupils, and anti-poaching activities by different NGOs etc. Furthermore, a combination of direct (such as poaching, hunting, livestock grazing) and indirect pressures (such as lack of vehicles for patrols, weak laws, poor funding) inhibit any reasonable efforts towards adequate management of the game reserve. A study such as this will therefore inform, direct, and help prioritize the conservation needs of Yankari.

Trends in Potential Drivers of Savannah Vegetation Change in Yankari Game Reserve, Nigeria.

Abstract

Relatively little is known about the dominant threats to African Savannah systems and how these threats interact. Yankari Game Reserve (Yankari), Nigeria, was used as a case study to examine trends and drivers of woody vegetation change in the reserve. The work builds on previous studies by Geerling (1973) and Green (1986), which highlighted elephant activities, droughts, fire and human activities as the drivers of the woody vegetation in Yankari. Elephant population studies in Yankari (1964-2011) were collated and trends over time were examined. Potential evapotranspiration (PET) was estimated from climate data (1961-2010), obtained from Nigerian Meteorological Agency (NIMET). MODIS active fire and burnt area products were used to determine trends in dates and incidences and to calculate frequency of burning (2000-2014). Landsat 5, 7 and 8 land cover images were used to estimate park incursion over time. Among the key findings are a climate with high variability in annual rainfall, prevalence of droughts and fire scars throughout the reserve except in the area bisecting Yankari and park edges to the west. Climate appears to be an important driver of woody vegetation. The trends are also consistent with global climate change effects, most likely due to high inter-annual variability in rainfall. However, trends in elephant population seemed ambiguous because of the different methods used in the previous surveys. It was also found that there was prevalence and increase in human activities at the boundary of Yankari. In 2013, encroachment has extended into Yankari. There were difficulties in reconstructing historic trends in drivers of woody vegetation change but the combination of climate and human activities suggests negative impacts on woody vegetation that require urgent monitoring and intervention

3.1 Introduction

There exists controversy globally on whether the widespread changes in the woody cover of the savannah are driven by local or global drivers (O'Connor, 1985; Archer *et al.,* 1995; Sankaran *et al.,* 2005; Wigley *et al.,* 2010), and the scale-dependent interactions between these drivers (Scholes and Archer, 1997; Bond, 2008; Sankaran *et al.,* 2008; Staver *et al.,* 2011). The most likely drivers of local change in woody vegetation would include changes in land use, for example, heavy stocking and associated over-grazing (Archer *et al.,* 1995; Van Langeveld *et al.,* 2003; Fensham *et al.,* 2005), burning activities (Bowman *et al.,* 2001; Briggs *et al.,* 2005; Brook and Bowman, 2006), and exclusion from fire and grazing (Muller *et al.,* 2007; Wigley *et al.,* 2010). Potential global drivers of woody vegetation change include climate change and rainfall (Fensham *et al.,* 2005), atmospheric nitrogen deposition (Brown and Archer, 1989), and elevated CO_2 (Polley, 1997; Bond and Midgley, 2000; Hoffmann *et al.,* 2000; Bond *et al.,* 2003). It is often difficult to unravel the effects and evaluate the relative importance of global versus local drivers (Archer *et al.,* 1995; Hoffman and Todd, 2000; Wigley *et al.,* 2010). However, dissection of the relative importance of these drivers can provide valuable insight into the dynamics of the savannah ecosystem (House *et al.,* 2003; Sankaran, *et al.,* 2004).

Savannahs cover the majority of annual global burned areas (Scholes and Archer, 1997; Archibald *et al.,* 2013; Lehmann *et al.,* 2014). Fire is a prominent change agent, affecting ecosystem structure and the cycling of carbon and nutrients, as well as a globally-significant cause of greenhouse gas emission (Srivastava and Garg, 2013). Wildfires have played a determining role in the distribution, composition and structure of many ecosystems worldwide, and climatic changes are widely considered to be a major driver of future fire regime changes (Pausas and Keeley, 2014). Prescribed burning is used as a management tool in many of the world's savannah ecosystems. Hundreds of millions of hectares of savannah areas are burned annually (Hao *et al.,* 1990), making tropical grasslands the most frequently and extensively burned biome in the world (Hao and Liu 1994; Barbosa *et al.,* 1999; Bond *et al.,* 2005). Most fires occur in sub-Saharan Africa, where savannah fires account for nearly two-thirds of the global burned area (FAO, 2007). Although fires can result from natural causes such as lightning, the majority of present-day bush fires are of anthropogenic origin (Bond and Van Wilgen 1996). Fires are used for a multitude of reasons, including land clearance for agriculture, providing breaks around fields or villages, and clearing paths (Laris

2002). Therefore, mapping the timing and the extent of fires is important (Srivastava and Garg, 2013) as fire effects are reported to change vegetation composition and structure (Goldammer and Price, 1998; Collins and Calabrese, 2012) and are expected to increase with the impacts of human induced climate change (Stocks *et al.,* 1998; Dale *et al.,* 2001; Flannigan *et al.*, 2000, 2009).

In African savannah ecosystems, elephants are considered important in structuring plant communities (Penzhorn *et al.,* 1974; Owen-Smith, 1988; Moolman and Cowling, 1994; Lombard *et al.,* 2001; Conybeare, 2004), and in influencing ecological processes such as trampling, seed dispersal, and nutrient cycling (Boshoff *et al.,* 2001). Elephant herbivory is also responsible for changes to plant richness, density and biomass (Barratt and Hall-Martin, 1981; Midgley and Joubert, 1991; Lombard *et al.,* 2001; Kerley and Landman 2006; Hayward and Zawadzka, 2010), and has the potential to severely reduce the foraging opportunities of co-occurring browsing herbivores (Landman and Kerley, 2006).

The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4; IPCC 2007) established that climate change will have serious impacts on many aspects of biological diversity and on ecological interactions. These impacts will result in long-term instability of natural resources and their benefits and services to human livelihoods. Additionally, the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) re-confirmed that: i) The future of African ecosystems are already affected by climate change, and future impacts will be to be substantial; ii) Beyond the impacts of land-use change and other non-climate stressors, there appears to be shifting ranges of some species and ecosystems due to elevated CO_2 and climate change; and iii) Over the past 50 years, near surface temperatures have increased in West Africa.

Furthermore, temperatures in Africa are projected to rise faster than the global average increase during the 21st Century (Christensen *et al.,* 2007; Joshi *et al.,* 2011; Sanderson *et al.,* 2011; James and Washington, 2013). In a related study, Collins (2011) showed significant warming of between 0.5-0.8 degrees between 1970 and 2010 over the region using remotely sensed data with a greater magnitude of change in the latter 20 years of the period compared to the former. Recurrent droughts over the past decades and rates of desert encroachment in this region have been widely recorded and documented (Mortimore, 1989; Wiggins, 1995; Batterbury, 2001; Dai *et al.,* 2004; Mortimore, 2010; Dai, 2011). Additionally, the effects of these droughts have been seen, for example, in poor harvests and shortages of food (Mortimore, 1989; Wiggins, 1995), livestock mortality (Kloos and Zein, 1993; Barbier *et al.,* 2009), and forced and increased human migration rates southwards (Afolayan *et al.,* 1999; Olsson *et al.,* 2005; Bassett and Turner, 2007). These effects have increased the vulnerabilities of the rural poor to cope with adverse effects of climate change.

These impacts will result in long-term instability of natural resources and their benefits and services to human livelihoods. Research from three principal sources: direct observation (Parmasan and Yohe 2003), experimental studies (Morgan *et al.,* 2006; Bloor *et al.,* 2008; Hovenden *et al.,* 2008) and modelling studies (Botkin *et al.,* 2007; Martinez-Meyer *et al.,* 2004; Nogués-Bravo *et al.,* 2008) have strengthened the key findings of the time of IPCC AR4. Consequent to this, adaptation strategies are needed to respond to these impacts.

There is currently little certainty regarding the ongoing human-driven global changes and how they will have major impacts in West African savannah ecosystem. Historical biome distributions were affected by humans in some areas (Willis *et al.,* 2004; Mayle *et al.,* 2007), but modern human activities such as expansion of agro-pastoralism and increased ability to create and manipulate fire are much more extensive and intensive (Staver *et al.,* 2011). In the West African savannah, the impacts of the changes, are unlikely to be smooth or easily reversible. Alternatively, historical records can provide critical insights into former landscape conditions and processes, and reasons for subsequent changes (Foster 2000; Whitney and DeCant 2005; Rhemtulla *et al.,* 2009). Although it has been established that woody vegetation had changed over time and the direction of the change has not been the same for all woody species (see chapter 2), there exists limited knowledge on the extent and trends in drivers of woody vegetation change and their synergies in Yankari.

Previous studies of Yankari (Geerling, 1973; Green, 1987) have highlighted some drivers of the woody vegetation at the time. These drivers include elephant activities, droughts, fire activities and human activities. Green (1986), in his report on the human activities on Yankari has a detailed description of the activities of poachers and livestock grazing in Yankari (Appendix 1). In 1996, Malachi Amance in his letter to Arthur Green reported:

"…the influx of Fulani herds has greatly increased in the whole area. Their incursions into the park is really serious in spite [sic] of the arrests and prosecutions taking place at the local courts……From January to March of this year, there were 130 days [sic] and 42 night patrols that resulted in the arrests of 56 poachers/herdsmen (only ten of which were game hunters – the remaining 46 of which were herdsmen…with the coming of [sic] the oncoming of the raining season, the Fulani move North. Neither Fulani nor game poachers were arrested in June."

Although there are few known studies and reports carried out on the drivers of woody vegetation, no study has investigated the trends in these drivers. Consequently, Yankari serves as a good case study in West African savannah. The sources of data collated for this study provide time series observations from reliable sources. Therefore, the sources present potentials to understand the trends in drivers of woody vegetation change in Yankari. The study asks the question: what are the trends in drivers of woody vegetation change in Yankari Game Reserve, from the 1980s to 2011? To answer the question the author carried out the following tasks.

- Investigation of the trends in the elephant population of Yankari, between 1980s 2011
- Investigation of the trends in the climate of Yankari, between 1980s 2011
- Investigation of the trends in fire activities for Yankari, between 1980s - 2011
- Investigation of the trends in human activities in Yankari between 1980s – 2011

3.2. Methods

3.2.1 Data types, sources and analysis

3.2.1.1 Elephant population estimates

Historical trends in the population of elephants were compiled from a variety of sources, including scientific literature, using databases such as Web of Knowledge, Science Direct and Google Scholar. Published and unpublished reports were obtained from libraries and by contacting the authors. In addition, observations and informal interactions with rangers and staff of Yankari provided additional useful information.

A total of nine studies were identified; eight of the studies estimated elephant population below 500, but one study (Mohammed *et al.,* 2009) was excluded as estimates in elephant numbers and other mammals were exaggerated (not consistent with other studies), reporting elephant estimates as 8000 individuals. Such numbers as reported can only be found in East and South Africa, and not West Africa (Wittemyer *et al.,* 2013). Furthermore, the timing of surveys was not consistent and also not systematic. Therefore, the data gathered were scattered between the surveys of Sikes (1964) and Bergl *et al.,* (2011). The nine studies included in this research were carried out by 3 main methods: ground surveys, informed guesses and aerial counts. The aerial counts are the more recent surveys (Nicolas, 1999; Omondi *et al.,* 2006 and Bergl *et al.,* 2011).

The elephant population studies in Yankari (1964-2011) were collated and the elephant density (number of elephants/total area of Yankari) calculated for each study (Said *et al.,* 1995, Barnes *et al.,* 1998, Blanc *et al.,* 2003, 2007). The estimate of each elephant population was plotted, and trends over time were examined visually. This was to determine any trends in elephant numbers in Yankari (Bouche *et al.,* 2011). This method is similar to that used in the study carried out in Addo, a South African national park (Boshoff *et al.,* 2002). There was limitation in the choice of analyses because of the incomparable methods in data collection. Three main methods of the estimation of elephant population were identified in eight reviewed studies. In one particular study, lower and upper limits (i.e. 300 – 500) of elephant population estimation was reported (Geerling, 1983). In another study, the writer inferred that "at least there were 100 elephants in Yankari" (Henshaw, 1979). The author therefore decided that calculating the population density of the elephants and presenting the estimates for individual study is the most justifiable way to deal with this inconsistency/situation.

3.2.1.2 Climate data

Data were obtained from the Nigerian Meteorological Agency (NIMET) on the following climate parameters: monthly annual rainfall (1961-2010), minimum and maximum average monthly temperatures (1961-2010), daily solar radiation (1971-2013), relative humidity (1971-2006) and daily average wind speed from the nearby Bauchi airstrip (10°17′35″N 9°49′50″E / 10°.29′30″N 9°.83′05″E). The climate data from the Bauchi airstrip served as proxy for Yankari as both locations are on the same Isohyets and the distance between the two locations is 135 km. Bauchi airstrip serves as the nearest and most reliable climate data source suitable for this study.

Five years of rainfall data from Yankari was compared with records from the Bauchi airstrip. The rainfall data were collected in Yankari between1982-1986 (Green and Amance, 1986). Pearson product-moment correlation coefficient was used to correlate the data from the two sites. The fifty years' climate data for Bauchi airport was summarised by calculating averages, and plotting simple line graphs to show the trends in annual rainfall and average maximum temperatures. Furthermore, the aridity index (AI_U) for Yankari was estimated using the UNEP (1992) formula:

$AI_U = \frac{P}{PET}$ where, PET is annual potential evapotranspiration, and P is the average annual precipitation; both are expressed in millimetres. The boundaries that define various degrees of aridity and the approximate areas involved are shown in Table 3.1.

Table 3.1: Global classification of aridity index (UNEP, 1992)

Classification	Aridity Index	Global land area
Hyper-arid	AI < 0.05	7.5%
Arid	0.05 < AI < 0.20	12.1%
Semi-arid	0.20 < AI < 0.50	17.7%
Dry sub-humid	0.50 < AI < 0.65	9.9%

Several methods exist (Penman equation, Thornthwaith's, Turc's and Blaney's formulae) for calculating potential evapotranspiration (PET) from meteorological variables (FAO, 2013; Prudhomme, 2013). In this study the Penman equation was used to calculate the PET. PET is an estimate of the maximum volume of water that could pass into the atmosphere if the water supply was unlimited. Temperature trends can be used to infer changes in potential evapotranspiration: temperature presents a reasonable, but not perfect, correlation with evapotranspiration (Dai, 2011; Sheffield *et al.*, 2012) though it is not clear that the relationship will remain constant in a changing climate.

3.2.1.3 Fire data

Fourteen years' MODIS Active fire and burnt area products were downloaded from the United State Geological survey (USGS) site.

The 2000-2014 fire data were analysed for the Yankari Game Reserve. By using MODIS Active Fire in ArcGIS, fire data for one-year (October to April of a new year) can be obtained. This includes time and dates of fire occurrences. The onset and cessation of each fire, as well as the peak of fire activities, can be determined. Allowing fire seasonality and fire frequency for Yankari to be assessed. The data from the Burned Area Product was originally in Hierarchical Data Format - Earth Observing System (EOS – hdf) format, but had to be converted to raster, which is compatible with the ArcGIS software used for the analysis. The process of producing a raster map included using the data management tools to merge and clip the tiles to the boundary layer of Yankari. The raster calculator was used to calculate and add fourteen raster maps for the 14 years' period. Under the Spatial analyst tools, reclassify tool was used to create three classes: 0 = unburned, 1 = burned and No Data = absence of Data. Finally, the area calculation was done using the attribute table. Total burned area was multiplied by 463*463 (the area of the pixel) and data was exported to Excel for analysis

Fire analysis was conducted on yearly data layers from November 2000 to April 2014, which combined to calculate the number of times a pixel burned during a fourteen year period (fire frequency). Pixels that showed no status (neither burn nor unburned) were included in the processing for the fourteen seasons. This yielded a 500-m resolution map of the number of burns in fourteen years (ranging from 0 to 14 burns). By extracting times and dates of fire incidences from the MODIS Active Fires product, the averages of onset, cessation and peak activities of fire were all determined on a monthly basis. This provided the estimates of season and fire frequency for the Yankari.

3.2.1.4 Human impacts

Landsat 5, 7 and 8 images covering the area of Yankari and its surrounding environment were selected and downloaded from the USGS website based on clarity of the images, time of year, and years to give appropriate time intervals. Given the time interval used, data originated from different satellite sensors (Multispectral Scanner sensor and Thematic Mapper). The images were displayed in ArcGIS as false colour composites showing the Green, Red and nIR reflectance (assigned to the Blue, Green and Red screen elements respectively). This allowed the vegetation of Yankari to be clearly distinguished from urbanisation and agricultural fields. However, attempts to classify the images, in order to try and create a land use image, failed to produce satisfactory results. So it was decided to manually digitise the urban and agriculture location within 5km of the Yankari border, and their areas were calculated.

To estimate the human impacts a 5 km buffer was calculated from the boundary of Yankari. The drawing tool from ArcGIS was used to draw polygons around the areas visualized as being urbanised within the buffer zone. The total area of the drawn polygons was calculated for each year, and bar graphs plotted to show the increase in urbanization from 1986 to 2013. This analysis was subjective as visual estimates were used to determine the areas urbanized. However, polygons drawn around the areas are consistent across the years. Additionally, for 2013, polygons were drawn inside the reserve due to obvious encroachment extending within the boundary. Table 3.2 shows the data sources and periods covered by the data used for this study.

Table 3.2: Secondary data sources and time periods covered for the study of the four main drivers of woody vegetation change in Yankari.

Driver	Data source	Time covered
Elephants	Eight elephant surveys done in Yankari, Nigeria. From web and published and unpublished reports of Yankari.	1964 - 2011
Climate	Fifty years climate data: rainfall data, temperature (minimum and maximum data), relative humidity, radiation and sunshine of Bauchi airport (Lat. 10.30; long. 9.82), from Nigerian Meteorological Agency	1961 - 2010
Fire	14 years MODIS Active fire and burnt area products: http://modis-fire.umd.edu/Active_Fire_Products.html http://modis-fire.umd.edu/BA_getdata.html	2000 - 2014
Human	Landsat 5, 7 and 8 satellite images were accessed and downloaded from USGS.	1986, 1999, 2006 and 2013

3.3. Results

3.3.1 Elephant population trends

Surveys of elephants in the Yankari Game Reserve from 1964 suggest an increase in the population of elephants from about 150 individuals in 1964 (Sikes, 1964) to about 361 individuals in 2011 (Bergl *et al.*, 2011). This equates to an increase in population density of elephants from 0.06 elephants/km^2 to 0.16 elephants/km^2. Figure 3.1 shows the trend of elephant population estimates. The trend pre-1983 showed a decline in elephant population. Post 1983, presents an increasing trend in elephant population. There are many uncertainties caused by the different survey methods which are discussed later in the chapter.

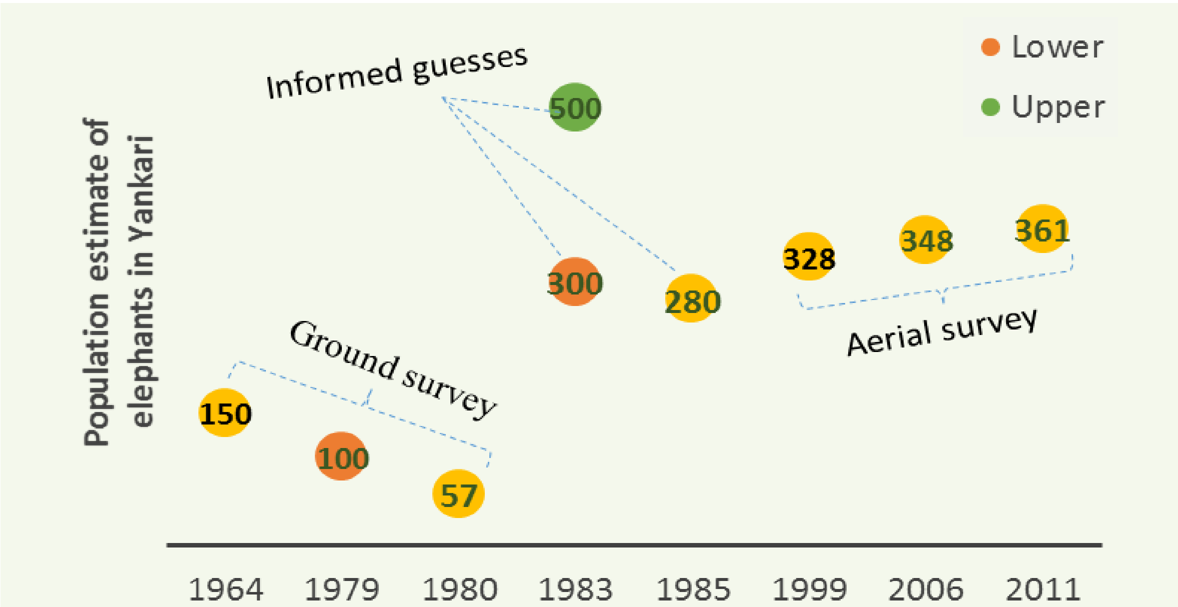
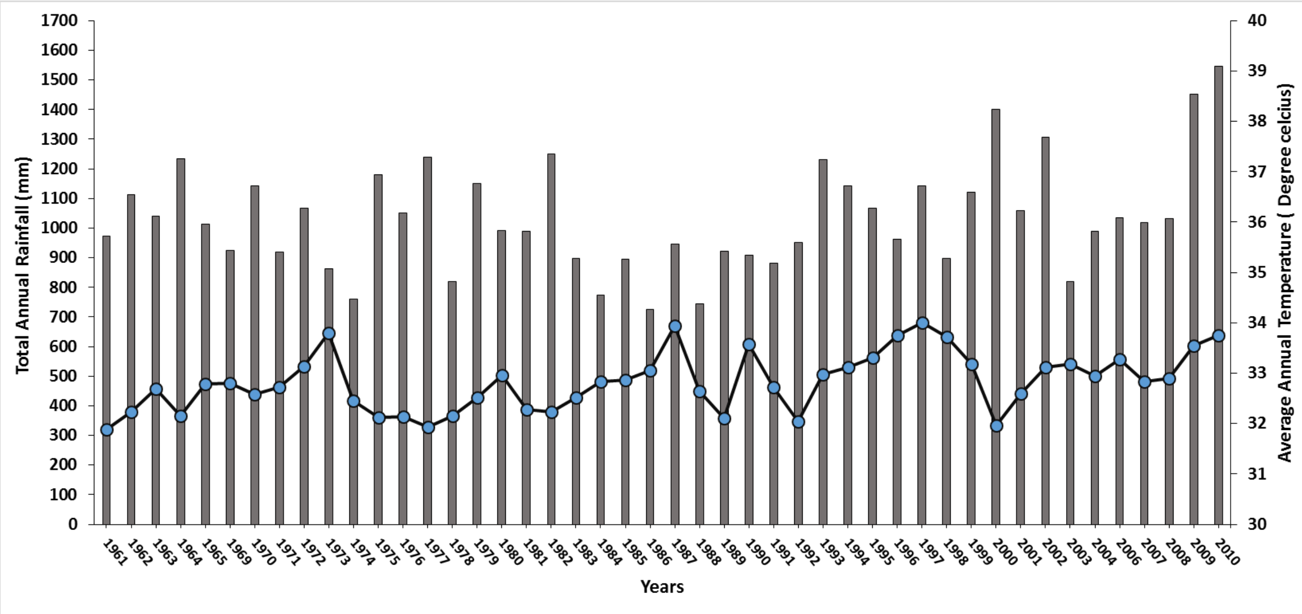


Figure 3.1: Trend in elephant population in the Yankari: Data stem from three different estimation strategies: ground surveys, informed estimates and aerial total count, conducted in the years shown on the x axis (between 1964 and 2011). Some of the studies' reported upper and lower estimates as seen on the graph (Henshaw, 1979; Geerling, 1983). Studies included in this population estimates are: Sikes, 1964: Henshaw, 1979; Afolayan and Ajayi, 1980; Geerling, 1983; Marshall, 1985; Nicolas, 1999; Omonde *et al.*, 2006 and Bergl *et al.*, 2011

3.3.2 Climate trend

The average maximum temperature and the total annual rainfall for Bauchi airstrip were summarized and compared across the period 1961–2010 (Fig.3.2). Figure 2 shows high rainfall variability across the years, with 1986 having as low as 725 mm mean rainfall, and as high as 1547mm in 2011. The periods 1973-1974 and 1984-1986 were drought periods, with mean annual figures below the average rainfall (900 - 1000 mm) for the Yankari and surroundings. The monthly average maximum temperatures show a more stable pattern (32° C – 34.3° C) than the rainfall figures.



.

Figure 3.2: Fifty years' climate trend in Bauchi and surroundings (1960 – 2010). Grey bars represent total annual rainfall (mm) from 1960 to 2010 while the line graph represent average annual temperature for the same period (° C). Years 1966, 1968 and 2005 are not included because of incomplete data

Similar patterns were seen in the overlapping Bauchi and Yankari climate records (Fig.3.3). There is a strong positive correlation between the two data sets (r- 0.84), which shows they are strongly linked together. However, the Bauchi rainfall figures were generally higher than those for the Yankari. Therefore, there is some evidence that the Bauchi airport data can be used to determine the trends in the Yankari data.

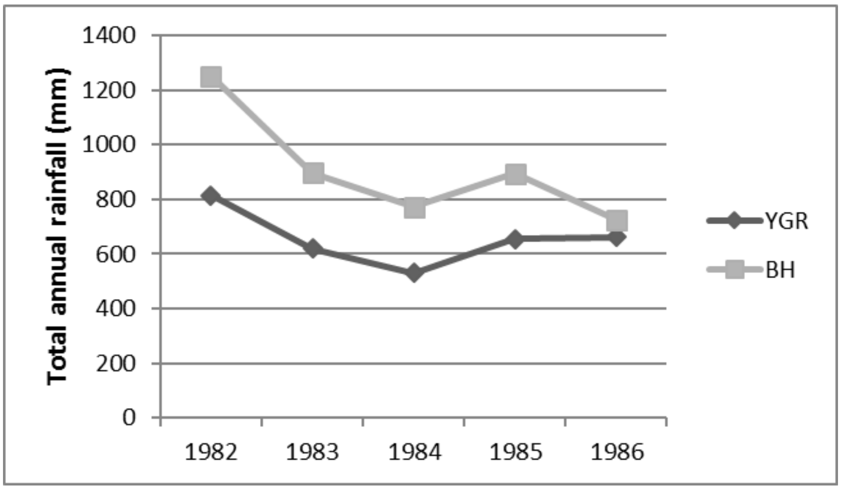


Figure 3.3: Comparison of trends in rainfall records for Yankari and Bauchi Nigeria (1982 -1986). YGR = Yankari and BH = Bauchi.

The result from the Potential evapotranspiration model (PET) and the aridity index model (Figure 3.4; 3.5), shows most years falling within the semi-arid zone based on the global classification of aridity index (UNEP, 1992). However the Potential evapotranspiration model (PET) shows inter-annual variability in data whereas the aridity index model doesn't show the inter annual variability. The mid-1980s particularly, are seen as the driest years in Yankari from the fifty years data. Additionally, there is a high variability in the model across the years; for example while the mid-1980s showed dry period of 0.2, late 1990s were wet years with up to 0.7 and belonging to dry sub-humid global classification.

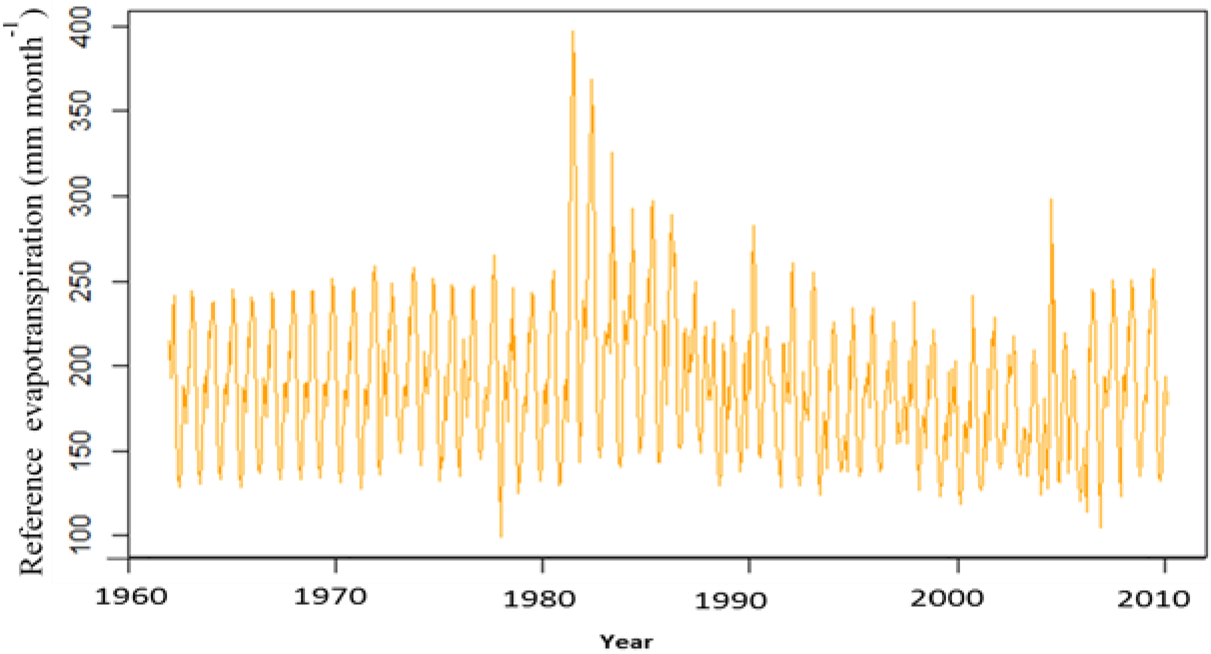


Figure 3.4: Potential evapotranspiration for fifty years, from 1961 to 2010. Data shows inter annual variability. Data is in mm month^{-1}

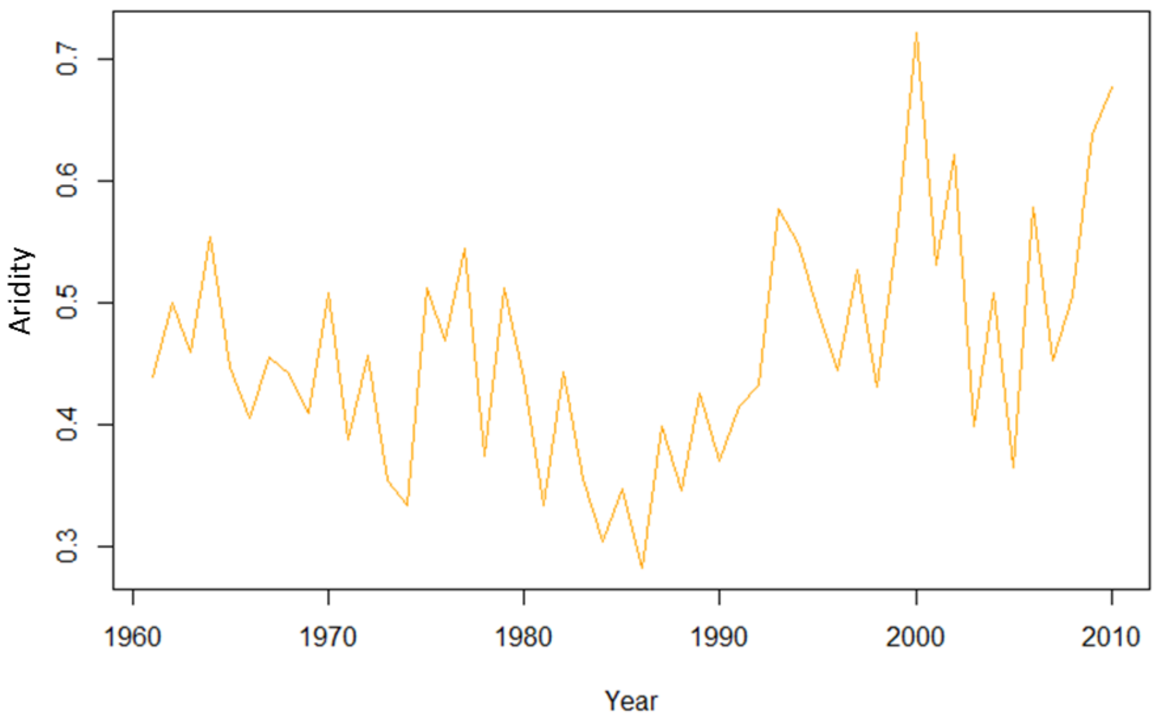


Figure 3.5: Yankari Aridity index model for fifty years, from 1961 to 2010: Hyper-arid = AI <0.05; Arid =0.05 < AI < 0.20; Semi-arid 0.20 < AI < 0.50; Dry sub-humid 0.50 < AI < 0.65

3.3.3 Trend in fire activities/extent

3.3.3.1 Fire Season in Yankari

The fire season in Yankari corresponds with the long dry season in Nigeria. Fires start at the beginning of the dry season in November and lasts until the end of the dry season in March /April of the following year, with the peak period of fire activities in December. Fig 3.6 shows data for the years between 2000 and 2014 for the fire season in Yankari. In all fourteen seasons, the onset of fire in Yankari was in November, and climaxed in December with the exception of the 2004–2005 season, with peak activities in January. The cessation of fire ranges between March and April, with most seasons showing March as the month when the fires end.

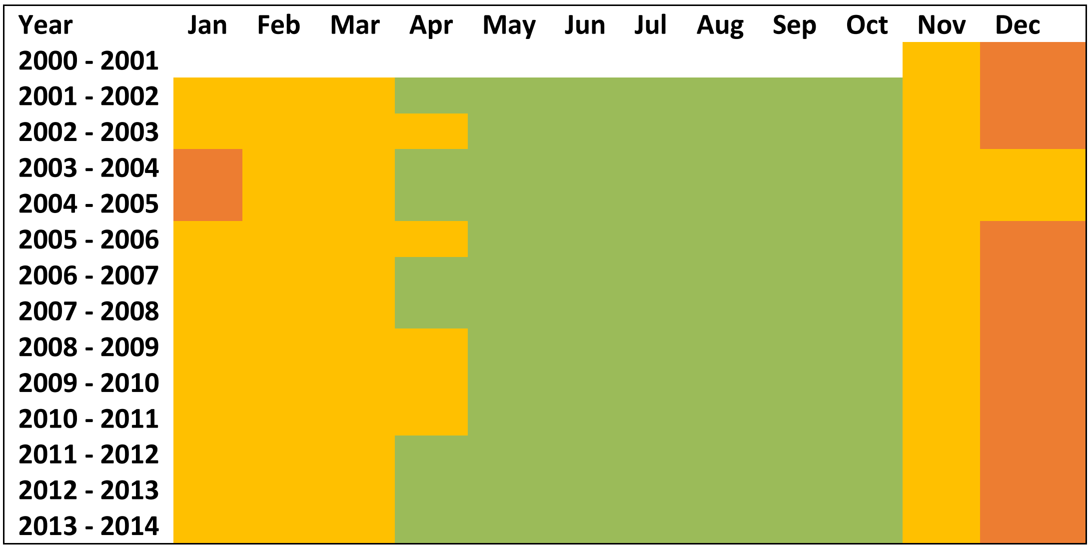


Figure 3.6: Fire season in Yankari Game Reserve, Nigeria (2000 – 2014). Yellow colour shows fire event: orange, peak of fire activity and green, no fire activity.

3.3.3.2 Extent of burnt area in Yankari for fourteen seasons

A time series raster map shows that Yankari is consistently burned on a yearly basis, in most parts of the reserve, with the exception of the areas along the riparian strip and the western edges of the reserve (Fig.3.7). Only burnt areas within the Yankari (2,244 km^2) were calculated. The cumulative burned is 94%; unburned area is 2% and the No data is 3% of the total area of Yankari from the fourteen years analysed.

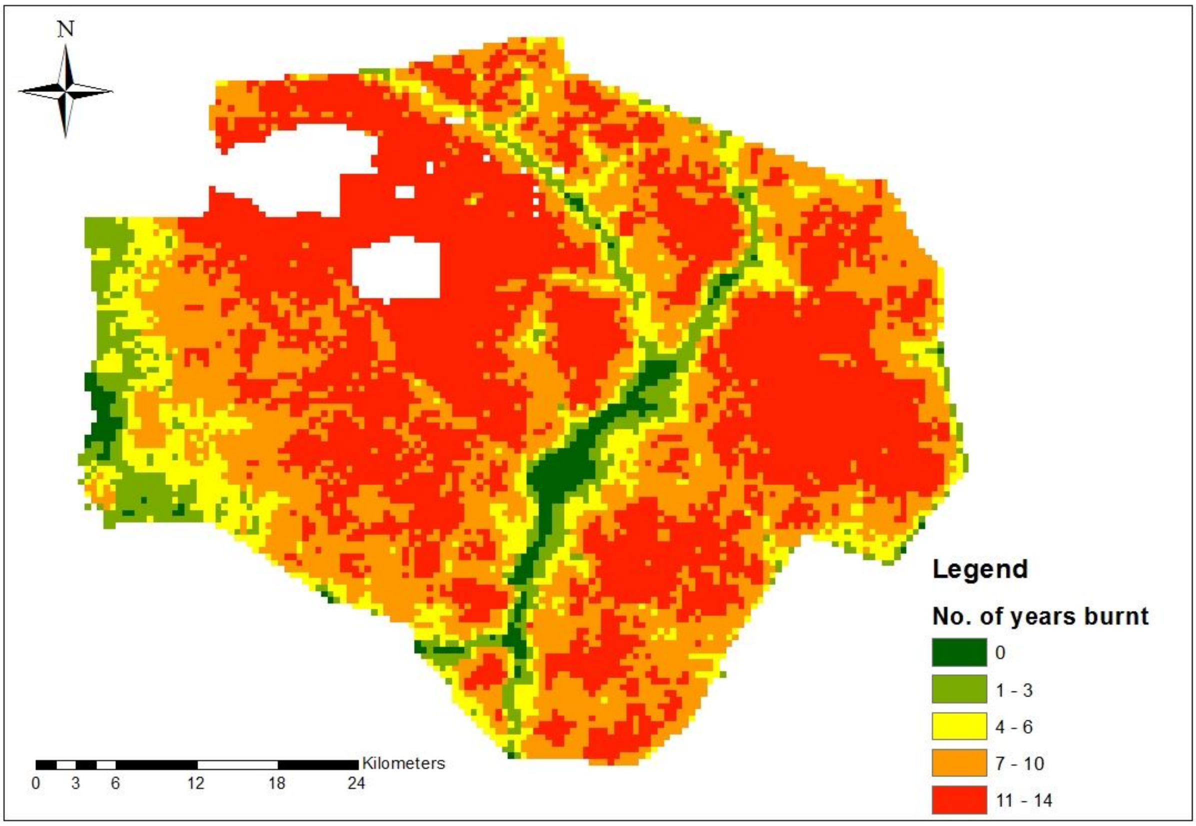


Figure 3.7: Trend in burnt area extent for Yankari Game Reserve, Nigeria: Each pixel represents sum of burned/unburned/No data totalled for fourteen seasons (2000 – 2014). The white areas are pixels without data for the same fourteen years period.

3.3.3.4 Human impacts in and around Yankari

Land cover in the buffer zone of Yankari has changed significantly across the images analysed. The changes were consistent, and observed to have been gradual. The imageries of 1986 showed little encroachment, but by 2013, the encroachment was seen to have advanced, beyond the boundary into Yankari. Additionally, from the imageries, there is a clear difference between Yankari and the land cover immediately outside the boundary i.e. the 5 km^2 buffer zone which was created. Visually, the difference in the 5 km^2 buffer zone is clear even in the years between 1986 and 1999 (Figure 3.8). However, the 2006 image is striped, caused by the failure of the scan line corrector (SLC) in 2003. The SLC failure introduced major striping in Landsat-7 ETM+ imagery, it also shows the changes in Land use/land cover in the buffer. The most current image (2013) shows the most change in the buffer, together with some changes within the reserve which were not detected in the earlier images. Two of the three areas that showed encroachment are to the south and south–western parts of the reserve, and the third area is to be found to the north-eastern part of Yankari.

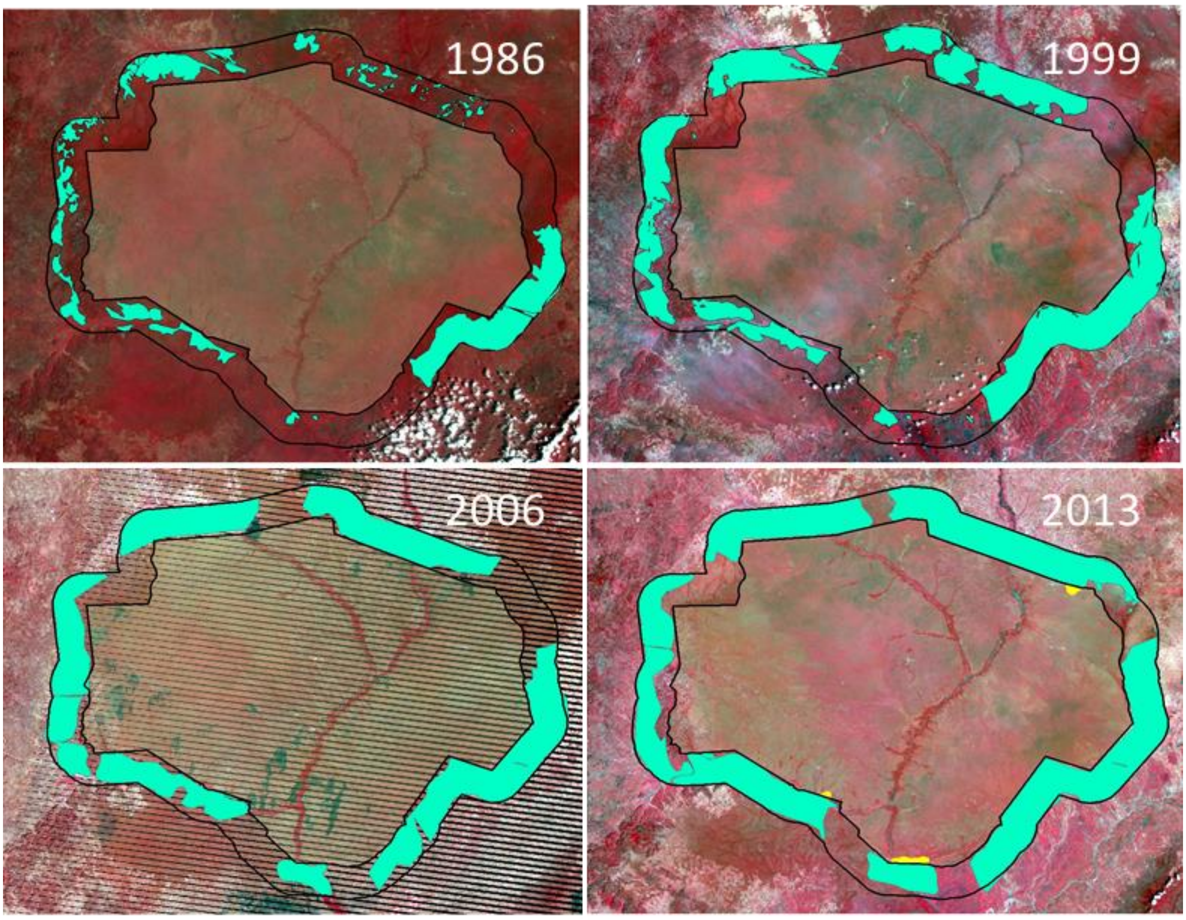


Figure 3.8: Land cover maps of Yankari including 5 Km buffer zone showing growth in incursion across the period (1986 – 2013) in green colour. Yellow dots on 2013 image and more recently within Yankari 2013, an area of 3.7km^2

The estimated percentage increase in park incursion is presented in a bar graph (Figure 3.9). The graph shows consistent change across the images. Up to 1986 there was 27% recorded encroachment but between 1986 and 2013 (27 years), there was an increase of 48% in encroachment.

Figure 3.9: Yankari park incursions from land cover maps of 1986, 1999, 2006 and 2013. Y axis = total land area (km$^{2)}$ total and x axis = the land cover maps by years analysed.

3.4. Discussion

3.4.1 Difficulties in reconstructing historical trends in drivers of woody vegetation change

Gathering and acquiring data on elephant studies was challenging. For the nine studies found, three methods were used to estimate elephant numbers. The surveys were conducted at irregular intervals, and not in a systematic way. Earlier studies undertaken by Sikes (1964) and Afolayan *et al.*, (1980) were ground surveys. Surveys by Geerling (1983) and Marshall (1985) reported elephant numbers based on informed estimates. These methods did not allow for repeatability, as some of their statements were based on their interaction with the elephant herbivory at the time, thus making Marshall (1985) report subjective. The later surveys, therefore, were expected to be more reliable and should serve as a baseline for future surveys. Nicolas (1999) was not accessible and regrettably, the survey carried out by Omondi *et al.,* (2009) was highly criticised by Bergl *et al.*, (2011) on the basis of reporting an erroneous boundary for the reserve among other things.

These difficulties encountered are in line with IUCN (2013) which states that “surveys of the same site are sometimes conducted using different techniques, making comparability even at the site level challenging" Additionally, the report found very few surveys in West Africa. The W-Arly-Pendjari WAP complex in Benin, Burkina Faso, Niger and Togo houses the largest elephant population in the West African region and additionally, only three comparable surveys were conducted in the past 5 years. These surveys do not show any change in elephant numbers in those sites (CITES, 2013). Consequently, it was difficult to conclude on the trends in elephant population in Yankari, but the little evidence explored, suggests that there is still a viable elephants population that can be researched and monitored. The population estimates from the aerial survey show that their densities appear stable.

Similarly, there were difficulties in gathering climate data for this study. Statements such as “We urgently need more research into the global drivers of African climate and into the detailed consequences at local levels” (Conway, 2009) and “Africa needs climate data to fight disease" (Thomson *et al.,* 2011), the authors argued that climate data is a "resource for development" are however not surprising to hear. The lack of weather stations in Yankari and the inability to collect data on climate parameters since 1950s were a huge setback to exploring and understanding the drivers of African climate. Similar to that found in Yankari, scientists in Africa are limited by the lack of historical data available to use as a baseline when measuring changes in climate (Thomson *et al.,* 2011). These problems of lack of weather stations and the problems of malfunctions in existing ones, is a common phenomenon in West Africa (Ermert *et al.,* 2011; Polcher *et al.,* 2011; Hobby *et al.,* 2013).

Rainfall was highly variable for the 50 years data analysed. The drought events in the early seventies and the mid-eighties were clearly apparent when validating reports by Geerling (1973), Green (1986) and Haruna (2011). Depending on the sensitivity of the vegetation, climate variability is potentially an important driver of woody vegetation change in Yankari. However, the extent and magnitude could not be investigated, but indications suggest that climate is not working alone, as fire activities appear to be equally, if not a more important driver.

Few fire studies exist on Yankari beside a fire report (Green, 1987) and the management plan of Yankari (Green and Amance, 1987), which summarized the then fire activities and gave recommendations for a 2-3 years fire plan, but this plan was not used to date. The existing information was considered inadequate to establish any trends in fire activities in this study. Consequently, MODIS active and burnt area products provided the medium to estimate fire occurrence and trends for Yankari. This was not without challenges, as low resolution images (30 m), along with different calibrations between Landsat 5, 7 and 8, had to be taken into account in the choice of image to include. Finally, only recent images from the period between 2000 –2013, could be included in the analyses because of their accessibility.

Yankari was found to be exposed to severe burning every year, as seen from the fire scars. Almost all of the land area of the reserve was covered in fire scars over this period. It could not be detected whether or not the scars were accumulative, from previous years that have not fully recovered. It was reported that the rangers in Yankari are responsible for early burning in the reserve, and this is usually carried out early in the dry season to provide lush grass for the herbivores and to avoid more severe impacts on trees from the late dry season (November–December) (Haruna, 2011). There were no reports as to whether or not the rangers burn the reserve in a systematic way, as prescribed by Green (1986). Additionally, fire activities and scars outside the boundary of Yankari were not investigated, although Green (1986) had reported that many burns in Yankari at the time were a result of wildfires. Therefore, there is sufficient evidence from our findings to suggest that fire activities in Yankari are prevalent and consistent throughout the years under investigation therefore there is a clear trend. However, the study did not investigate the relationship between the trends in fire activities on the woody vegetation.

In assessing the trends in human impacts, some challenges of data gathering and acquisition were encountered. Census data in Nigeria were available only for up to 1999, and not for 2006, and this frustrated our efforts to determine any trends. As an alternative, the land cover images for four years (1986, 1999, 2006 and 2012) were used in our analyses. The polygons, which had been drawn to estimate encroachment activities, were subjective as they were based on visual estimates. Additionally, observations were limited only to a 5 km buffer from Yankari boundary, because the terrain is heterogeneous and the satellite images used were of low resolution. Currently, human activities are found to be prevalent at the boundary of Yankari (result section 3.8). This suggests an increase in population and expansion of the local communities. In addition, the farmlands were observed to be at the Yankari border during the field visit by the author. Although Yankari is an exclusive reserve and not open to the local communities surrounding the reserve, there is sufficient evidence to suggest that the people interact with the reserve in various forms (Geerling, 1973; Green, 1986; Tende and Onoja, 2011) as discussed in chapter 2.

Additionally, studies have shown that areas of biodiversity conservation in Sub-Saharan Africa, coincide with dense human settlement (Balmford *et al.,* 2001; Kuper *et al.,* 2004; Cordeiro *et al.,* 2007). Human impacts (such as hunting and grazing, wood collection and illegal fires) create gradients from the edge to the centre of reserves, reducing the use of some habitats by limiting animal movement, because animals avoid areas with high human activities (such as reserve edges). Edges of protected areas are often not effectively protected, and are often encroached upon by local people for a variety of resources. Therefore, such areas usually suffer severe human disturbances.

3.4.2 Interactions of drivers of woody vegetation change

In Yankari, the combination of droughts, fire and human drivers of woody vegetation change could be working together to make the woody vegetation changes recorded. Elephant numbers appear not to be currently a primary driver. This may be because the number of elephants in West Africa is only 2% of the continent's known elephant populations, compared with South African (55%) and Eastern African (23%) populations (CITES, 2013), where historically, elephants have been culled to reduce their impact on habitats (Van Wyk and Fairall 1969; Cumming *et al.,* 1997). Similarly, the illegal killing of elephants for ivory may be another reason for their low numbers in Yankari. Unfortunately, there are no records of the number of killings. However, on one of the trips the author made to survey the vegetation of Yankari, in 2011, within 2 weeks approximately 5 elephants were found dead and reported by the rangers.

In a recent report compiled by Monitoring the Illegal Killing of Elephants (MIKE) (Wittemyer *et al.,* 2014) on the differences in poaching levels between the different African sub regions, West Africa was shown to have the smallest elephant population, and has submitted the smallest number of records. Consequently, there is a high level of uncertainty around MIKE estimates in that sub-region, which makes it difficult to determine the trend in the elephant population estimates for the region (CITES, 2014). Whether or not these factors are responsible for the present stable number of elephants in Yankari, the elephant population appears not to be a current threat to the woody vegetation. Meanwhile, the findings from this study on fire effects and climate change corroborate the observation of previous authors, who reported that the combination of fire and climate worked together to cause the dearth of trees and shrubs during the droughts of the early 1970s and mid-1980s in Yankari and its environment (Green, 1987).

3.4.4 Implication for conservation and management

Despite the challenges of reconstructing the data on the various drivers of woody vegetation change assessed in this study, findings have pointed to possible ways to systematically gather data. It is important that scientists/authors find ways of documenting and saving manuscripts, reports and even published articles for future studies and posterity. It is in doing such that conservation strategies can be initiated, reviewed or monitoring will be meaningful and beneficial.

The case of land cover changes around Yankari is not so different from other cases seen world-wide. There are no signs that human population rates will stop growing in Nigeria or in other parts of the West African region. In a related study, Wittemyer *et al.,* (2008) found higher population growth on edges of protected areas as evident across ecoregions, countries, and continents, indicating that protected areas attract human settlements. Additionally, the local communities surrounding Yankari are characterized by agro-pastoralists (crop cultivators and herders), and as their numbers grow, their dependence on the Yankari increases. The land cover images analysed revealed lands have been cleared up to the boundary of Yankari. These lands could be grazing lands converted to farmlands. This action will make the pastoralists especially desperate for food for their cattle. Yankari seems to be the only area left of natural vegetation. Consequently, there will be competition in grazing for the wild herbivores and livestock (from the local communities) and this will result in erosion of the browse species and will equally expose the wild herbivores to diseases like the rinderpest scourge of the 1982 which killed many antelopes and buffaloes in Yankari (Geerling 1973, Green and Amance, 1987)

The study also revealed that very few records exists on fire and climate studies in this region. Fire is known as an important modifier of Savannahs and not only does it influence the total biomass of savannah systems but also influences the structure of savannahs (Andersen *et al.,* 2005; Bond *et al.,* 2005; Higgins *et al.,* 2007). These structural changes in turn influence the microclimate and the distribution of resources such as nutrients and moisture (Ludwig *et al.,* 2004). Consequently having cascading effects on biodiversity (Walker and Peet, 1983; Higgins *et al.,* 2007), causing some organisms to respond to microclimate and resource availability, and others are influenced directly by woodland structure (Raman *et al.,* 1998, Williams *et al.,* 2002; Ripple and Beschta, 2004). The combination of these two drivers of woody vegetation change are very important for any conservation initiative in the drylands. Therefore, monitoring climate and fire events in Yankari Game reserve, and other PAs alike are as a matter of urgency. Unfortunately, this study has not gone beyond these general findings for all four drivers of woody vegetation change.

3.5. Conclusion

Our findings show that all the drivers of woody vegetation change should be investigated further as this study gives general trends in the drivers of the woody vegetation of Yankari and not rigorous assessments of these trends. Elephant studies should be thought out carefully so that ways to systematically engage in aerial counts will be beneficial. Additionally, the climate and firestudies are highly recommended as the trends in these drivers of vegetation change showed high importance in Yankari Game Reserve.

In the scope of this study, the human driver can be investigated further, because it is possible with a one-off field inventories and observations, unlike climate change studies that require a long term data set or the fire studies that needs data from seasonal monitoring and more ground truthing. Therefore the next chapter (Chapter 4) shall seek to investigate patterns and the extent of human activities and interactions in Yankari, which should serve as a guide for any immediate conservation goal in Yankari and other important protected areas in this region with similar anthropogenic challenges.

Impact of herders' harvests of fodder plants in Yankari Game Reserve, Nigeria: patterns and extent.

Abstract

Understanding the social drivers of resource use is of key importance in conservation and environmental management. In this study a survey of six plants (Afzelia africana, Ptericarpus erinaceus, Strychnos spinosa, Balanites aegyptiaca, Khaya senegalensis and Tamarindus indica) was carried out. These are species used widely in tropical Africa and are threatened in their natural environment. Additionally, these species are widely used as cattle fodder in the Yankari Game Reserve, Nigeria. In an earlier study on the ecological change in woody vegetation of Yankari, high rates of decline in these fodder plants were recorded. This study therefore, investigates the degree to which observed changes in the fodder plants may have been driven by herders' activities. A non-random cluster method was used to sample 82, 100 m^2 x 100 m^2 plots. The characteristics of fodder plants, i.e. basal area, size classes, growth levels and fire impacts, were estimated using, means of counts and standard errors across the plots, also visual estimates of harvest intensity and fire impacts on the plants were done. Evidence of park incursions were recorded and plotted on a map of Yankari using ArcGIS tools. *Data was analysed using Arc Map 10.1, ERDAS IMAGINE 2013 and R 3.1.2 statistics packages and Microsoft EXCEL 2010. The key findings suggests Afzelia africana and Balanites aegyptiaca are severely harvested in Yankari. A regression analysis showed a strong relationship between core- boundary distance and harvest rate of Afzelia africana ($P = 0.0001$). In addition, Poisson regressions showed significant impacts of distance on the seedlings, saplings and adults of the fodder plants. There is urgent need for conservation and monitoring of fodder plants in Yankari and similar parks in West African Savannah.*

4.1 Introduction

For millennia, human interaction and dependence on forests have largely centred on non-wood forest products (FAO, 1993; Agustino *et al.,* 2011). In many communities this trend has been maintained. Based on human's dependence on forests and trees, it is important to understand the broad range of products and services from forests, trees and woodlands. Of particular importance in this study are Non-Wood Forest Products and Services (NWFPS) that are very important in enhancing livelihoods of many people in Africa (Tieguhong *et al.,* 2009; Agustino *et al.,* 2011). One such broad use of the NWFPS that is popular in Africa's arid and semi-arid areas is where forests and woodlands provide the pasture for grazing as well as fodder for stall-feeding, to rural families who keep domestic animals and depend heavily on services provided by ecosystems and agro-ecological systems.

In West African savannah, *Afzelia africana, Ptericarpus erinaceous, Strychnos spinosa, Balanites aegyptiaca, Khaya senegalensis* and *Tamarandus indica* fodder plants) are fodder plants that support and represent important natural resources to livelihoods of millions of peoples (Gaoue and Ticktin, 2007; Agustino *et al.,* 2011). These plants are used as traditional medicine (Arbonnier, 2004; Akinpelu 2008; Ouédraogo-Koné *et al.,* 2008), timber (Ahouangonou and Bris, 1997; Bayer and Waters-Bayer, 1999), and as forage for feeding livestock (Sinsin 1993; Onana 1998; Lykke, 1998; Cunningham, 2001; Belem *et al.,* 2007).

Fodder plants are essential as they provide the bulk of the nutritive requirements and supplement that constitute the diet of livestock with vital minerals, vitamins and proteins in which straw is deficient during the dry season (Speedy and Pierre-Luc, 1992; McDowell *et al.,* 2008). The leaves of *A. africana*, *P. erinaceous* and *K. senegalensis* are considered as important fodder and nitrogen sources for livestock in agro-pastoral systems (Petit and Mallet, 2001; Sinsin *et al.,* 2004; Ouédraogo-Koné *et al.,* 2008). The branches are pruned by the Fulani to feed their animals. The powdered bark of *A. africana* mixed with salt was reported to have improved fodder consumption rate in cattle (Sinsin *et al.,* 2004). Similarly, wild herbivory equally rely on these species for their nutritive purposes. Thus, these species are highly valued throughout the Sudanian zone, including the area around the W-Arly-Pendjari (WAP) complex (Sieglstetter and Wittig, 2002; Krohmer *et al.,* 2006; Koadima, 2008).

The WAP complex is an important park in West Africa (Benin republic), as it holds the largest number of elephants (3,800) amongst other important floral and faunal species (Clerici *et al.,* 2007). It was also nominated as proposed site for UNESCO's World Heritage Site program in 2009 (Clerici *et al.,* 2007). Consequently, the combined effects of increased human population and agricultural intensification and impacts of climate change in these recent years, results in an increasing pressure on natural resources. The impact of these drivers of change is particularly accentuated in West Africa leading to habitat degradation and loss of biodiversity. The WAP protected area complex, for example, lost more than 14.5% of their habitats between 1984 and 2002. This resulted in considerable reduction in the capacity of the area to conserve species (Clerici *et al.,* 2007)

The regional importance of fodder trees has exposed them to high utilization and a growing demand (Hamilton, 2004 and Botha, *et al.,* 2004a) which has led to degradation and reduction in their populations and habitats (Cunningham and Mbenkum, 1993, Peres *et al.,* 2003 and Botha *et al.,* 2004). Fodder plants are often subject to bark and foliage harvesting, which could affect the long-term viability of their populations. Furthermore, the harvesting of stems, leaves and barks significantly threatens the survival of fodder plant populations (Peter, 1994; Delvaux *et al.,* 2009; Nacoulma, 2011). Consequently, declines in the populations of *A. africana*, *K. senegalensis* and *P. erinaceous* have resulted in their classification as threatened by the IUCN Red List and also in the national red list species database of threatened species in Burkina Faso (Paré *et al.,* 2009, IUCN, 2011).

Reported degradation and population declines in these plants points both to ecological (biological) and cultural consequences. The most direct ecological consequence of fodder plant extraction is alteration of the rates of survival, growth and reproduction of harvested individuals (Gaoue and Ticktin, 2007). In turn, these alterations affect the structure and dynamics of harvested populations (Peres *et al.,* 2003; Ticktin, 2004; Gaoue and Ticktin, 2007). Furthermore, a study in South Africa revealed that repeated harvest of Warburgia salutaris decreased basal diameter and height, and increased rates of fungal attack and mortality (Botha *et al.,* 2004). The impacts of fodder plants harvests are highly dependent on harvest patterns, and on size-specific harvest preferences (Nantel *et al.,* 1996, Ticktin *et al.,* 2002 and Shackleton *et al.,* 2005).

Relatively few studies have assessed the spatial variation in harvest patterns of fodder plants or their impacts; it is important as fodder plants are harvested in the context of other kinds of disturbances such as fire, weather conditions, etc. and their responses to harvest may be affected by these factors (Sinha and Brault, 2005 and Ticktin, 2005). Similarly, harvest of fodder plants and the resulting impacts may also be affected by variation in environmental variables (Siebert, 2000; Ticktin and Nantel, 2004). Studies on fodder plants have focused primarily on regeneration and seedling survival constraints (Bationo *et al.,* 2001; Ouédraogo et al. 2006), characterization of nutritive value, chemical composition (Ouédraogo-Koné *et al.,* 2008) and medicinal properties (Akinpelu *et al.,* 2008). Sinsin *et al.,* (2004) used the dendrometric characteristics as indicators of pressure of *A. africana* to assess the dynamic changes in trees between climatic zones.

Several authors (Paradis and Houngnon 1997; Cunningham 2001; Sokpon and Biaou, 2002) have used the diameter size-class distribution as a field method to assess the impact of harvest practices on the regeneration offodder plants. Size-class distributions (SCDs) are considered to be useful predictive tools (Geldenhuys, 1992) as they have been used to understand the population dynamics of trees (Cunningham 2001). SCDs could be used to evaluate the impact of anthropogenic activities on tree populations (Cunningham 2001) which could affect the shape and the size of classes of distribution of a species (Van Wyk *et al.,* 1996; Sokpon and Biaou 2002). However, it is important to take into consideration the species' life history and the development stage of the population when analysing its diameter-size-class distribution or height-size-class distribution.

Greater insight into the population dynamics of harvested fodder plants is necessary for improved conservation. Population structure therefore is a useful tool to investigate the demographic health of harvested populations and also provide the basis for effective management decisions if it is combined with information related to species specific growth rate, spatial distribution (Fandohan *et al.,* 2010), and patterns of use and harvest (Gouwakinnou *et al.,* 2009; Schumann *et al.,* 2010).

Fulani, are known to maintain a management practice for fodder plant harvest known as sopoodu (Gaoue and Ticktin 2009). Fulani are the largest pastoral nomadic group in the world (Dyson-Hudson, and Dyson-Hudson, 1980), but mainly found in West Africa (Petit, 2004) their herds are the basis of their social and economic lives. The Fulani maintain that they leave the sopoodu to allow the fodder tree to grow and reproduce. The probability that a sopoodu produces fruits may depend on its size and the number of branches left out (Gaoue and Ticktin, 2007; Gaoue and Ticktin, 2009). The size of sopoodu varies from one tree to another and from one region to another and also depends on the personality of the harvesters. A small sized *sopoodu* for example, is associated with young and inexperienced harvesters and migrant Fulani harvesters who have less personal investment in the regeneration of the fodder plants.

Further investigation is warranted on the impact of leaving *sopoodu* and whether or not *sopoodu* is an acceptable practise generally amongst the Fulani; and also if there are regional or local differences in the practise between the Fulani and different species of fodder plants. *Sopoodu* or not, an understanding of the rates and patterns of harvest as well as their ecological impacts in the differing contexts in which these species occur, should provide important insight for the sustainable management of these species.

A resurvey of the woody vegetation of Yankari (Chapter 2), suggests high rates of decline of plants used for cattle fodder. Furthermore, the study on trends in drivers of woody vegetation change (Chapter 3), showed the presence of park incursion around the boundary of Yankari and encroachment within the reserve. Many of the fodder plants have been heavily and continuously harvested over the years. Records show continuous activities of herders at varying distances within Yankari (Green, 1986). Figure 4.1 is a sketch map on lopping and cutting of fodder plants in Yankari (Green, 1987). The summary of the activities are reported in (Chapter 3, Appendix 1). The dotted parts to the west and east that are numbered 1 – 8 are areas of high activities of the herds and herders within Yankari.

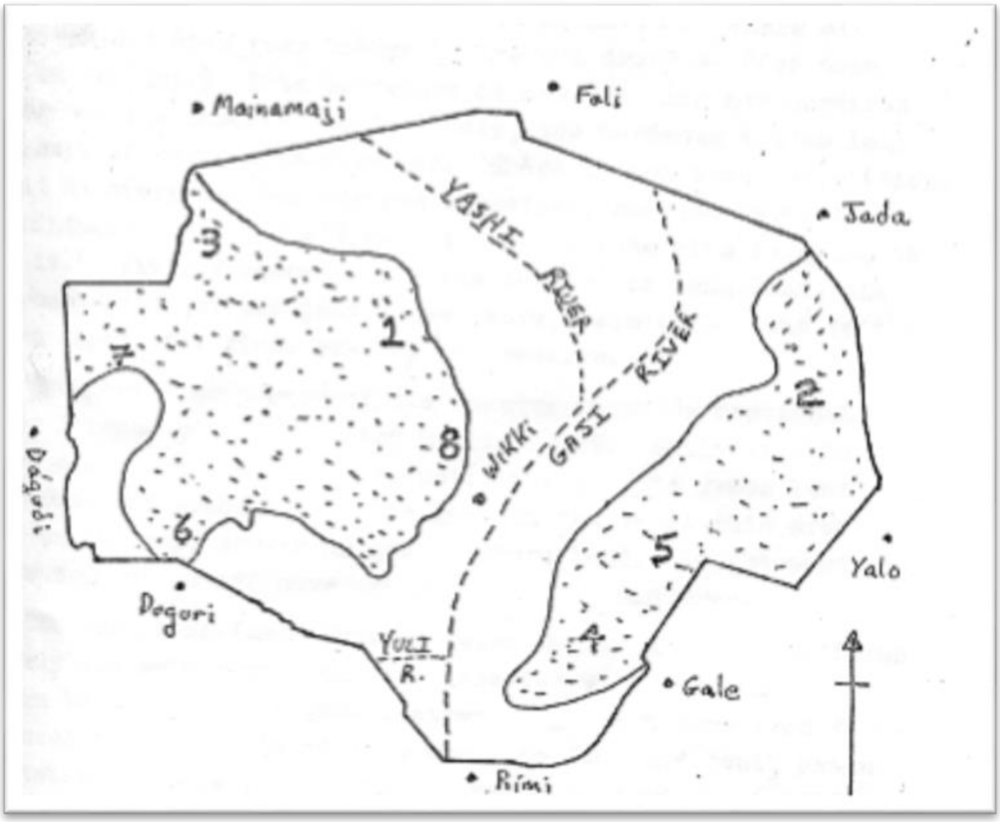


Figure 4.1: Sketch map of Yankari Game Reserve at scale 1:500,000 by Green (1987). Showing the area of *A. africana* tree/woodland savannah formation (stippled area). Numbers on map are game tracks 1 = Buri; 2 = Wala Kerol; 3 = Northern Sha'aman; 4 = Junction of Gale; Tungulum, Randall, Shehu Maska and Kalli imam; 5 = Kariyo hill; 6 = Duguri; 7= Dagudi; and 8= area surrounded by Loopline 4, Lipji Kashim Ibrahim and Ahmadu Bello road.

Yankari therefore presents a good case study to investigate the patterns and extent of herder's activities and incursions in the reserve. This will aid greater understanding of these interactions and an improved basis for developing management strategies for sustainable use and conservation of these species in the drylands of West African. Thus, this study aimed to investigate the degree to which the observed changes in the fodder plants: *A. africana*, *P. erinaceous*, *S. spinosa*, *B. aegyptiaca*, *K. senegalensis* and *T. indica* are likely to have been driven by herders 'activities. This study is designed under the following objectives:

- To estimate the characteristics (density, basal area) and population structure (size-class-distribution) of fodder species in Yankari
- To investigate the rates and patterns of harvest of fodder plants in Yankari and if they vary between species

- To investigate if core-boundary distance influence harvest rates and recruitment of fodder species in Yankari
- To explore the types of incursions are made by herders and their livestock in Yankari

4.2 Methods

4.2.1 Sampling and data collection

The objective here is to characterize the woody vegetation of Yankari and assess the population structure of six fodder plants (*A. africana*, *P. erinaceous*, *S. spinosa*, *B. aegyptiaca*, *K. senegalensis* and *T. indica*, see Table 4.1 for the fodder plants characteristics). Plot sampling was designed based on the density of the fodder plants in Yankari from the resurvey of woody vegetation of Yankari (Chapter 2, Appendix 1). The availability of sketch maps (see, Fig. 4.1) made it easier to locate the fodder plant locations in the park. The author drove from Wikki camp (administrative core) through many accessible game tracks and marked the patches of the fodder plants visible on ground. *A. africana* is the most prominent of all the study fodder plants, therefore sightings and emphasis were made to a large extent on patches of *A. africana* generally but for few plots, on sightings of *P. erinaceus* along the Bogwatrack

Table 4.1: Fodder plants and their characteristics: MD = medicine; FU = furniture; CR =; FD = Fodder; FO = food; FR = TM = timber; CA =; OR =; DY =; SD =

Botanical name	Common name (Fulde /Hausa)	Family	Geographic range	Description	Uses	IUCN status (2007)	Threats	Reference
Afzelia africana	Talihi/Kawo	Fabaceae-Caesalpinioideae	Tropical Africa	Large deciduous tree with a spreading crown, up to 35 m in forests and 18 m tall in Savannah. Tree has a spreading and open crown with large branches. . The bark is a reddish-grey, scaly, about 2 cm thick. It exfoliates in rounded patches, protecting the tree effectively against the frequent bush-fires of the dry sea. Flowering occurs at the end of the dry season. Fruiting takes place from December to February. Wind and animals disperse the seeds.	MD, FU, CR, FD CA	Vulnerable	Seeds are fire sensitive	Bationo *et al.*, 2001, impetus, 2003; biota, 2005, Sacandé, 2007. http://www.worldagroforestry.org/treedb/AFTPDFS/Afzelia_africana.PDF
Balanite aegyptiaca	Tanni/Aduwa	Zygophyllaceae/ Balanitaceae	Sahel –savannah regions of Africa and parts of the Middle east and India	Spinescent evergreen tree with a dark brown stem. Height of 6-10 m and up to diameter of 30-50 cm at breast height. Leaves and seeds are used as food, bark as a substance for fishing and the wood as yoke for draught animals and hand implements.	MD, FO, FD	Least concern	Desertification	Parkan, 1993; Hiernaux *et al.*, 2006; Sagna *et al.*, 2014 ; Aviara et al.,2005
Khaya senegalensis	Kahi/Madacci	Meliaceae	Savannahs and gallery forests	Semi deciduous tree. Height up to 30 m high and up to 3 m in girth, wide dense crown, large branches and thick stems. Bark is dark grey, with small and thin dark pink slash exuding red latex. Has compound leaves	MD, FU, CR, FD CA, TM	Endangered	Saplings are fire sensitive	Keay, 1989; Natta, 2003; Jøker and Gaméné, 2003; ICRAF, 2008
Ptericarpus erinaceous	Banuhi/Madobiya	Fabaceae-Papilionoideae	African Savannahs and woodlands	Height of 8 - 15 m. The tree has an open spreading crown that is less wide and dense compared to *Afzelia africana* and *Khaya senegalensis*.	MD, FU, CR, FD CA	Vulnerable	Extraction for cattle fodder Agricutural expansion,	Bonkoungou, 1999; Petit, 2004. Pre *et al.*, ’ 2010

							population pressure	
Strychnos spinosa	Buttohi/Kokiya	Loganiaceae /Strychnaceae	Savannah forests of tropical Africa	Small tree, 1-7 m in height, 6-12 cm in diameter. It bears edible, balled-shaped fruits. Unripe fruits have a bright green woody peel (3-4 mm thick), which turns yellow-brown when ripened. The fruit has an edible, juicy, sweet-sour pulp, which is pale brown in colour and contains numerous hard brown (1-3 cm) seeds.	MD, FO, FU, FD	Least concern	Agricultural expansion	Sitrit *et al.*, 2003
Tamarindus indica	Zasni/Tsamiya	Fabaceae /Leguminosae Caesalpinioideae	Tropical (org: Africa and Madagascar)	Evergreen tree moderate to large in size, up to 24 m in height and 7m in girth. Leaves alternate, compound, with 10-18 pairs of opposite leaflets. Flowers pale yellow or pinkish, in small, lax spikes about 2.5 cm in width. Fruit is a pod, the shell of the pod is brittle and the seeds are embedded in a sticky edible pulp.	FO, MD, SD, OR, DY, FR.	Least concern	Extraction for food. Desertification	Diallo *et al.*, 2007; Bhadoriya *et al.*, 2011; http://www.kew.org/plants-fungi/Tamarindus-indica.htm

249 patches of fodder plants were marked, and mature trees (adults), saplings and seedling populations of the fodder plants were sampled. The game viewing tracks aided the access to survey the fodder plants. From the patches of fodder plants marked, 82 (100 m^2 x 100 m^2) plots were selected using the non-random cluster method. The parameters measured for each individual tree were: height, diameter at breast height (DBH), canopy cover and recruitment or growth levels (seedlings: counts saplings: 10 < cm DBH and at least 2 m in height and adults: >10 cm DBH) estimated for the fodder trees: *A. africana*, *P. erinaceus*, *B. aegyptiaca*, *K. senegalensis* and *T. indica* but for the *S. spinosa* which is a smaller tree (seedlings: counts, saplings: > 5 cm DBH at least 2 m in height and adults: > 6 cm DBH). Figure 4.2 below is the Yankari map showing the complete survey coverage of the study.

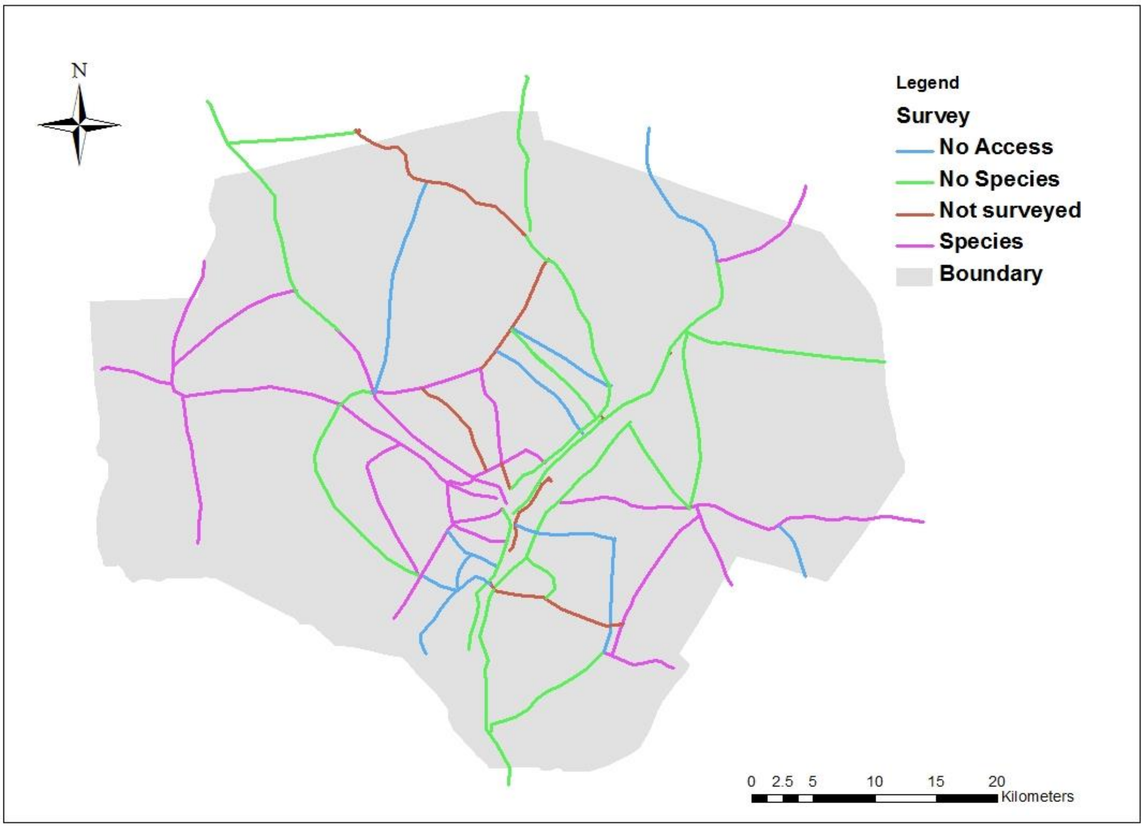


Figure 4.2: Survey coverage in Yankari Game Reserve, Nigeria (2011). 'No access': tracks were not accessible during surveys; 'No species': tracks identify tracks where fodder plants were not encountered; 'Not surveyed': tracks identify tracks that were not surveyed; and 'Species' tracks identify tracks where fodder plants were encountered.

Other parameters measured include: counts of trees showing fire activities, dieback effects, and diseased plants. All these parameters were recorded based on visual assessment. Photographs of plots were also taken to show some of the activities mentioned.

To estimate the rates and patterns of harvests of fodder plants in Yankari and to see whether there is between-species variance, eye estimates of crown/branches harvested were made (see figure 4.3) following the four levels of percentage harvests reported by previous studies (Cunningham, 2001; Nacoulma *et al.*, 2011) and as described in Table 4.2. These measurements were done on adult and sapling individuals of the fodder plants only.

Figure 4.3 (a - d): Harvest rates in *Afzelia africana*: a and b = complete removal of crown and branches; c = partial removal of crown and branches; d = crown and branches intact.

Table 4.2: Description of four levels of harvest intensity adapted from Cunningham (2001) and Nacoulma *et al.,* (2011).

Percentage of harvest	Intensity of harvest
Individuals without their crown harvested	Null
Individuals with 0 -25% of their crown harvested	Weak
Individuals with 25 -50% of their crown harvested	Medium
Individuals with > 50% of their crown harvested	Severe

To determine whether core-boundary distance influences harvest rates and recruitment of fodder plants in Yankari, the core is defined as the Wikki camp and the plots (e.g. Lipji track, Ahmadu Bello way and Loopline1 – 4) closer in proximity to Wikki camp are considered core and those farthest away are considered boundary (e.g. Bogha track, Gale track, and the end of Sha'aman track). In order to describe the types of interaction and incursions that herders and their livestock have in Yankari, a GPS was used to record the location of any encounters with domestic livestock. In addition, other indirect activities (e.g., cattle hooves, cattle dung, activity around a water source etc.) were recorded and included as evidence of herders' interaction with Yankari in the study.

4.2.2 Data analysis:

Arc Map 10.1, ERDAS IMAGINE 2013 and R 3.1.2 statistics packages and Microsoft EXCEL 2010, were used to analyse the data for this chapter. Firstly, the characteristics of fodder plants, i.e. basal area, size classes, growth levels and fire impacts, were estimated using, means of counts and standard errors across the plots. Secondly, to determine the patterns and extent of harvest rates across the fodder plants, weighted averages (weighting in this thesis was based on the midpoint of harvest rate categories weighted by number of individuals of the fodder plants. The categories are the harvest rates across the four classes (Cunningham (2001) and Nacoulma et al., (2011) expressed in percentage. The harvests rate used in my thesis followed the description of four levels of harvest intensity adapted from Cunningham (2001) and Nacoulma et al., (2011)). In fodder plants per plot were calculated, and mean percentages were plotted on maps (per species) using different colours. A regression analysis was carried out to test the influence of core – boundary distance (km) on harvest rates (%) of the fodder plants and a generalized linear model (Poisson family) was fitted to determine the influence of core - boundary distance (km) on counts of seedlings, saplings and adult fodder plants. Lastly, evidence of incursions (direct and indirect) were recorded and plotted on the map of Yankari using ArcGIS tools.

4.3 Results

4.3.1 Summary of plot measurements for the fodder plants surveyed

Figures 4.4 and 4.5 show the mean numbers of stems per plot and mean diameter at breast height (DBH) respectively for the all sampled plots. *A. africana* have both the highest stems per plot (4.3) and the highest DBH (27.3cm). *S. spinosa*, though the second most abundant in terms of mean number of stems per plot has the lowest DBH (5.8 cm). *B. aegyptiaca* appears the least abundant (5.4) species among the four that were surveyed yet *P. erinaceus* and *B. aegyptiaca* have similar DBH (18.3 cm and 18.8 cm).

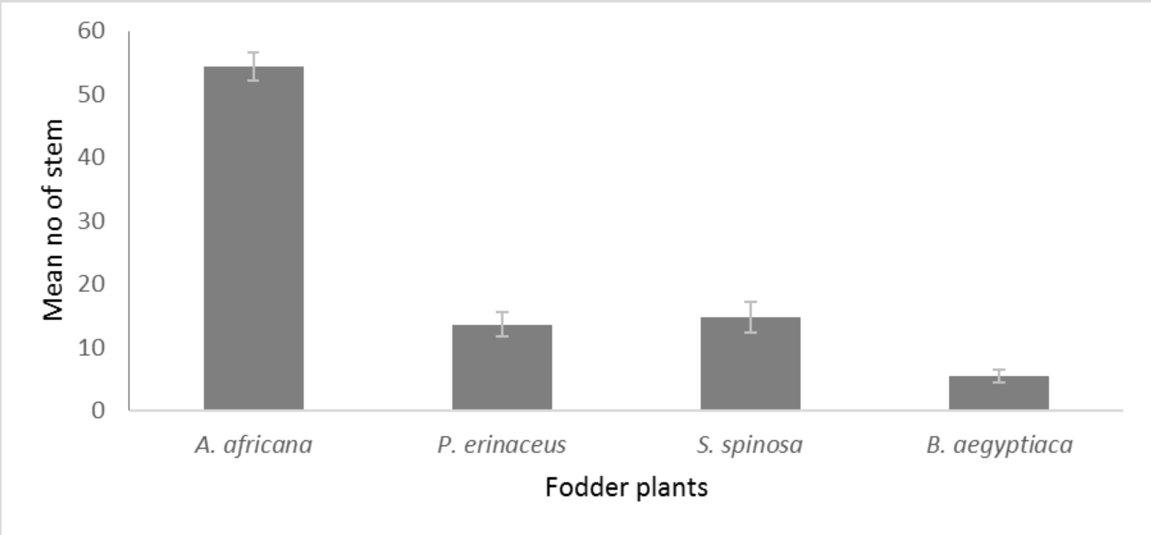


Figure 4.4: Mean number of stem per plot +/- SE of fodder plants sampled across all plots. *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca.*

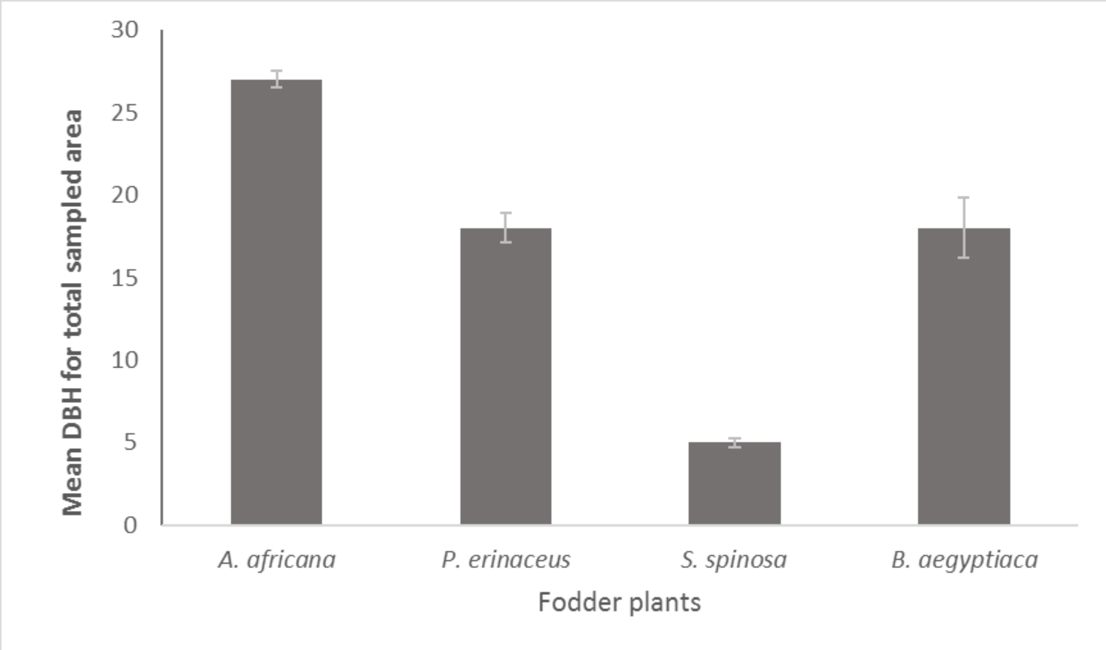


Figure 4.5: Mean DBH +/- SE of fodder plants sampled across all plots *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca*.

.

Size classes of the fodder plants are presented in Figure 4.6. The size classes show different distributions. *A. africana* showed a bell-shaped distribution with the greatest number of plants being in the 20 - 30 DBH class. The lowest number of plants are within the 0 – 10 and 50+ DBH classes. *B. aegyptiaca* showed an inverse J-distribution (A reversed or inverse J-shaped size distribution has been regarded as a proxy of population growth or dynamic equilibrium (Bin Y *et al.,* 2012). *P. erinaceus* and *S. spinosa* showed similar distributions that were neither bell-shaped nor inverse J shape (negative slopes indicate the occurrence of sufficient recruitment and 'stable' populations (see Leak, 1965; Helm and Witkowski, 2012; Haarmeyer *et al.*, 2013). Except for *P. erinaceus* which shows the dominant DBH class with (10 - 20 DBH). *S. spinosa* has the more dominant DBH classes of >10 cm.

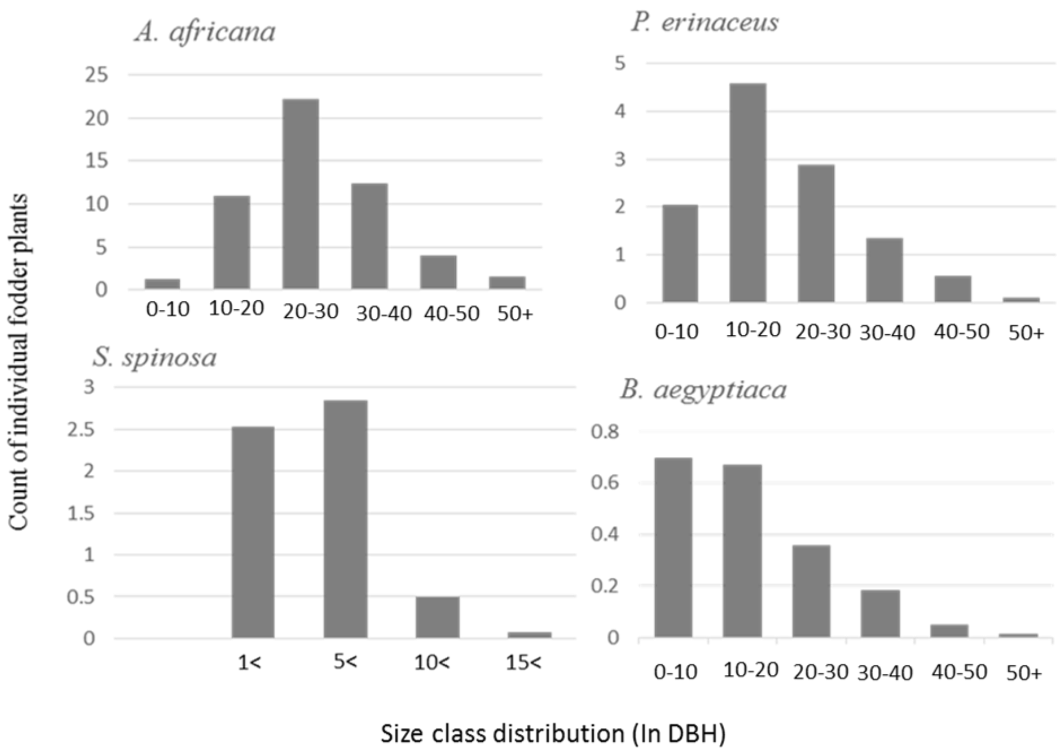


Figure 4.6: Size class (in DBH) distribution of mean counts of fodder plant in Yankari.

Photographs of some fire-affected areas are presented in Figure 4.7. Various types of fire impacts were observed on the trees. Some impacts were seen on the tree crowns however the most severe impacts were seen on the bark of the trees. In addition, dead standing trees and logs were observed throughout the reserve. Mean counts of dead trees, trees with dieback effects and live trees are shown in Figure 4.8. *A. africana* showed 14 out of 66 sampled trees having some fire impacts. Conversely *P. erinaceus, S. spinosa* and *B. aegyptiaca* all showed low mean count values of fire impacts.

Figure 4.7: Photos of fire impacts on fodder plants in Yankari Game Reserve, Nigeria. Fire impacts vary in intensify, severity and timing in Yankari.

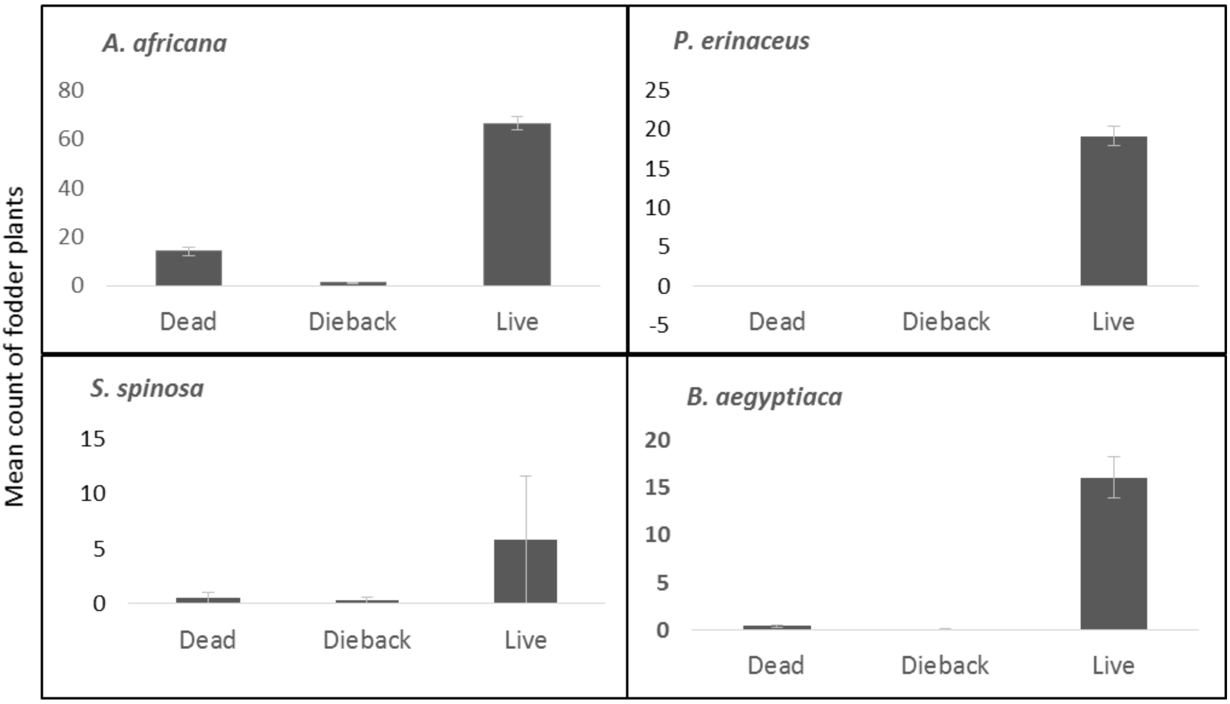


Figure 4.8: Mean counts and standard errors of fire impacts on fodder plants. Dead = dead trees; Dieback = trees with severe fire impacts showing signs of not being able to recover; Live = plants with mild or no fire impacts. *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca.*

4.3.2 Rates of harvests of Fodder plants as indicators of herders' activities

The core-boundary distance map of Yankari was created with intervals of 5 km separating each layer (Figure 4.9). The map covered all plots surveyed from core to the boundary of the reserve.

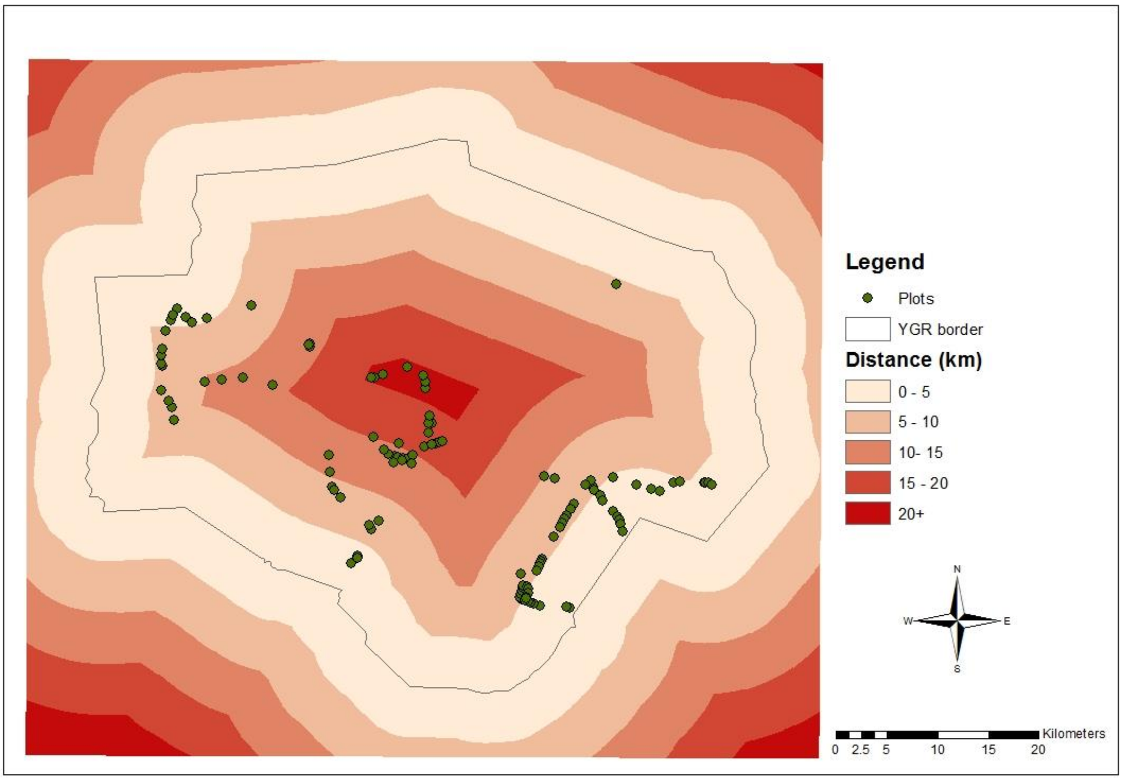


Figure 4.9: Relationship between surveyed plots and boundary distances in Yankari Game Reserve, Nigeria. Green dots represent the surveyed plots. Distance is from Yankari boundary, both inside and outside.

Bar plots of the percentage harvest rates of the fodder plants were created, Figure 4.10. *A. africana* shows the highest percentage of harvest with mean of 51%. *B. aegyptiaca* showed a moderate percentage rate of 31% *P. erinaceus* and *S. spinosa* had low harvest rates of at 21% and 12% respectively.

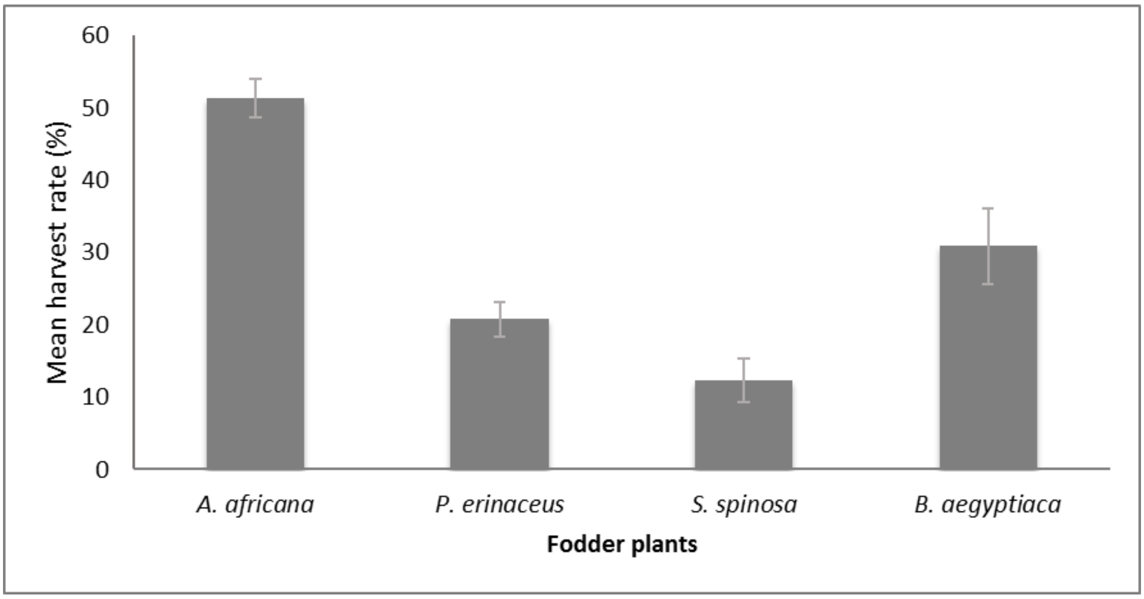


Figure 4.10: Plot means +/- SE of percentage harvest rates of fodder plant species in Yankari Game Reserve, Nigeria. *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca*.

The harvest rates of the fodder plants s from core – boundary is also presented in Figure 4.11. There is no clear pattern between the spatial distribution of the species and the rates of harvests of the species. *A. africana* for example is harvested severely both at the core and the boundary of the reserve. Nevertheless, a few plots showed weak harvest rates at the core.

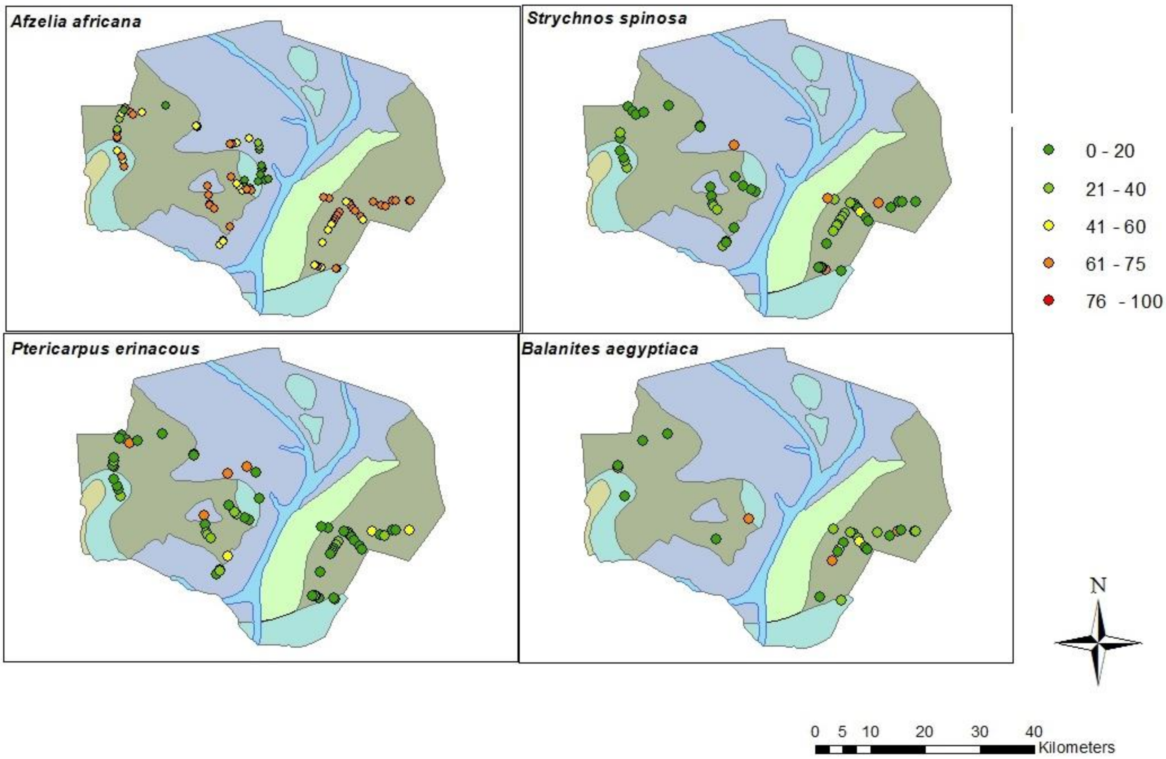


Figure 4.11: Spatial distribution of harvest rates of fodder plants in Yankari Games Reserve, Nigeria. Harvest rates are: Individuals with 0 - 20% = weak harvest; 25 – 50% = medium harvest; and > 50% = severe harvest.

Scatter plots of core - boundary distance on harvest rates of fodder plants were created (Figure 4.12). The regression analysis used to determine the impact of core - boundary distance on harvest rates of the fodder plants showed that there is a positive correlation and high significant impact of distance on the harvest rates of *A. africana* (p = 0.0001) but not so for *P. erinaceus* (p = 0.4358), *B. aegyptiaca* (p = 0.9083) and *S. spinosa* (p = 0.5818). The regression coefficient values are presented in Table 4.3 below.

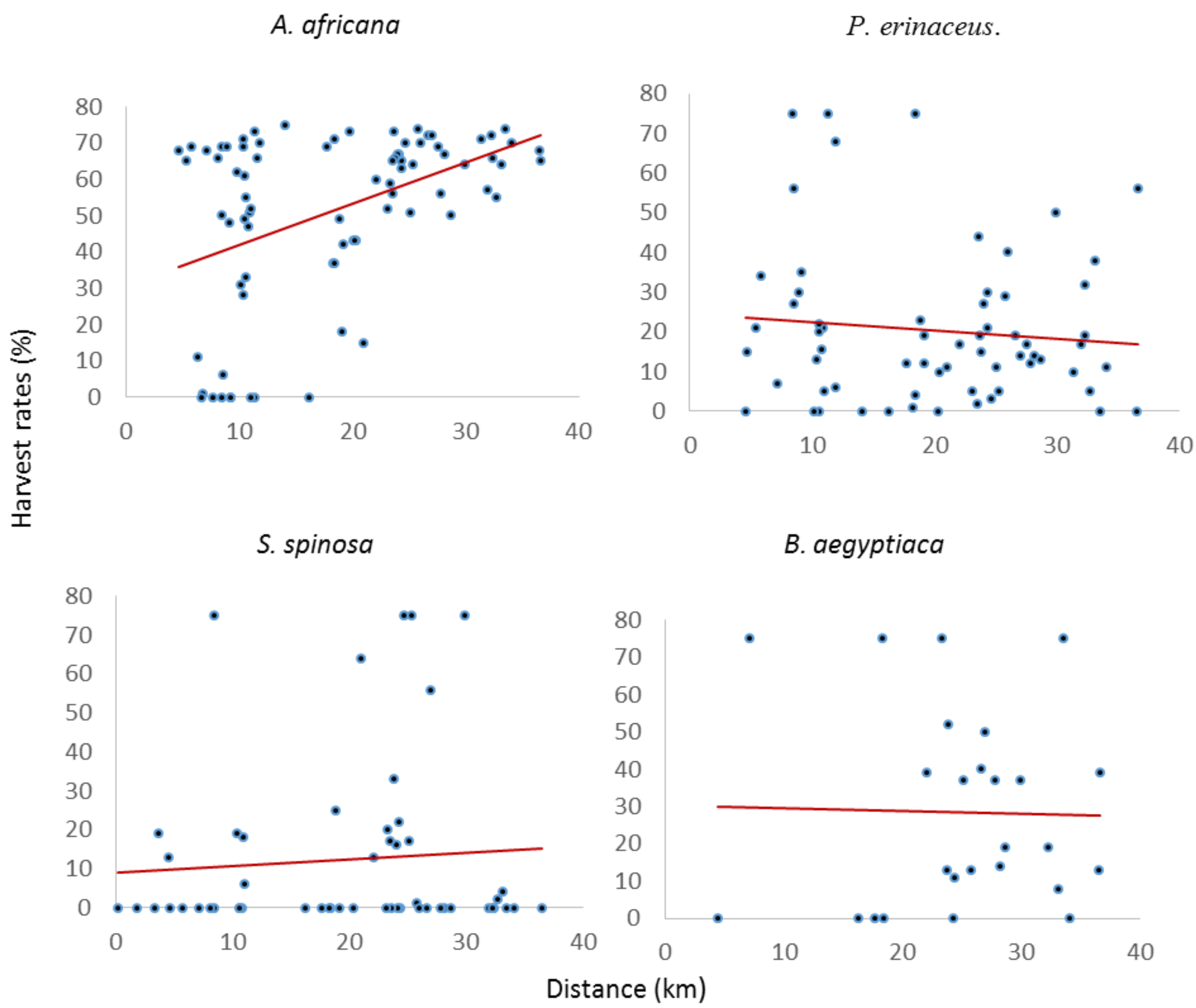


Figure 4.12: Core – boundary distance relationship to harvest rates for fodder plants in Yankari Game Reserve, Nigeria. Each blue dot represents percentage of weighted mean harvest rate per plot and red line = regression line.

Table 4.3: Regression Coefficient values of *Afzelia africana, Ptericarpus erinaceous, Strychnos spinosa* and *Balanite aegyptiaca.*

	A. africana	***P. erinaceous***	***S. spinosa***	***B. aegyptiaca***
Adjusted r^2	0.1774	-0.0061	-0.0132	-0.0410
p	**0.0001**	0.4358	0.5818	0.9083
Slope	1.1317	-0.2108	0.1731	-0.0777
Intercept	30.4771	24.6575	8.8909	30.4442

Table 4.3 presents the output from the regression analysis. Only *A. africana* had a statistically significant relationship between harvest rates and distance at the 5% interval

level. However the regression model only accounted for 14.1% of the variability in the model. *P. erinaceous*, No significant results were found for *S. spinosa* and *B. aegyptiaca*.

4.3.2 Impacts of core - boundary distance on fodder plants recruitment (seedling, sapling and adults)

The mean counts of the fodder plants showed the dominance in seedlings across the three of the four species investigated (Figure 4.13). The exception was *B. aegyptiaca* where adult trees are dominant. Saplings are the least abundant of the 3 growth levels. *A. africana* was found to be the most abundant species, followed by *S. spinosa*, and then *P. erinaceus*. Observations of *B. aegyptiaca* were fewest with mean counts of seedlings, saplings and adult trees all totalling fewer than 10 individuals.

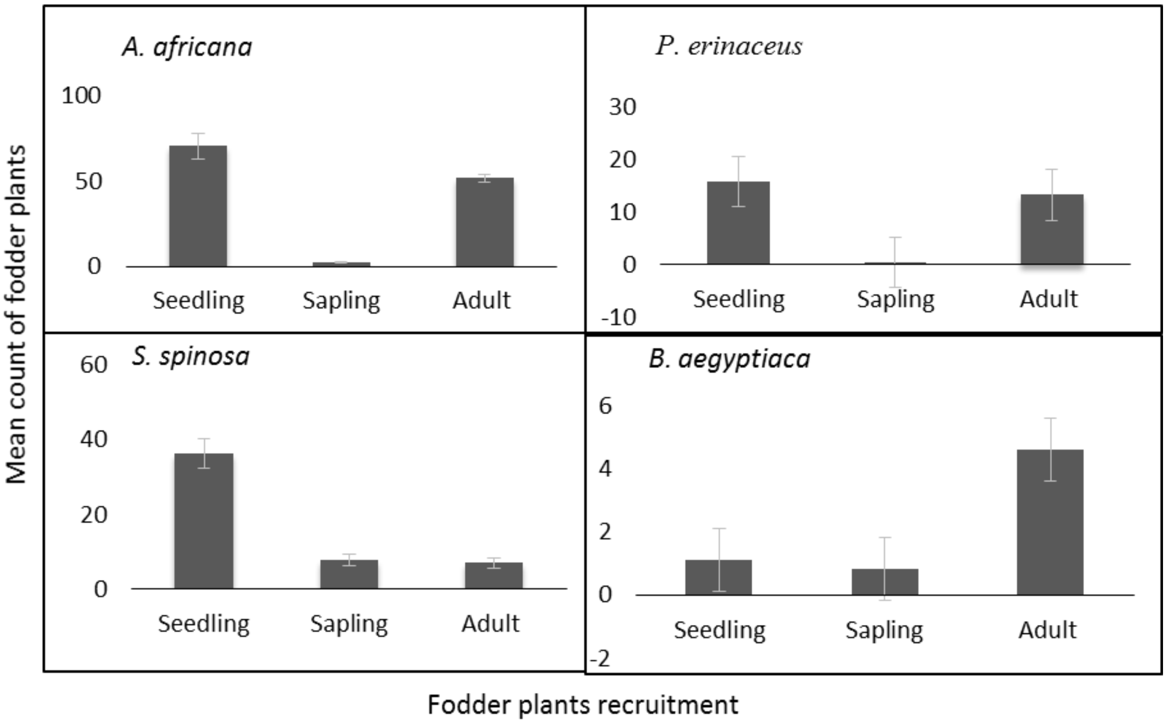


Figure 4.13: Mean +/- SE counts of fodder plants recruitment in Yankari Game Reserve, Nigeria.

Scatter plots of the core – boundary relationship between distance and fodder plants are shown in Figure 4.14. In all 3 growth levels (seedlings, saplings and adults) for all fodder plants, there are positive impact of distance on the fodder plants. The linear slopes show both negative and positive correlation. The Poisson coefficient table (Table 4.4) further gives evidence on the significant impacts distance has on the recruitment of fodder plants in Yankari.

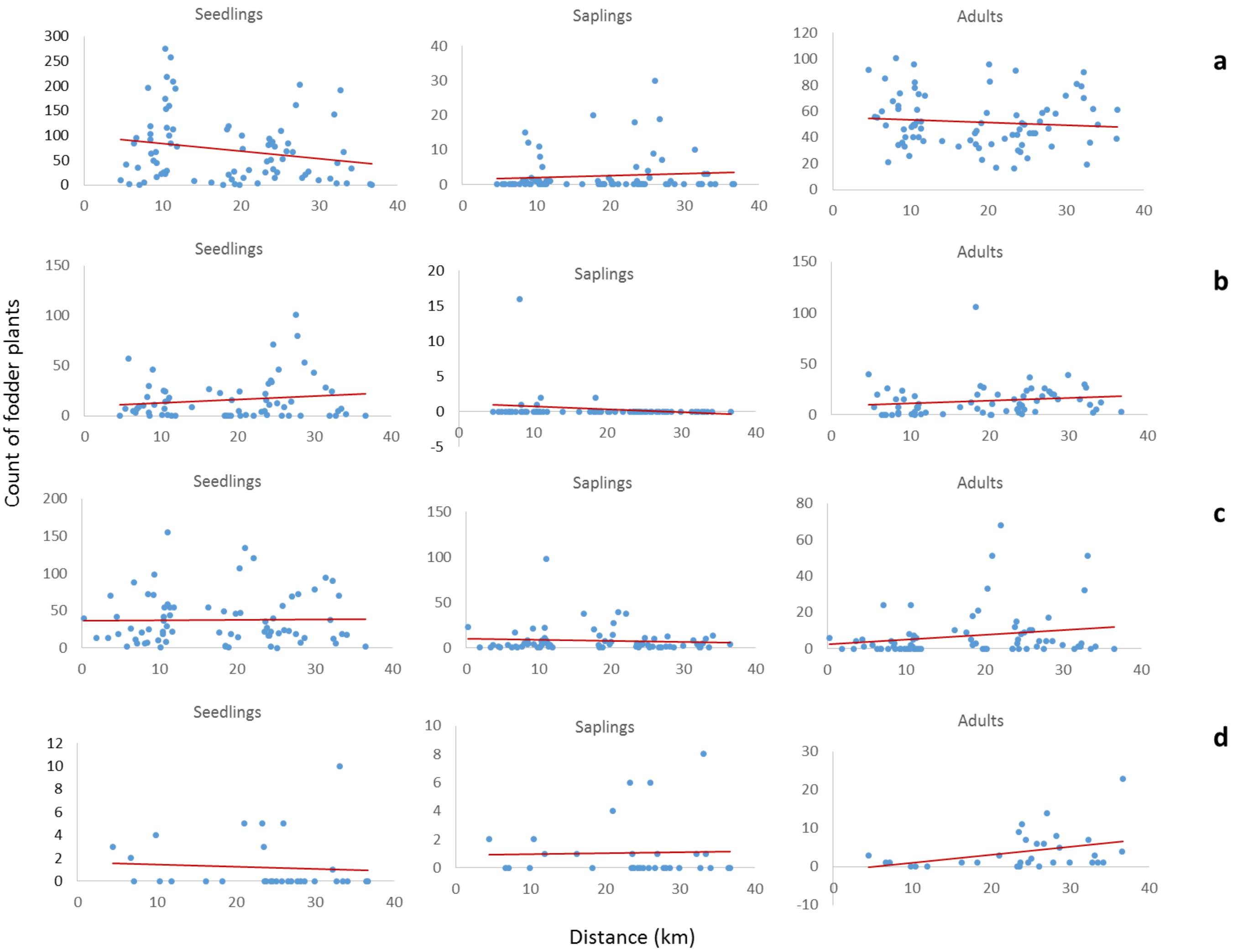


Figure 4.14 (a-d): Relationship between core-boundary distances and recruitment of four fodder plants in Yankari Game Reserve, Nigeria. a = *Afzelia africana*; b = *Ptericarpus erinaceous*; c = *Strychnos. spinosa*; d= *Balanites aegyptiaca*. Blue dots represent plot location and redline is indicative of linear relationship.

The Poisson models fitted to determine the impact of distance on counts of the seedlings, saplings and adults of fodder plants gave positive statistically significant results (See, Table 4.4 for the Poisson coefficients). Results presented in Table 4.4 shows a range of weak, medium and strong relationships between the parameters.

Table 4.4: Poisson regression coefficients for relation between core-boundary distances of fodder plants in Yankari Game Reserve, Nigeria.

Species	Growth level	P- value	Coefficient for Poisson
A. africana	Seedlings	**0.0001**	-0.0342
	Saplings	0.0130	0.0193
	Adult	0.0320	-0.0036
P. erinaceous	Seedlings	**0.0001**	0.0278
	Saplings	**0.0001**	-5.8350
	Adult	**0.0001**	0.0243
S. spinosa	Seedlings	0.0030	0.0062
	Saplings	0.0009	-3.3000
	Adult	0.0027	0.0144
B. aegyptiaca	Seedlings	**0.0001**	-0.0874
	Saplings	0.0130	-2.4840
	Adult	**0.0001**	0.0548

4.3.3 Park incursions in and around Yankari Game reserve

4.3.3a Direct and indirect incursions by herders and their livestock

Evidence of incursions from herders and their livestock were observed and recorded along some of the tracks, throughout the reserve during the survey (see, Figure 4.15). Up to 440 cows, sheep, goats, and donkeys were estimated in total, also more than 40 cow tracks and several cow dung and cow hooves were marked.

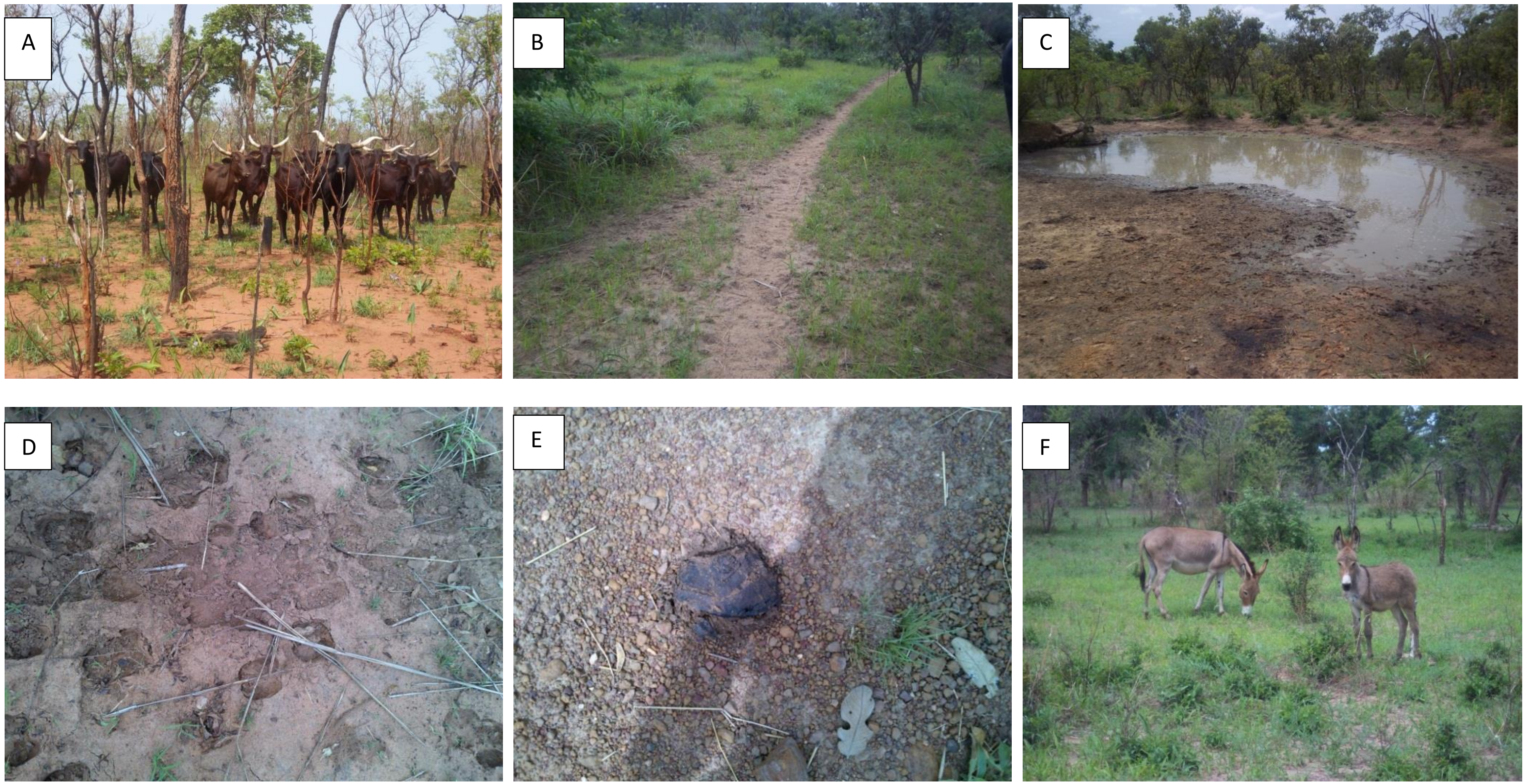


Figure 4.15: Evidence of incursions from herds/herders in Yankari Game Reserve, Nigeria: A = presence of cows in the reserve during the survey; B = various cow tracks throughout the reserve; C = herd's activities along the watering ponds; D = prints of cow hooves throughout the reserve; E = cow dungs throughout the survey plots; F = donkeys were also seen tied to graze in the reserve.

These incursions were grouped into direct (cows, sheep, goats, donkeys) and indirect (cow tracks, cow dung and cow hooves) incursions. The survey coverage and the points and extent of the incursions of the herders in Yankari are shown in Figure 4.16.

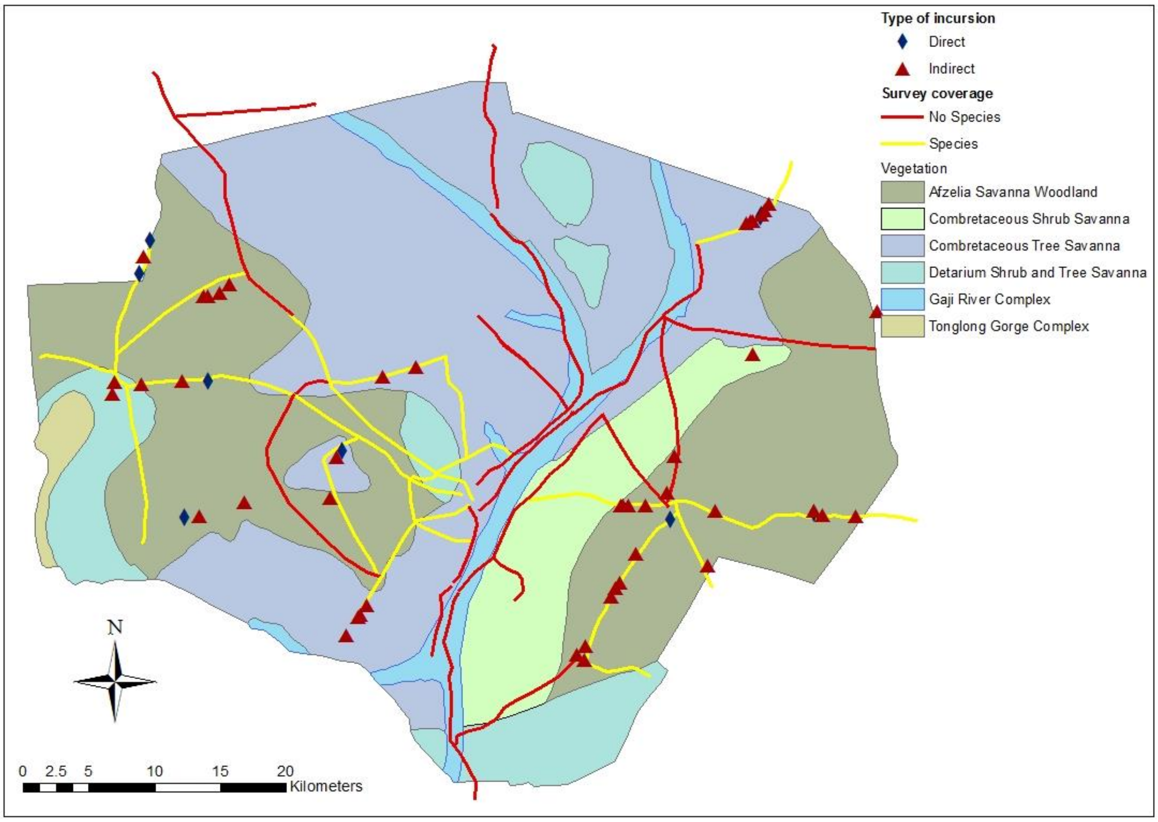


Figure 4.16: Incursions from herds/herders' activities in Yankari Game Reserve, Nigeria. Each blue diamond/red triangle represent a GPS point of any of cow tracks, cows, cow dung, cow hooves, sheep, goats, and donkeys. Red and yellow lines are game viewing tracks traversed.

4.4. Discussion

4.4.1 Population structure of fodder trees

Most size classes are represented in the fodder plants studied with a high concentration of individuals in the “20 to 40 cm” size class dominating for all species excluding *S. spinosa* which showed the characteristics of a shrub species (greatest abundance of individuals sized 5 - 15 cm). *B. aegyptiaca* is the only species that showed the inverse J- shape of the size distribution curve which is indicative of a stable population structure, with abundant individuals in small size classes and a progressive decrease of individuals in upper size classes. Unfortunately, the low population of *B. aegyptiaca* restricted the drawing of meaningful conclusions on the size classes. Conversely, *A. africana* had a bell shape distribution indicative of an unstable population structure suggesting important perturbations affecting population structures. This may be due to the combined effects of illegal and uncontrolled human activities evident by the high level of fire activities found in Chapter 3 and the impacts of the burning on trees as seen in Figures 4.7 and 4.8. The same distribution was observed by Paradis and Houngnon (1997) in the Lama Reserve, Benin and in Bassila forest reserve in Benin (Sinsin *et al.*, 2004) across three bioclimatic zones in Benin. However, *A. africana* is known as a shade-intolerant species (Sinsin *et al.*, 2004); similarly, Sokpon and Biaou (2002) reported that its size-class distribution indicates the absence of young trees with less than 20 cm diameter and also the difficulty in its recruitment in a heavy clayed-soil forest such as the Lama Reserve.

The size class distributions of *P. erineaceus* and *S. spinosa* could not be determined. This scenario could point to the fact that these two species are not under immediate primary threats in Yankari.

4.4.2 Rates and patterns of harvest of fodder plants

With the close proximity of the local communities to Yankari (mostly within 5 km of the boundary), the expectation was to find higher harvest rates at the boundary than in the core however this hypothesis was only supported for *A. africana* (see Figures 4.9, 4.10 and 4.11). Our study findings also showed that *A. africana* and *B. aegyptiaca* are severely harvested in Yankari by the herders while the harvest rates for *P. erinaceus* and. *S. spinosa* are low. The high proportions of harvested *A. africana* and *B. aegyptiaca* trees show that these species are highly used by herders for their livestock in Yankari. *A. africana* appeared and generally was identified as being the most preferred fodder plant by the herders. This may be attributed to its high nutritional values to the ruminants (Ikhimioya, *et al.,* 2007; Ouédraogo-Koné, 2008; Gaoue and Ticktin, 2011). Throughout Yankari *A. africana* trees are severely harvested. *A. africana*, sprouts earlier than other trees before the onset of rains. This period coincides with herders' peak period of foliage need for their livestock with the soft bright green leaves being ideal for the livestock (Green, 1986). Harvesting impacts identified in this study are in line with the findings of Petit and Maillet (2001), Ouédraogo-Koné *et al.,* (2008) and Nacoulma (2011), who all found high proportions of harvested *A. africana* and *P. erinaceus* and concluded that they are high value species particularly appreciated by herders for their livestock in the Sudanian zone. The results also suggest clear but different patterns of foliage harvest between the species of fodder plants investigated.

Generally, the fodder plants were subject to a foliage-specific harvest pattern, where the fodder plants were totally, partially or not harvested at all. This was clearly seen in few saplings and most adults of *A. africana*, *P. erinaceus* and *B. aegyptiaca*. Individuals of *S. spinosa* are generally slashed into two and the crown falls to the ground, such that it is accessible to the grazing livestock. Steps are cut into the tall *A. africana* trees by herders with sharp knives for ease of climbing. Leftover branches were observed under most of the *A. africana* affected by harvesting. This was similar to both *P. erinaceus* and *B. aegyptiaca* but there were no signs of bark harvesting on any of the fodder plants surveyed. A previous study in southern Africa by Geldenhuys (2004), also reported that smaller trees were not bark-harvested.

The spatial distribution of the fodder plants in Yankari does not seem to be an indication of the extent and rates of harvests of these plants. *A africana*, for example, showed severe harvest at the core as well as at the boundary of the reserve. Similarly, the same pattern was seen in the other fodder plants. This is an indication that, the herders move and harvest the trees freely within the park, revealing none or weak monitoring in Yankari. Nevertheless, a few plots showed no or low harvest rates at the core.

Studies have shown that Fulani harvesters maximize the amount of foliage harvested for each tree in order to reduce the number of trees they need to climb (Gaoue and Ticktin, 2007). In addition, traditional Fulani practices such as the *sopoodu* provide a basis for sustainable management of fodder plants (Gaoue and Ticktin 2009). However, this practise was not observed in this study; it may be that the *sopoodu* is only applicable to *K. senegalensis*. Further survey on the *sapoodu*, including interviews, are recommended to find out whether it is used in the Yankari or not.

4.4.3 Core-boundary-distance influence on harvest rates and recruitment of fodder trees

The mean count of fodder trees recruitment corroborates typical good seedlings dominance in *A. africana*, *P. erinaceus* and *S. spinosa*, while *B. aegyptiaca* showed the adult as the dominant growth level. However, less than 10 individuals were observed during surveys reducing the robustness of conclusions. For all four species, the mean counts of saplings were very low in the survey.

In all four fodder plants, there were observed relationship s between distances (0 - 21 km) along the core-boundary of Yankari and the counts of seedlings, saplings and adults. However, the sapling population was low among all fodder plants investigated. The observed low number of saplings in this area could be due to other biotic and abiotic stresses. The low counts in sapling population can be attributable to other factors that hinder the survival of fodder plants in Yankari. The study found that some of the seedlings and saplings were browsed on during the survey although these may be the result of utilization of these species by other herbivores in the reserve including the buffalos and the antelopes. In related studies, Ouédraogo-Koné *et al.,* (2008), found herbivore pressures through consumption of seeds and seedlings in West Africa sub-humid zone, while Onana and Duvineau (2002) observed these pressures through trampling, hinder the regeneration process in plants.

Fire is synonymous with the savannahs. In most species fire is generally assumed to kill seedlings of woody plants (Grellier *et al.,* 2012) and significantly hinder sapling growth (Grellier *et al.,* 2012; Saha and Howe, 2006). However, seedlings and saplings, such as *C. molle, E. abyssinica and S. spinosa*, died back to ground level even in the absence of fire. Wakeling *et al.,* (2011) observed that saplings growing at mean rates under typical fire regimes in African savannahs are not likely ever to escape the fire-trap and become adults. African savannah woody plant species normally experience and survive more than one fire event as saplings before advancing into the adult species (Hoffman, 1999). However, Werner

(2012) observed that early dry-season fires enhanced growth in the height of eucalyptus saplings compared to fire-protected saplings and concluded that sapling growth responds to fire and the probability to reach the tree phase vary with life history stage. Dry season drought may also be responsible for the survival of saplings. It is likely that some species may re-sprout during the rainy season depending on their root system etc. (Turner, 2001).

There is a high level of incursions in Yankari by the surrounding local communities. Jada (northeast) and Kwankwani (southwest) tracks had the highest numbers of cow tracks however no patches of fodder plants were identified on these tracks although indications of *A. africana* were noted in both locations suggesting these plants has been greatly degraded. The cattle tracks that were marked, differed both in length and width. Some of the cattle tracks were wider than the game viewing tracks and the hoofs on the tracks showed that large herds of cattle had used the tracks recently. Many herds of cattle and other livestock were encountered during the surveys but they were always without a herdsman. This is because "the herdsmen are very smart and they hide in the bushes immediately they detect any sounds of vehicles or they hear human voices" according to an old park ranger.

A few yards outside the boundary of Yankari, near the Bogha track and also to the far north of the Sha'aman track, many Fulani tents were observed. Some of the donkeys and camels that belonged to the Fulani, were tied in the reserve to graze. These findings further validate the reports of Green (1986) (Chapter 2, Appendix 1) who reported a high level of activity in Yankari from cattle grazers during the dry season. Also more recent reports (Tiseer, 2009; Omotoriogun *et al.*, 2011and Tende *et al.*, 2011), highlighted the high levels of anthropogenic activities around the Yankari boundary.

4.4.4 Study implication for conservation and management

This research highlights that all parts of the reserve are accessed by the herders who graze their livestock in Yankari. There is evidence that species of *A. africana* and the other fodder plants were harvested at high rates near the core (Lipji track and Ahmadu Bello way) as well as near the boundary of Yankari. It is therefore important for the staff and rangers in Yankari to improve on existing monitoring, including patrol schedules, so as to reduce or completely stop the illegal harvests of fodder plants. The Wildlife Conservation Society (WCS) has been involved with anti-poaching activities since 2009 using cyber trackers and collaring of elephants to monitor their herds. In 2014, the WCS signed a memorandum of understanding with the Bauchi state Government and have taken over the responsibility of conservation and protection in Yankari (WCS, 2014).The new management plan (WCS, 2014) details improved patrol efforts, especially in 2014, and it is possible therefore that there may have been some improvement in the reserve between the period of the survey (2010 - 2014) and the new role of WCS.

The observed patterns of foliage harvest provides insight on what kinds of conservation plans may be most appropriate to initiate/adapt in Yankari.

Clearly, Yankari herders severely harvest *A. africana* species. Herder's prefer to harvest the young light green leaves, as opposed to the old dark green leaves that have not been harvested over long periods. Therefore, the already harvested trees stand more chances of being harvested than the ones not harvested the previous season. Of course, increased demand could lead to the exploitation of these populations in the future, and their status will therefore depend on their level of protection and availability of alternative harvest options.

Low sapling densities in fodder plants prevail in Yankari. Consequently the genetic diversity should be assessed in order to opt for the best strategy that will maintain and maximize the genetic diversity. Protection might efficiently provide better conditions for sapling regeneration and favour the recruitment and conservation of tree densities

Lastly, the establishment of fodder plants plantations is worth considering for both ex situ conservation of highly harvested plants and to reducing the harvesting pressure on wild natural populations. Studies in Benin found that Fulani people avoided pruning *K. senegalensis* trees planted along roadsides or in plantations (Petit, 2003; Gaoue and Ticktin, 2007). Consequently, if the herders in Yankari are encouraged to plant fodder plants around their own compounds, it may be a conservation option.

Findings from this study suggest that multi-scale assessments are needed to understand the synergic interaction of the threats and predict how fodder plants may fare in future. These assessments should include estimating densities of local communities and farmlands near the boundary and changes over time, because any increase in human population will suggest more pressure on Yankari

4.5 Conclusion

The findings from this study reveal that fodder plants are harvested in Yankari but the extent of the harvest varies by species (*A. africana* and *B. aegyptiaca* are severely harvested). *A. africana* and *B. aegyptiaca* seem to be the preferred fodder by the herders of all the species investigated. Additionally, the findings showed that distance is not a constraint to herders' activities in Yankari, as harvested fodder plants were encountered to the same extent at the core (e.g. Lipji track and Ahmadu Bello Way) as well as at the boundary (e.g. Bogha track, Yalo track, end of Sha'aman track). Findings from this study also revealed that fodder plants recruitment were significantly impacted by distance from the core to the boundary at all growth levels. Furthermore, Yankari was found to be surrounded by many local communities, most of the local communities were 5 km and less from the boundary of Yankari and many of the herds' of livestock found in the reserve belong to those communities. The wide and narrow cow tracks found within Yankari can be traced to the routes of incursions from the local communities.

The management of Yankari needs to set out effective monitoring of habitats, especially areas around the boundary to evaluate current strategies for conservation and liaise with other regional conservation strategies to maintain the protected area.

The results of this current study have given evidence of change in the woody vegetation of Yankari (see, Chapter 2), which suggests a rising trend in human activities at the boundary of Yankari (see, Chapter 3). The findings also confirm that these human activities have recently extended into the reserve. Finally, this study has also shown the high interaction of the local communities surrounding Yankari with the reserve. Consequently, it will be beneficial to involve the local communities in the next phase of this research in order to determine whether local communities are aware of the changes in their environment, particularly with regards to the fodder plants being investigated. Globally, in the fields of conservation biology and environmental science, participatory studies have been a main consideration. Therefore, to explore the perception of the herders in the local communities on the trends in their herds and fodder availability, will be interesting. This is to aid the author in making effective recommendations towards best sustainable use options (e.g. agroforestry parklands, sensitization for seedlings protection) for the fodder plants under investigation.

Perceptions of herders on trends in their herds and abundance of fodder plants.

Abstract

This study gauges the perceptions of the herders in the local communities surrounding Yankari on fodder availability, and trends in their herds' status over time. Surveys were conducted in five local communities (Dagudi, Galen sanji, Jada, Yalo and Pali) surrounding Yankari. Only male sedentary herders were included in this survey, with majority of the herders being Fulani. Focus group discussions with Yara, Mattassa and Dattijai were conducted. Additionally, 122 questionnaires were administered. Both the FGDs and the questionnaires were designed to focus on understanding herder's perceptions of fodder plants (Afzelia africana, Pterocarpus erinaceous, Strynos spinosa, Balanites aegyptiaca, Tamarandus indica, Khaya senegalensis). Data analysis was performed with R version 3.1.2. Cross-tabulation was used to determine differences between herders' responses on rarity and preferences of fodder plants between local communities. Additionally, descriptive statistics were used to compare data and trends in herds' status. Data on demographic characteristics was also summarized with descriptive statistics. Major findings include: Afzelia africana and Khaya senegalensis as being perceived as very rare by the herders from local communities' sampled. On livestock preferences of fodder plants, herders perceived that cattle prefer Afzelia africana, Khaya senegalensis and Ptericarpus erinaceous while sheep and goats prefer Balanites aegyptiaca and Strychnos spinosa in local communities sampled. Furthermore, the herders in Yankari inconsistently reported on the trends in their livestock but had clear knowledge of the preference and availability of fodder plants in their surroundings. Conclusively, the study found out that many Fulani and their livestock undertook major migrations to the local communities in the 1980s and 1990s. Herders are aware of the decline in the abundance of fodder plants and have devised temporary migration as a strategy to cope with the situation.

5.1 Introduction

Understanding the social drivers of resource use has recently become a key question in conservation biology and environmental management (Bawa *et al.,* 2004; Milner-Gulland, 2008; Mace *et al.,* 2008 Gaoue and Ticktin, 2009). Issues regarding how indigenous people perceive their environment; make resource use decisions, and what factors influence their perceptions and interactions, are central questions in ethno-ecology (Gaoue and Ticktin, 2009). Furthermore, ethno-ecological studies advocate an integration of indigenous knowledge base into ecological studies to advance the understanding of ecological processes, improve ecological impact assessments, and develop better plans for sustainable resource use (Ticktin and Johns 2002; Bawa *et al.,* 2004; Donovan and Puri, 2004; Ghimire *et al.,* 2004; Fraser *et al.,* 2006; Gaoue and Ticktin, 2009). Consequently, it is important to analyse results from an indigenous knowledge base and evaluate its consistency with scientific knowledge base (Fraser *et al.,* 2006; López-Hoffman *et al.,* 2006; Gaoue and Ticktin, 2009), so as to identify key ideas that can be consolidated into scientific research and programmes for sustainable resource use.

In the drylands of West Africa, rural families keep domestic animals as source of food and nutrition, for cash, for cultural heritage and for household security. Forests and woodlands provide the pasture for grazing as well as fodder for stall-feeding. Fodder plants (e.g., *Afzelia africana, Khaya senegalensis, Pterocarpus erinaceus, Balanites aegyptiaca)* are highly utilized as feed for livestock in the long period of dry season (Petit, 2003; Gaoue and Ticktin, 2007; Jurisch *et al.,* 2012; Bufford and Gaoue, 2014). While fodder is found and used locally, uncontrolled fodder collection and frequent grazing has led to forest depletion (FAO, 1995; Agustino *et al.,* 2011). In the period between November and March, grasses are completely dry and do not contain any carotene and nitrogen represents only 1% of the dried matter. The only source of digestible nitrogenous matter comes from the green leaves of trees and shrubs. Therefore woody plants serve as reserves that support livestock (LeHoue'rou, 1980, Lykke *et al.,* 2004).

Herding is a common practice among pastoralists who are highly mobile. The mobility of the pastoralists has positive as well as negative impacts on the uses of natural resources (Monod, 1975 and 1975b; Toupet, 1975 and Scoones, 1995). The movement of the pastoralists is characterised by sporadic livestock grazing which allows for the regeneration of the grazed vegetation, which is beneficial for the environment (Gulliver, 1955 and Stenning, 1959; Behnke *et al.*, 1993; Dupire, 1996). However, pastoralists' movements have also been shown to negatively affect natural resources, through heavy harvest and misuse (Petit, 2003; Gaoue and Ticktin, 2007). Such harvest, has economic and cultural implications (Ticktin, 2004; Bawa *et al.,* 2004) and has also shaped this tropical landscape for several decades (Petit, 2003; Gaoue and Ticktin, 2007; Jurisch *et al.,* 2012, 2013).

Sustainable management and conservation of these fodder plants require an understanding of indigenous ecological knowledge and perceptions of the impacts of harvest and other sources of disturbance, and how these influence resource use patterns. This information is critical for designing and implementing management plans that fit with local cultural practices and perceptions. Therefore, ethno-ecological interviews adapted for this study should help explore herders' knowledge, practices, and perceptions of the ecological impacts of harvesting fodder plants.

In the previous chapter, (see, Chapter 4), findings suggests that herding activities are prevalent in Yankari and severe rates of harvests in some fodder plants is one of the most important factors causing decline in the fodder plants. The level of degradation of these fodder plants could not be easily quantified with the vegetative assessment alone, hence this chapter will add evidence to the findings from chapter 4, on fodder preference. Additionally, as a result of the local communities living in close proximity to the reserve, the expectation is that these herders will be more knowledgeable on the changes in fodder plants hence their knowledge will also help substantiate the findings of the previous chapter. Furthermore, in designing major conservation programmes it is important to understand the natural resources that local people value from protected areas, therefore, understanding their perspective in this regard is important for this study.

This study explores the perceptions of herders in the local communities surrounding the reserve, with regards to trends in their herds and abundance of fodder plants. By combining information on use-preferences and fodder plants dynamics, fodder plants will be evaluated to identify aspects of importance for local use and conservation. The study is designed under two objectives.

- To ascertain trends in livestock abundance of herders in the local communities surrounding Yankari.

- To determine herders' perception on fodder preference and availability

5.2 Brief Background of human communities under study

The Fulani or Fula or Fulbe (Fula: Fulɓe; French: Peul; Hausa: Fulani; Portuguese: Fula; Wolof: Pël; Bambara: Fulaw) are a very significant ethnolinguistic group in Africa numbering approximately 40 million people (Iro, 2008; Petit, 2004). The Fulani speak Fulfulde and they are a widely dispersed and culturally diverse people. Fulani are mainly found in West Africa in a region extending from Senegal to Cameroon in Sahelo - Sudanian Africa (Petit, 2004), in the northern parts of Central Africa, and North Africa (Tishkoff *et al.,* 2009). An estimated 13 million Fulani are nomadic, making them the largest pastoral nomadic group in the world (Dyson-Hudson, and Dyson-Hudson, 1980). The Fulani are a heterogeneous group. Some are nomadic, pastoral, and Bororo. Another group are semi-nomadic, and the last group are the settled Fulani or "town Fulani" (Bierschenk and Le Meur, 1997). Nomadic pastoralists herd their livestock in order to find fresh pastures on which to graze. The pastoral Fulani move around with their cattle throughout the year, they typically do not stay longer than 2- 4 months at a particular area at any time i.e. the nomads follow an irregular pattern of movement (Blench, 2001).

Generally, the loss of cattle from the past decades has resulted in increasing sedentarisation of the Fulani (Hamphire and Smith, 2001; Juul 2005; Iro, 2009). In Nigeria, for example, Fulani can be categorized sociologically into four groups: 1) the ruling dynasties of most of the Northern Nigerian Emirates (Hogben 1930); 2) the settled Fulani, who are in occupations as court officials, judges, scribes, entrepreneurs and farmers; 3) the semi-sedentary Fulani (in Northern Nigerian), who are primarily farmers, but who also maintain herds of cattle for which pasture is sought at a distance; and 4) the pastoral Fulani (Bororo, in Northern Nigeria) who depend completely on their herds of zebu cattle for subsistence, and whose lives are tuned to continuous transhumance, migratory drift, and periodic migration (Dongmo *et al.,* 2012).

The household is the herd-owning and rearing unit for the Fulani (Iro, 2008). Tasks are assigned to individual members of the family as a form of division of labour. Each individual member of the family in turn contributes to, and benefits from livestock rearing (Stenning, 1959; Sutter, 1987; Bierschenk, 1988). Through this division of labour, the Fulani optimize their production methods (Wilson 1985). Regardless of age, gender and assigned tasks, a member of the household learns all the herding skills. The Fulani has a fixed routine - each day at sunrise, Fulani free the livestock from the tether and take them out to the field to graze. The animals are returned home/camp in the afternoon for milking and watering and taken back again to graze until sunset. At night the Fulani keep vigil on the livestock, protecting them from bandits (Iro, 2009).

In a Fulani household, men are the providers. They protect both the household members and the herds from carnivores and raiding tribes. The men also take the animals to long-distance pasturelands, find fodder, dig wells, and make or buy weapons such as guns, knives, swords, herding sticks, and bows and arrows (Iro, 2009). The sons of the Fulani are herd boys for the family till they marry and establish their own families. . In return for their service as herd boys, the Fulani father gives some cattle to his son(s) so that they can start their own herd. The wife or wives of the Fulani herdsman are responsible for milking the cattle, take care of the basic domestic tasks and raise the children.

During the nineteenth and twentieth century, one significant development in the geography of livestock raising was the southerly movement of the Fulani herds from the Sudano-Sahelian zone to the more humid Sudanian and Guinean savannahs of West Africa (Blench, 1994; Boutrais, 1994; Gautier *et al.,* 2005). For example, the appearance of large numbers of humpbacked zebu cattle in areas where they were formerly absent was viewed by peoples of the southern savannah as an invasion (Coulibaly, 1980; Bernardet, 1984; Arditi, 1990). Many studies have reported that the severe droughts of the early 1970s and mid-1980s were the main reason for the southerly invasion of Fulani pastoralism (Delgadoand Staatz, 1980; Arditi, 1990; Bernardet, 1999; Diallo, 2000). Similarly, the literature suggests that Fulani pastoralists have settled down in large numbers near less densely populated villages of farmers in Sudano - Sahelian zones over the past 30 years (Niamir-Fuller 1998; Swift *et al.,* 1996; Bassett and Turner 2007).

The Fulani migrants account for a fraction of the population in the host communities although they own the majority of livestock. Furthermore, they have few property rights leading to their continuing marginalization (Bassett 2009; Benjaminsen and Ba 2009; Dongmo *et al.,* 2012). Moreover, the recent expansion of cropping areas by farmers has further led to more frequent conflicts between farmers and Fulani, as well as increased competition over limited resources, as the resources are threatened (Dugué *et al.*, 2004; Kiéma 2007; Benjaminsen and

Ba 2009; Weber and Horst, 2011). Furthermore, there has been significant restriction and reduction of pasture, significantly reducing forage supply for herds, making herds' mobility more difficult especially during the rainy season (Turner *et al.*, 2005; Dongmo *et al.*, 2007; Vall and Diallo 2009).

Faced with all these challenges, these settled herders have been forced to increase the mobility of their livestock (Dongmo *et al.*, 2007; Adriansen 2008; Moritz *et al.*, 2010). Thus, mobility is an important characteristic of the Fulani strategy for survival, combining daily movements with minor and major transhumance based on different opportunities and challenges (Turner *et al.*, 2005; Bassett, 2009; Moritz, 2010; Dongmo *et al.*, 2012).

5.2.1 Study Area

Yankari is located in Bauchi state (see, Chapter 1 for general description of study area). There are 20 Local Government Areas (LGAs) in Bauchi state of Nigeria. Alkaleri where Yankari is located is one of the 20 LGAs. Alkaleri LGA has an area of 6,092 km^2 and Yankari partly (2,244 km^2) covers Alkaleri. During this study, the author could only access limited census figures for Bauchi State which served as a guide to interpreting the trends in herders and subsequently herds. Figure 1 shows the population density of the 20 Local Government Area (LGAs). Yankari is marked Green within Alkaleri. Since Yankari is an exclusive game reserve without any human habitation, the population density therefore applies to the local communities outside Yankari.

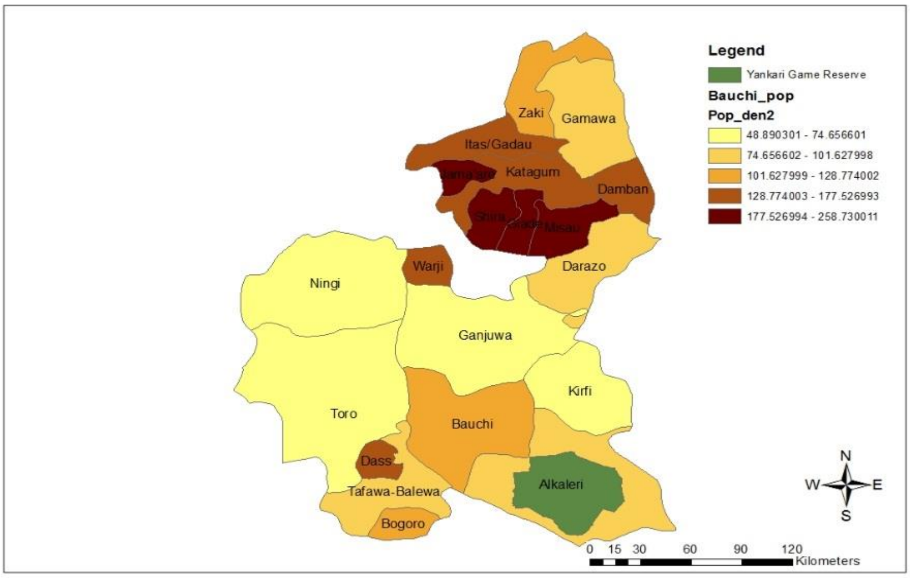


Figure 5.1: Population density of 20 Local Government Authorities of Bauchi state, Nigeria showing Yankari Game Reserve.

Alkaleri's population is reported as 329,424 in the 2006 Census. The main natives' in Alkaleri from author's interaction with the people in Alkaleri are the Bolawa, Hausa, and Fulani.

Yankari is traversed by game viewing tracks that are linked to local communities surrounding the reserve and by which these local communities illegally access and utilize renewable natural resources within the reserve (Tende *et al.*, 2011). Previous studies have described the nature of the interaction and recommended that urgent action be taken (Green, 1987). A recent study has reported the patterns and extent of foliage harvest in Yankari (see Chapter 4) impacting on the population structure and dynamics of the fodder plants investigated. The plants that are reported to be highly harvested are also evidently browsed by wild stock (Tiseer, 2009). Additionally, several interactions of herders were mapped in Yankari which gives evidence of local communities' high interaction with the reserve. (see, Chapter 4).

5.3.0 Methods

5. 3.1: Data collection

Five local communities, Dagudi, Galen sanji, Jada, Yalo, and Pali, surrounding Yankari were included in this survey. Stratified random sampling based on the three main districts of Alkaleri LGA was used. The five local communities represented approximately 30% of total number of local communities (18). All the local communities selected are within 5 km from the Yankari boundary.

Firstly, an initial round of visits to the heads of the local communities were made. This was to familiarize the survey team with the environment, the people and to seek permission to work in the local communities. In all five local communities, the survey protocol was accepted and permission to work with the people granted. Each local community head committed the permission granted in writing. The interaction with the local communities heads was great across the communities and convenient/suitable days for the survey were suggested when herders gather in the community square for prayers or for other social reasons. Figure 5.2, shows the survey design, which includes all local communities: those in the initial survey plan and those that were eventually surveyed.

Several attempts to get data on the total number of local communities' proved challenging as reports from previous authors were not consistent and reliable. Documents showing patrol points used by the rangers of Yankari were accessed, and used as a guide in estimating the total number of local communities around Yankari and to determine an appropriate sample size. Also the main reason opportunistic sampling was considered and carried out is because of the limitations encountered as regards scattered herders' population, large area of herders' settlements, difficulties in reaching and making contact with the herders etc.

Both qualitative (i.e., focus group discussions (FGDs), Appendix 2) and quantitative methods (questionnaires, Appendix 3) were used to collect data from the local communities. Themes for FGDs and the questionnaires were carefully designed to focus on understanding herder's perceptions of fodder plants (*Afzelia africana, Pterocarpus erinaceous, Strynos spinosa, Balanites aegyptiaca, Tamarandus indica, Khaya senegalensis*) and also on trends in their herds' abundance. Only male sedentary herders were included in this survey, although majority of the herders in the local communities are Fulani. Furthermore, the Fulani believe what determines a family is the heart size, which refers to the number of household members that eat from the same pot. Therefore a typical family comprises of a man, his wife (or wives) his children and his son/sons' families. Plant samples (leaves, seeds and branches of the fodder plants) were used as tools for both surveys. Questions on plant-based indicators and livestock based indicators were included in the themes for the FGDs and the questionnaire interviews. All the themes for the FGD were open ended, which allowed for more detailed discussion with the respondents, while questionnaires were both open ended (see, question

35) and pre coded questions. For the open-ended questions the author improvised measuring scale using tin containers of different sizes as indicators of severity or mildness of a particular action or situation (see, questions 20, 22 and 23 as examples in Appendices 3). The respondents understood the idea behind using the tin containers and they readily assessed and answered the questions asked with sufficient clarity.

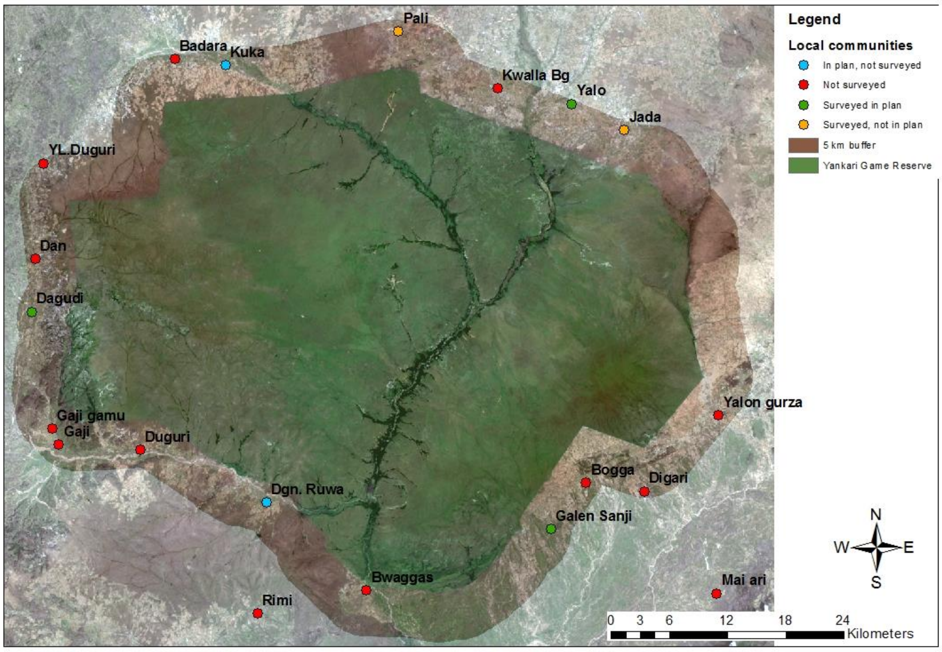


Figure 5.2: Map of Yankari Game Reserve, Nigeria showing survey design. Blue dots represent local communities in the original survey but eventually not surveyed; red dots are local communities not in original plan and not surveyed; green dots represent local communities in survey plan and eventually surveyed and orange dots represent local communities surveyed but not in original plan.

The FGDs were done on an average of 30 minutes with each group per local community. Only sedentary herders from age 10 and above were interviewed. This decision was influenced by the author's constraints on budget, time and ability to achieve a degree of precision to answer the study objectives. Three categories of male migrant and indigenous Fulani herders were included in the FGDs: Yara (children, age = 10 -18); Matassa (youth, age = 19 – 45); Dattijai (elders, age = 46 & above). (See, Table 5.1). One group (4 to 7 people) each of Yara, Mattassa and Dattijjai were interviewed. A test run on questionnaires was also conducted during the FGDs to see if there might be unanticipated problems of wordings, instructions and to familiarization with local terminologies.

Table 5.1. Shows target population, sample size and key informants in the local communities surrounding Yankari Game Reserve, Bauchi State. FGD = Focus Group Discussion. Yara = children; Mattassa = Youth; Dattijai = Elderly. Hardo is the leader of the Fulani.

Communities	FGD	Key Informant	Questionnaire
Dagudi	Yara 7 Matassa 7 Dattijai 7	Hardo	19
Galen sanji	Yara 6 Matassa 7 Dattijai 7	Community head	22
Jada	Yara 5 Matassa 6 Dattijai 7	Hardo	23
Yalo	Yara 6 Matassa 7 Dattijai 7	Sarkin fada	32
Pali	Yara 4 Matassa 5 Dattijai 7	Community head	26
Total = 5	95	5	122

The village heads recommended the children to be part of the survey because they are the ones involved in active herding, therefore they are expected to have best knowledge of the current status of the fodder plants. All children were interviewed with elders present. Before the start of each interview, each individual was briefed on the objectives of the study. Each individual was made aware that the interview would cost them time, that participation in the interview was voluntary, and that they could opt out of the interview at any time. The respondents were assured that the information collected would not be disclosed nor released in any form that would allow their identity to be disclosed or inferred, so as to ensure confidentiality.

A total of 122 herders were interviewed using a semi-structured questionnaire (see, table 5.1). Figure 5.3 (a – d) are pictures from the survey. Caution should be exercised in relation to the herd size of the pastoralists reported in this study because they usually underreport their animal numbers to limit taxation (Pouillon, 1988; Ayantunde *et al.*, 2007). Responses are usually dependent on who is asking the question and for what purpose.

Figure 5.3: a = species identification in Pali ; b = Questionnaire session in Yalo; c = Questionnaire session in Jada; d = Questionnaire session in Galen sanji

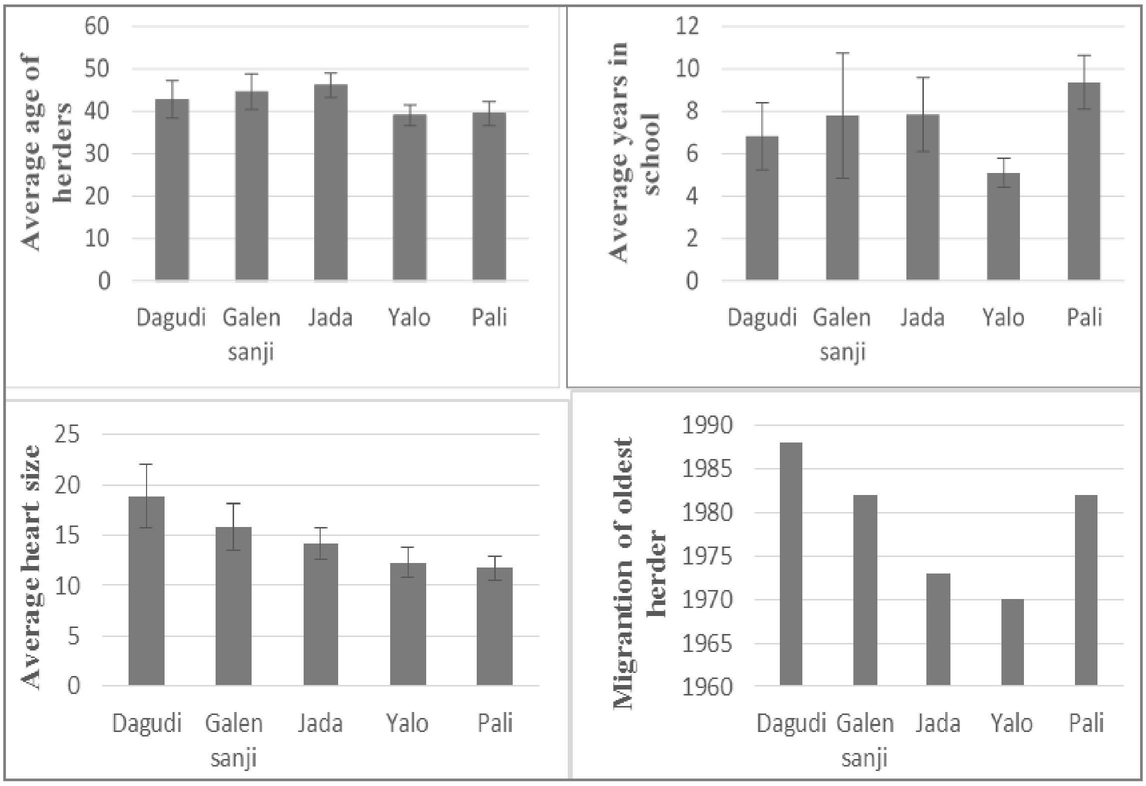
5.3.2: Analysis of surveyed data

Data analysis was performed with R version 3.1.2. Cross-tabulation, Chi-square and Kruskal Wallis tests were used to determine differences between herders' responses on rarity and preferences of fodder plants within and between local communities. Additionally, descriptive statistics were used to compare and present the population data and trends in herd abundance. Data on socio – economic characteristics was also summarized with descriptive statistics. The population density map of Bauchi state was reproduced with the ArcGIS software.

5.4.0 Results

5.4.1 Demographic characteristics herders

The demographic characteristics of the herders appear very similar in ages of the herders but differed in the years herders spent in school, heart size of herders' and year of migration of the oldest herder across the local communities surveyed (Figures 5.4 (a - d). Results from this study revealed that youth age group (Mattassa) dominate the herding population in all local communities surveyed. The average school age (Arabic) across the local communities' falls in the range of 5 – 9 years, with Pali having the highest average. Dagudi has the highest average number of the heart size, other communities have similar averages and Pali has the least average number. The oldest migrant herders was to Yalo and Jada in the early 1970s, and recently, to Dagudi in 1988. The periods mentioned above gives a picture of when herders started settling down in the local communities surrounding Yankari.



Figures 5.4 (a - d): Demographic characteristics of respondents in local communities sampled. Av. = Average. a = means +/- SE age of herders; b = means +/- SE school age of herders; c = means +/- SE heart size of herders; d = date of migration of oldest herder for each community.

The average herd sizes of the livestock are presented in Figure 5.5. The mean herd size of cattle generally appear higher than those of sheep and goats. Pali appears to have the highest population of cattle, and Jada the lowest. Additionally, the population of sheep and goats are similar across all local communities however in Pali the number of sheep and goats are equal. Galen sanji and Pali have the highest population of sheep and goats, while Jada has the lowest.

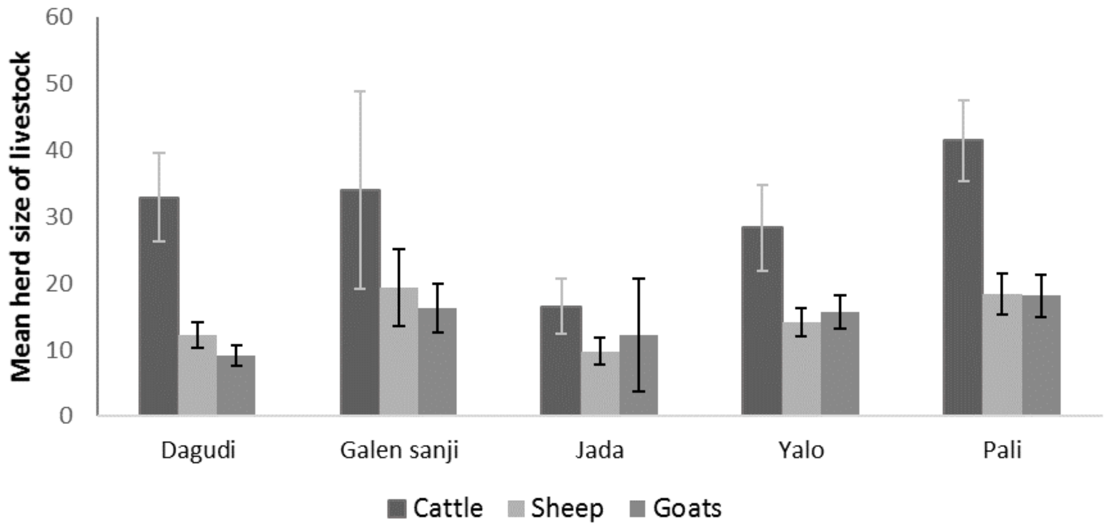


Figure 5.5: Mean +/- SE herd size of livestock per local community. Error bars represent 95% confidence level around the mean values.

Herder's responses on the trends in their livestock herds since the years they migrated are presented in Figures 5.6 and 5.7. The figures show general trends on the migration of herders to Yankari as well as what the herders perceive as the status of their herds since their migration. The herders' migration in the 1970s was low but this increased in the 1980s. The perception on the trends in the herders' livestock were described as "decreasing, stable and increasing".

Generally the herders' perception on the trends in status of their livestock was inconsistent and varied in responses in cattle as well as sheep and goats. Herders' migration seem to have gone down in recent times (0-20 years ago). Similarly the herders' perception of their cattle seem to have increased (see, Figure 5.6) in (11-30 years ago) and stable/increase in (0-10 years ago). However there seem to be no clear trends in the numbers of the herders that perceived their cattle as decreased, stable or increased. Figure 5.7 shows the perception of the herders on the trends in sheep and goats. The figure is also similar to the one of cattle trend i.e. no clear trend in seen. Whether these results have arisen as a result of herders' inability to recollect the status of their livestock over the years or not, it is not clear.

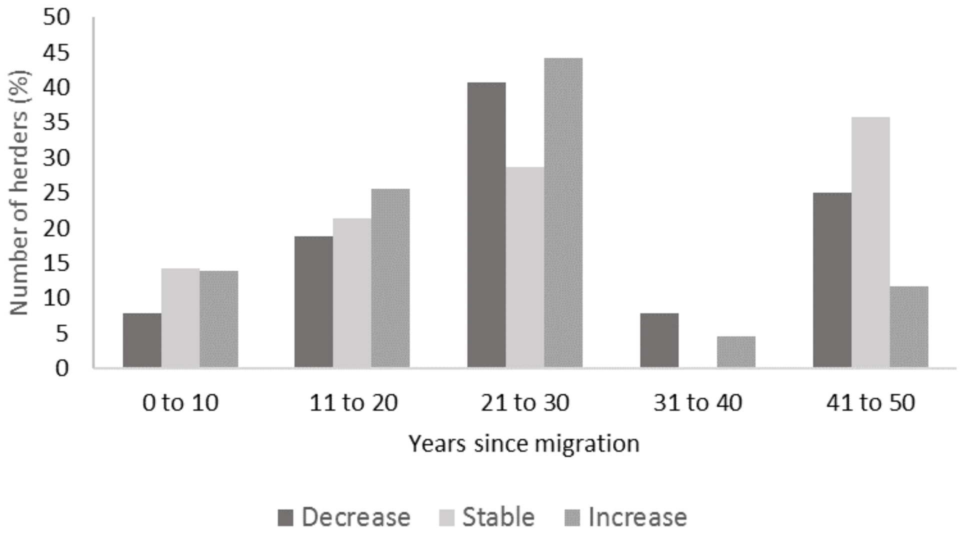


Figure 5.6: Trends in status of cattle since migration of herders: y - axis = percentage (%) of herders: x - axis, years since migration and status of herds

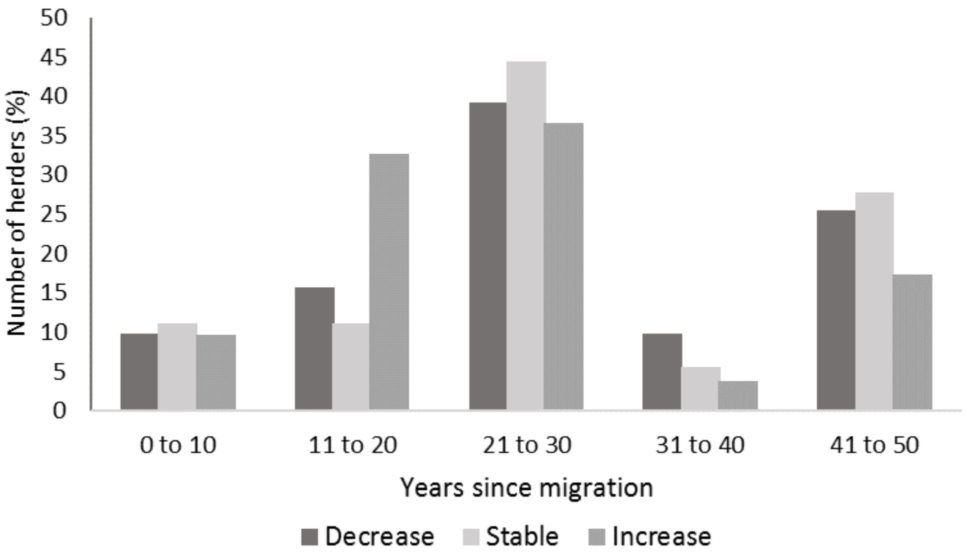


Figure 5.7: Trends in status of sheep and goats since migration of herders: y - axis = percentage (%) of herders: x - axis, years since migration and status of herds

5.4.3 Herders perception on fodder availability

5.4.3.1 Herders encounter of the fodder plant species

The results of herders' ranking of the fodder plants on an average herding day generally, is presented in Figure 5.8 whilst the details of trends across the communities are presented in Figure 5.9 (a- d). All herders ranked *A. africana* and *K. senegalensis* as very rare species. A majority (71%) of the herders' ranked *P. erinaceus* as rare. *B. aegyptiaca* (86%) and *S. spinosa* (82%) were perceived as being average in encounter, while *T. indica* (84%) was ranked as fairly common by the respondents.

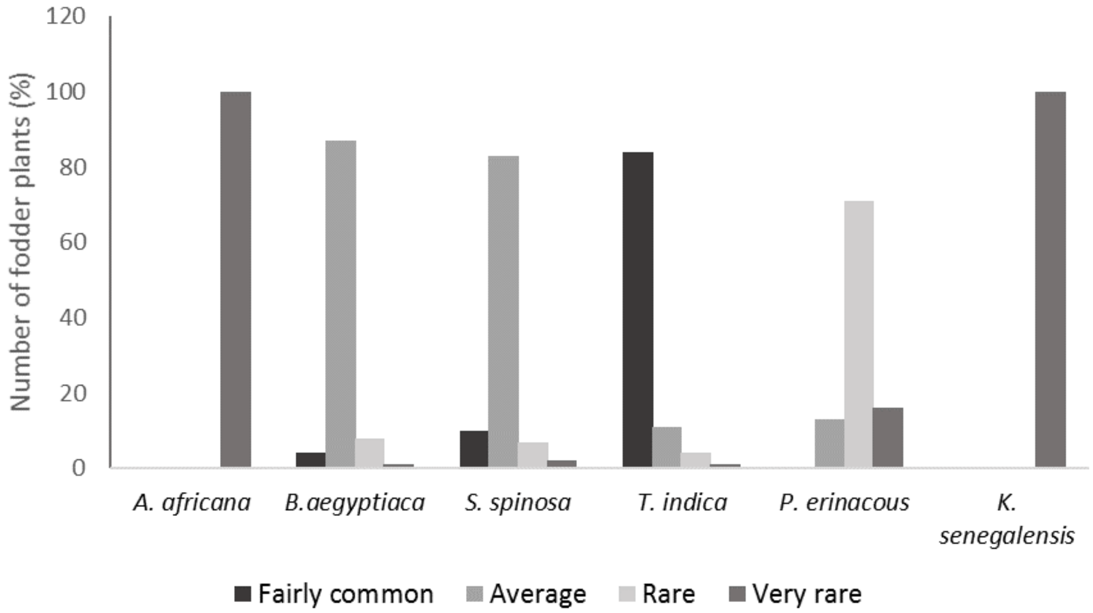


Figure 5.8 Rarity ranking of fodder plants in Yankari Game Reserve, Nigeria. Common = > 50 (No data); fairly common = 30 - 50; average = 20 - 30; rare = 10 – 20; very rare = < 10 *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca; K. senegalensis = Khaya Senegalensis; T. indica = Tamarindus indica*

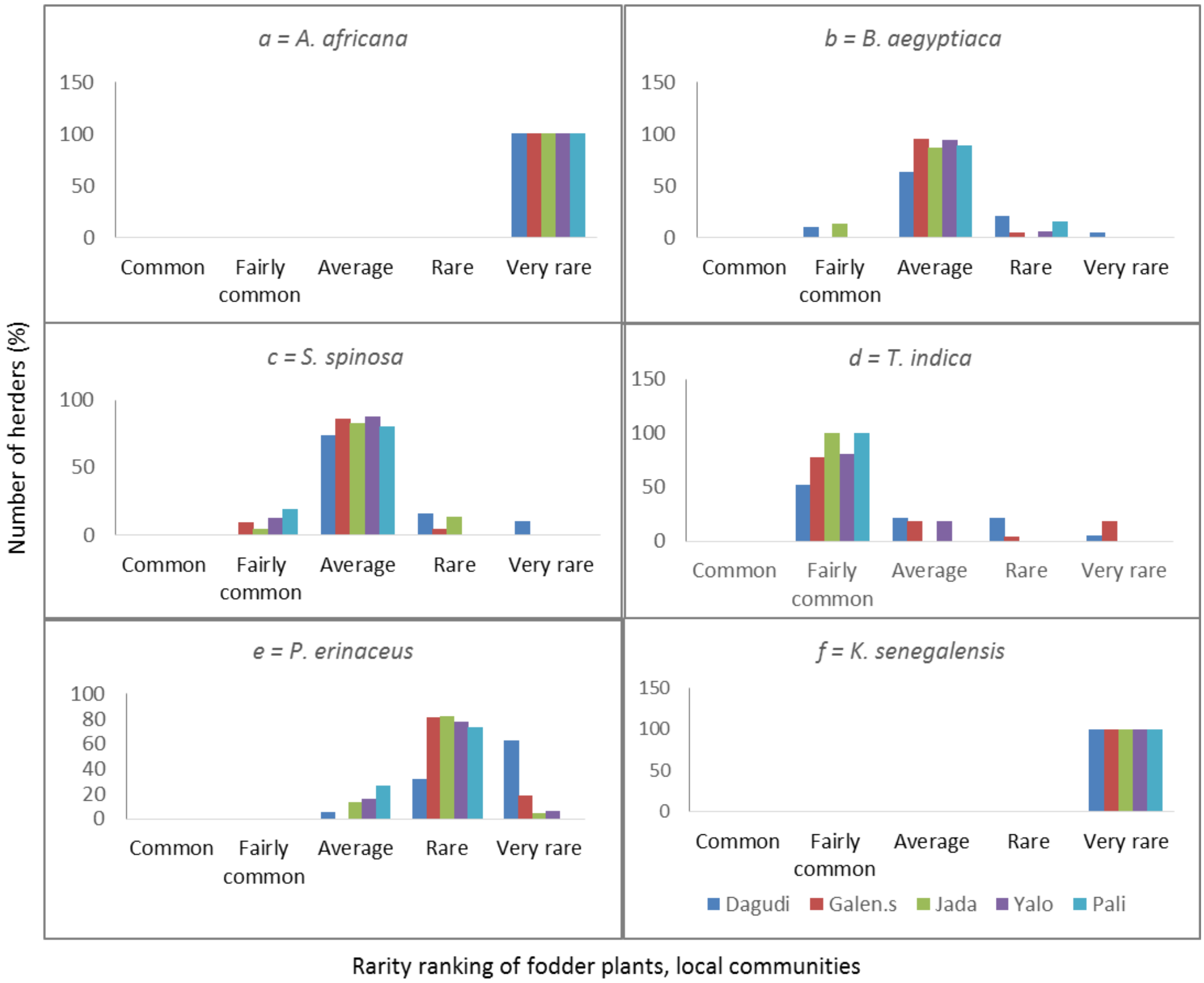


Figure 5.9 (a – f): Rarity ranking of fodder plants in the local communities surrounding Yankari Game Reserve, Nigeria. Common = > 50; fairly common = 30 - 50; average = 20 - 30; rare = 10 – 20; very rare = < 10. *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca; K. senegalensis = Khaya Senegalensis; T. indica = Tamarindus indica*

P. erinaceus perhaps has the most interesting ranking compared to the other species reported (see, Figure 5.8e). In all the local communities with the exception of Dagudi, *P. erinaceus* encounter was reported by the herders as being rare, but in Dagudi only 32% of the respondent's ranked *P. erinaceus* as rare and up to 63% ranked it as very rare.

Results of the Pearson's Chi-square test carried out showed that there is a statistically significant difference in herders responses on rarity of *B. aegyptiaca*, (p = 0.011), *S. spinosa*, (p = 0.009) and *T. indica* (p = 0.000) and *P. erinaceus* (0.000) between the local communities. However there were no values for *A. africana and K. senegalensis*. This may be as the result in herders' responses (all herder's ranked *A. africana and K. senegalensis* as 5 i.e.s very rarely encountered). Additionally, the Kruskal Wallis test which is a rank based test showed that there is a statistically significant variation in herders responses on rarity for *S. spinosa*, (p = 0.002) and *T. indica* (p = 0.000) and *P. erinaceus* (0.000) but not for *B. aegyptiaca*, (p =0.07), between the local communities.

5.4.3.2 Fodder plants preference per livestock

All herders from the five local communities ranked *A. africana*, *K. senegalensis*, and *P. erinaceus* as the most preferred species for their cattle. See figure 5:10 for the general trend in herders' preference in fodder plants. Herders' perception at the village level also agrees with the general perception see, figure 5:11. Only few herders picked *T. indica* as preferred species for their cattle in Dagudi and Galen sanji (see, figure 5.11).

Figure 5.10: Herders' preference of fodder plants for cattle in the local communities surrounding Yankari Game reserve, Nigeria. *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca; K. senegalensis = Khaya Senegalensis; T. indica = Tamarindus indica*

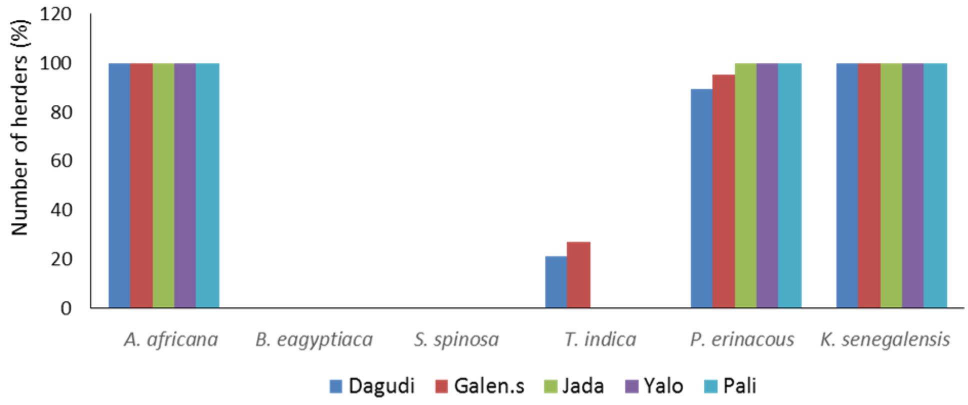


Figure 5.11: Herders' preference of fodder plants for cattle in the local communities surrounding Yankari Game reserve, Nigeria. *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca; K. senegalensis = Khaya Senegalensis; T. indica = Tamarindus indica*

In Figure 5.11, all respondents in Jada, Galen sanji and Yalo ranked *B. aegyptiaca* as the most preferred species by sheep and goats. Majority of the respondents in Dagudi and Galen sanji also ranked *B. aegyptiaca* as the most preferred species. Closely ranked is *S. spinosa* by the respondents in Jada, Galen sanji and Yalo and similarly the majority of the respondents in Dagudi and Galen sanji as the second most preferred species. In Dagudi, the majority of the respondents ranked *T. indica* as the third most preferred species to feed their sheep and goats. A little less than half of the respondents in Galen sanji also ranked *T. indica* as the third most preferred species, however *T. indica* was found not preferred in Jada, Pali and Yalo. The respondents also reported that *A. africana* and *K. senegalensis* are not utilized by sheep and goats.

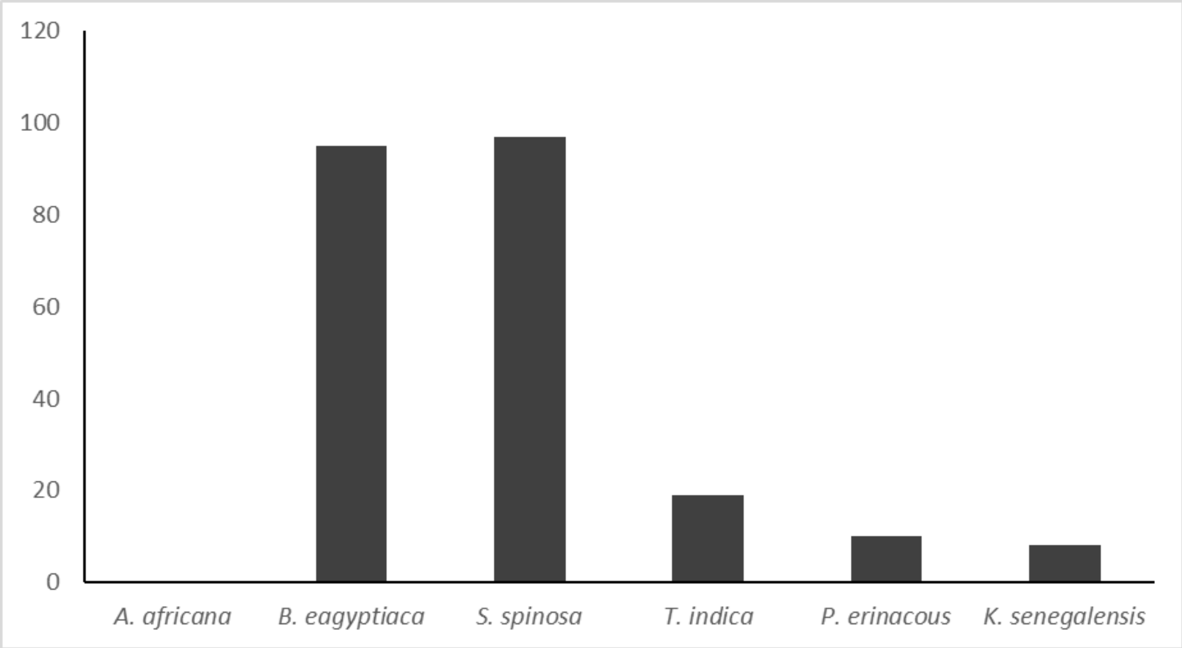


Figure 5.12: Herders' preference of fodder plants for Sheep and goats in the local communities surrounding Yankari Game reserve, Nigeria. *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca; K. senegalensis = Khaya Senegalensis; T. indica = Tamarindus indica*

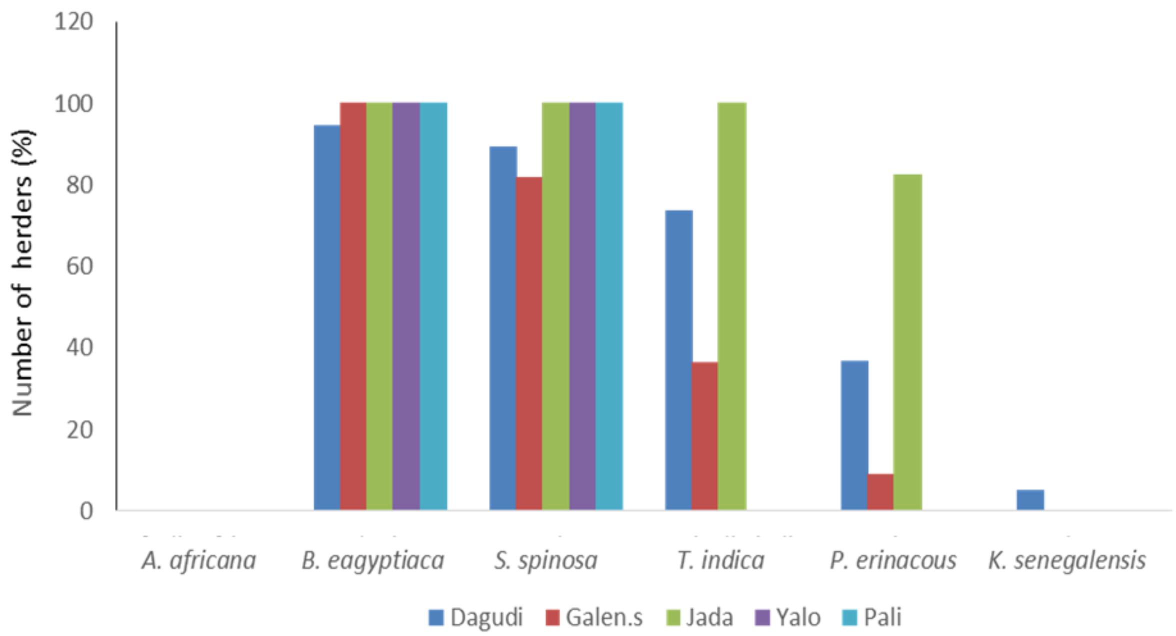


Figure 5.13: Herders' preference of fodder plants for Sheep and goats in the local communities surrounding Yankari Game reserve, Nigeria. *A. africana = Afzelia africana; P. erinaceus = Ptericarpus erinaceus; S. spinosa =Strychnos spinosa; B. aegyptiaca = Balanites aegyptiaca; K. senegalensis = Khaya Senegalensis; T. indica = Tamarindus indica*

5.4.3.2a Non-fodder use of study species

Although *B. aegyptiaca* and *S. spinosa* are ranked as averagely encountered, these fodder plants are popular among the local communities and are heavily utilized for purposes other than as fodder plants for their cattle. *B. aegyptiaca* is mostly used to make “Allo” (tablets used commonly in Koranic teaching) and “kota” (commonly used by hunters). The fruits of *B. aegyptiaca* is generally licked as sweets and the leaves are used for medicinal purposes and as foods. The commonest use of *T. indica* is for food purposes (Kunun tsamiya) and the herders claim they only use *T. indica* to feed their livestock in the absence of any other fodder plants. *B. egyptiaca* and *T. indica* are always spared in the local communities because of their uses. Additionally, *T. indica* gives good shade for the peoples’ relaxation in all the local communities. *K. senegalensis* was frequently reported to be used for medicinal purposes, especially to cure stomach aches in humans.

5.5 Discussion

In this study the author investigated herders’ perception in the dynamics of the key plants they interact with. Pastoral systems are always changing. Thus interpreting the results of a one-off survey may be problematic/unreliable considering the cyclic nature of livestock populations in this study and other sources of annual variability. The results from this study include herder perception derived from the survey data. The author recognises that bias could arise from long-term recollection of facts. Despite these and other limitations, the results from this study illustrate how information on indigenous ecological perceptions, knowledge and practices reveals a picture of system change. This information could subsequently inform locally appropriate sustainable management plans.

5.5.1 Herders’ characteristics and knowledge of fodder plants

Generally, the herders showed similar demographic characteristics, knowledge and use of the fodder plants across the five local communities surveyed. The Fulani herders indicated they shared tasks in the herding and concluded that children are actually the ones that tend cattle on a daily basis, except on distant trips, where the household head takes the responsibility of protecting the livestock herd and also the family. In a related study carried out in the Sahel (Niger), the majority of respondents (74% and 50% of the respondents in Kodey and

Toukounous) reported that only children herded livestock during the day (Ayantunde, 2000). Children are therefore a category to include in a survey such as this, because of their high interactions with the herding areas.

The herd sizes reported by the herders are suspected to be lower numbers than what they actually own. During the interview, the author observed hesitation and inconsistency (e.g. by asking same questions to different members of the household and each one giving different answers) in reporting their livestock herd size among family members. The hesitation among the Fulani herders in reporting accurate figures for their herds is founded on fears of taxation. Fulani herders are only known to give the right figures if they will benefit from livestock treatment from veterinary workers. In a similar study on why nomadic pastoralists cannot count their cattle (Pouillon, 1988), the author concluded that it is speculative to comment extensively on the herd size of the pastoralists because they usually underreport their animal numbers to limit taxation, also that there are strongly held taboos that discourage counting of their livestock such as, the herders believe they will attract divine wrath if they boast about herd size (Pouillon, 1988; Ayantunde, 2000). Nevertheless, the herd sizes when summed from all the local communities reported appear to be higher than the available fodder plants in Yankari, therefore it can be inferred that the herd size will continue to have negative effects on these species. Furthermore, herding has been recorded as factor in resource pressure (see, Desta and Coppock, 2004; Turner *et al.,* 2005).

The sedentary herders interviewed in this survey are grouped as migrant herders and indigenous herders. The data gathered did not allow the author to compare the two groups because of the very low number of the indigenous herders compared to the migrant herders. Therefore, comparison was done only between the local communities and not within the communities. Overall, the migrant herders gave two reasons for their migration to the local communities surveyed. The first was for grazing (kiwo) and the second to find water sources for their livestock. These are typically the primary reasons for herders to move at any given time based on literature (see, Hamphire, 2002; Gaoue and Ticktin 2008; Iro, 2009; Ouedraogo *et al.,* 2012; Brandt *et al.,* 2014).

The key aspect of the survey was when herders were quick to identify the fodder plants presented to them. The herders gave the names of the plants both in Fulani language (*A.*

africana = kawohi; *P. erinaceus* = Banuhi; *S. spinosa* = Butohi; *B. aegyptiaca* = Tanni; *T. indica* = Zasni and *K. senegalensis* = Kahi) and in Hausa language (*A. africana* = kawo; *P. erinaceus* = Madobiya; *S. spinosa* = Kokan biri; *B. aegyptiaca* = Addu'a; *T. indica* = Tsamiya and *K. senegalensis* = Madacci). The herders were also consistent in their ranking of both preference, and rarity of the plants across the local communities. The herders' responses in this study support the view that most herders have a good knowledge about the fodder tree resources available in their environment (Petit and Mallet, 2001; Komwihangilo *et al.*, 2001). All the herders have good knowledge of major tree species used for animal feeding in their area. This may be due to the fact that most of the herders interviewed have been involved directly in livestock herding activities for a long time. Additionally, the respondents also provided information on other uses of the fodder plants (see, 5.4.3.2a).

5.5.2 Herders' perception on trends in livestock abundance

From the results (see, figures 5.6 and 5.7) on perceptions of trends in livestock among herders, the lack of clear trend generally found in of herds status could be due to a number of factors such as herders inability to recollect the past, calving rates, death rates, diseases, and selling livestock for income. These factors must be considered in determining the trends in herds. For example, on further probe, some respondents were shaking their heads, in response saying "you can't compare sadly, of course there is a great reduction in the number of our herds". Furthermore the herders perceived a decline in the availability of grazing land (Daji) and scarcity of water as the major reasons for reduction in the calving rates in their cattle. Other threats mentioned included droughts, fire, wood cutters and natural changes. However diseases were the least mentioned threat. These findings are in contrast to studies by Desta (1999) who reported that the survey respondents felt that the overall number of cattle had actually increased over the longer term and attributed the primary reason for the pattern to be the improvement in cattle health from veterinary interventions.

Additionally, the increased sedentarisation has had its challenges for the herders. Longer settlers among the Fulani eventually become agro-pastoralists generally, this may be as a result of shortage of feed translating to the Fulani's inability to manage such large herds. In a related study of sedentarisation of cattle farmers in the Nigerian savannah (Jabbar *et al.*, 1995), the study found that: i). Fulani herds' size decreased with longer periods of settlement;

ii). Herds which moved longer distances between seasons were much larger than those which did not move or moved short distances; and iii). Herd sizes varied according to the nature of ownership of cattle, location of present and past settlement, duration of settlement, extent of seasonal movement and involvement in crop production.

The increase in both male and female population figures for Bauchi from the 1999 and 2006 censuses show that the population is fast-growing. Unfortunately, the study was limited to just the population figures of the states. Although it was possible to access the 1999 population figures of local communities, the categorization of the local communities were ambiguous, therefore the study is limited to interpreting only the 1999/2006 censuses for Bauchi State, which gives a general indication of population increase and caution is needed in drawing conclusions on these census data. This study is therefore not able to calculate the population density of the herders as there are no census data based on tribes in Nigeria. The movement of herders to Dagudi, Galen sanji, Yalo and Pali was found to be highest in the 1980s, and for the Jada communities, it was in the 1990s. It is not clear at this point why the herder's migration in Jada differed from the other local communities given that all other characteristics of the migrant herders are somewhat similar across the local communities. Generally the movements of these herders can only be attributed to the widely reported droughts of the1970s and the mid-1980s and the hardships associated with the droughts (Juul, 1999; Glantz, 1988). In line with our finding, a study in East Africa found that in the late 1980s the Ethiopian Boran appeared to be in a vicious cycle of cattle mortality due to an interaction between drought and high stocking rates (Desta and Coppock, 2002; Desta and Coppock, 2004).

5.5.3 Herder's perception on the availability of fodder plants

Overall the herders from all the local communities ranked *A. africana* and *K. senegalensis* as the rarest species of the fodder species surveyed. The herders further added that *A. africana* was common in the time past but now it can only be found in "Dajin Yankari" (Yankari). Conversely, *K. senegalensis* has never been common in these areas. The reports of the herders is validated by the findings from our previous study (see Chapter 4). Very few individuals of *K. senegalensis* were found in the riparian forests of Yankari. Nevertheless, other fodder plants were not perceived as rare, although all fodder plants surveyed were perceived by the herders to have declined. The herders were asked about their livestock diet during the dry season since they claimed, the fodder plants were very rare. The herders reported that, they store up straw, and stalks after harvesting farm produce (grains, legume and beans), which sustains the livestock for a while and at the driest periods those herders that have much livestock move southwards in search of fodder plants until the onset of the rains. The most popular destinations for the herders are Taraba (south of Yankari), Benue, Bayelsa, Plateau, Dampar and Lafiyan bari-bari (all areas are to the south where more lush vegetation can be found). This finding supports a related study done in Benin Republic (Gaoue and Ticktin 2008). The study reported that in the dry season, the Fulani move southwards in pursuit of fodder and water from the drier Sudanian region toward the Sudano–Guinean region. Additionally they reported high pruning pressures on *K. senegalensis* available along their migration corridor.

The herders' preference of fodder plants for their cattle was the same in all villages, but differed for the sheep and goats' fodder plants preference. Overall the herders believe that when cattle are fed with *A. africana*, the quantity and quality of milk increased and so too with *K. senegalensis* and *P. erinaceus*, but the latter two species are not as good as *A. africana*. In a related study in the sub–humid savannah zone of West Africa, the behaviour of sheep, goats and cattle on a shrub and tree showed that plant species with the highest frequency of consumption included were *A. africana*, *K. senegalensis*, *P. erinaceus* (Ouedraogo-Kone *et al.*, 2006). Furthermore, species with a high frequency of citation by farmers were *Afzelia africana* (92%), *K. senegalensis* (88%) and *P. erinaceus* (86%).

For sheep and goats, the herders reported that *B. aegyptiaca* and *S. spinosa* are the best fodder plants to use as feed for them because these smaller animals are slow eaters and prefer to browse on thorny plants species. The herders cautioned that most of the fodder plants under investigation have gone scarce and therefore at the peak of the dry season ("in rani yayi rani") any plant can be used to feed the livestock, they added that *T. indica* is such good example, that should never be used to feed livestock but in desperate times "we find ourselves using it as feed for our livestock".

Herders in Jada reported *P. erinaceus* to be very rare, whilst herders in the other local communities ranked *P. erinaceus* as rare. The difference between the two rankings is relative thus, the author is aware that the herders generally perceive the populations of these species to have reduced. Furthermore, it is possible that the populations of *P. erinaceus* could be more in the grazing areas of Jada herders but this study did not ask questions as to how herders interact with the fields or whether there are demarcations or territories of grazing per local community. The fodder plants that were highly preferred were the same as those with a high rarity rate for cattle but not so in sheep and goats preferred fodder plants (*B. aegyptiaca and S. Spinosa*). The probable explanation is that *B. aegyptiaca* and *S. spinosa* were not preferred by cattle which are more in number than sheep and goats in the local communities. These three plants species have also been found to be important for livestock during the dry season by Petit (2000) in a similar zone, but they were not ranked by importance.

5.5.4 Implication for conservation and management

Overall herders' perception on their interaction with the fodder plants have shown that they are fully aware of the changes in the status of the plants and threats the fodder plants are facing. However, the herders are handicapped in many ways in regards to finding alternatives to their interactions with these plants. They have devised short-term migrations in the driest season as their tool for survival in desperate times to keep their livestock alive.

Because the sedentary herders claimed that they do not go into Yankari as they are legally not allowed. They equally emphasized that the seasonal herders are those that heavily harvest the fodder plants in Yankari. Although it is hard to certainly prove this, there is possibility of the sedentary herders harvesting these fodder plants in Yankari (see, chapter 4 for evidence of their activities). Additionally during the focus group discussions, quite a few of the herders referred to Yankari to be the only place that still has some of the fodder plants. However, on further probing, the herders denied having any interactions with Yankari and quickly added that it was illegal to go into the reserve. There is the possibility and willingness in the herders in the local communities, to be engaged as protectors of Yankari as a conservation strategy. However for this to be implemented effectively, it has to be thoroughly thought through and planned for with all concerned stakeholders at all levels.

A. africana appears to be a very important plant for the herders, they have strong beliefs and conviction that their livestock need *A. africana* in the dry season in the absence of grasses. Therefore, it may be important to examine other best practices such as Fulbe parkland in the south west part of Burkina-Faso where practices of tree management to ensure sustainable land-use yielded success. This management is done in a land-use type called 'parkland' created by the Fulbe pastoralists in the village land of Kourouma (Petit, 2003).

5.6 Conclusions

The finding of this study presented in this chapter suggests that there is evidence that herders in Yankari have inconsistent reports on the trends in their livestock. However, they have clear knowledge on the availability of fodder plants in their surroundings. Additionally, the study also found that a large number of Fulani and their livestock migrated to the local communities surrounding Yankari in 1980s and 1990s. Herders are aware of decline in abundance of fodder trees and have adopted temporary migration as strategy to cope with the situation. This study has also revealed the vulnerabilities of the herders and their herds to harsh conditions especially during the driest period.

The findings on the fodder plants preference by herders for their cattle relates directly to the severe harvests in *A. africana* and for sheep and goats, *B. aegyptiaca* (see, chapter 4). The herders across all the local communities' ranked *A. africana* as the top preferred species for their cattle, as it boosts both calving and milking rates when the cattle are fed with this fodder plant. Yet, the *A. africana* is scarce throughout the immediate vicinity of the local communities.

Furthermore, the herders refused to engage in any conversations relating to harvesting fodder plants in Yankari, this is because Yankari is a strict game reserve under complete governance by the Bauchi state. The herders' therefore failed to cooperate during the interviews for fear of implication afterwards. However, it can be concluded that these herders, combined with the seasonal herders seem to be interacting with Yankari in diverse ways (see, chapter 4). The present study has re- emphasized the importance of these fodder plants as having multi use purposes in the local communities such as medicinal, foods, and local crafts.

The interview and ranking techniques used in the present study allowed rapid identification of browse species, which reflects the priorities of the livestock-keepers. Comparison of the ranking results and our earlier inventories (see, Chapter 4) showed that herders took forage quality into consideration when ranking the species. No difficulties with species identification was encountered, because the herders were approached with plants samples. Herders readily identified the fodder plants and further mentioned species of *P. erinaceus* and *S. spinosa* as having different types within the same family.

Making an inventory of the most important naturally occurring browse plants in a given area is only a first step toward developing forage resources (see, Chapter 4). Secondly, to gain an understanding of herder perception on the availability of fodder plants and the threats to these plants have proved interesting. The combined information from the fodder plant inventories and the results from the present study should serve as a guide to develop appropriate conservation strategies to maintain the viability of these fodder plants for Yankari as well as to contribute to the sustainability of the Fulani livestock systems.

General discussion

6.1 Overview of thesis

As a consequence of the unprecedented rate of the earth's biodiversity decline (IUCN, 2010), and the urgent need to understand the impacts of individual and the synergies of drivers of woody vegetation change over the long period, the current study evaluated four aims, which are discussed in depth in chapters 2, 3 4 and 5. This chapter gives a synthesis of all the major results/outcome of the four result chapters (2, 3, 4 and 5), and further considers the implications of the results.

This study assessed the processes and drivers of vegetation change in the West African savannah aiming to develop mitigation strategies to increase ecological resilience of the region (chapter 1). Chapter 2 characterized the key tree and shrub species in Yankari, re-surveyed and compared the current distribution and abundance of key species (across the sub-habitats) with those reported by Green (1986) and finally detected changes in vegetation cover for Yankari using remote sensing. In chapter 3, the trends in drivers (elephants' population, climate, fire and human activities) of woody vegetation change of Yankari from the 1980s to 2011 were assessed. In chapter 4, the fodder plants were characterized and their population structure were described. Additionally, between species variation was investigated to assess the rates and patterns of harvest of fodder plants in Yankari. The chapter also investigated whether proximity to boundary distance influences harvest rates and recruitment of fodder plants in Yankari. Finally the chapter also describes the types of interaction/incursions made by herders and their livestock in Yankari. Two objectives were laid out in chapter 5: to ascertain trends in livestock abundance of sedentary herders in the local communities, and to determine herders' perception of fodder preference and availability.

This study has provided quantitative evidence of current threats to the West African savannah. Overall, the woody vegetation of Yankari has changed over time, showing a general increase in species of Combretacaea family and decline in fodder species (see, chapter 2). Additionally, Yankari is characterized by a high variability in annual rainfall, prevalence of droughts, fire scars, prevalence of and increase in human activities at the boundary of Yankari and in 2013, human encroachment has extended into Yankari (see chapter 3). The study found that fodder plants are harvested in Yankari but the extent of harvest varies by species: *A. africana* and *B. aegyptiaca* are severely harvested - and there is a high level of herder activities in Yankari (see chapter 4). The herders in Yankari have inconsistent reports on the trends in their livestock but have clear knowledge of the availability of fodder plants in their surroundings. There was a large-scale migration of herders to the local communities surrounding Yankari in 1980s and 1990s. Herders are aware of the decline in the abundance of fodder trees and have adopted temporary migration as a strategy to cope with the situation (see chapter 5). This study has also revealed the vulnerabilities of the herders and their herds to harsh conditions especially during the driest period.

6.2 General implication of the thesis

6.2.1 Change in tree/fodder species abundance in Yankari

A two-way change in species abundance was found in this study: increase in abundance of most species in Combretacaea family and reductions in abundance of species used as cattle fodder, this is supported by Wezel and Lykke (2006). Most declining and disappeared species are reported to have high socio-economic importance (see, Lykke *et al.,* 2004; Sepasal, 2005; Wezel and Lykke, 2006). The species were also popularly used for handicrafts and as fodder for livestock. Therefore to reduce degradation in these species, there is need for i): introduction of alternative sources of income; and ii) training the herders' on sustainable harvesting practices, for example the traditional Fulani *sopoodu* method of conserving *K. senegalensis* in Benin republic (see, Gaoue and Ticklin 2009).

6.2.2 Climate with high variability in rainfall and drought prevalence

The climate in Yankari suggests high variability in annual rainfall. This trend in climate is consistent with both regional projections for West Africa (Vigaud *et al.,* 2011; Sylla *et al.,*2013) and the global climate change effects (IPCC, 2007; Moritz *et al.,* 2012; Dai *et al.,* 2013), most likely due to high interannual variability in rainfall. However, a related empirical study done on woody dynamics in the Australian savannah highlights the powerful influence of multi-year rainfall excesses and deficit on tree death (Fensham *et al.,* 2005). Also in a related study, changes in tree cover were attributed to climate variability and climate change (Gonzalez *et al.,* 2011).

The study also found the prevalence of droughts in Yankari. This situation corroborates findings by Geerling (1973) and Green (1986), who observed prevalence of droughts in Yankari. In fact, it was the effects of the drought since the mid I980s that motivated the baseline study of the vegetation of Yankari. In a related study done on the World's savannahs (Fensham, 2008), drought and their drought-induced tree death estimates were compiled according to the minimum value of the drought index 1901–1902. Colorado 53% (Breshears *et al.,* 2005) and Texas 37% (Archer *et al.,* 1988) are the only studies with higher estimates than the West African Senegal (Senegal I, 33% Senegal II, 22% (Poupon and Bille, 1974; Gonzalez, 2001; Fensham, 2008). The study concluded that extensive tree death in savannahs will become a stark consequence of climate change if predictions of increasing severity and frequency of drought are realized (Fensham, 2008).

Yankari and many protected areas lack weather stations despite the widely-recorded rainfall unpredictability and the prevalence of droughts in t general area. This situation shows lack of preparedness in case of drought emergencies. Therefore, there is a need to collect and foster the use of climate data to decision-makers. One way to do this is by developing seasonal weather forecasts for Yankari and also for the local communities to avoid surprises, and make the right decisions in case of an impending drought (see, Adele 2011; RPL_WA, 2013).

6.2.3 Fire impacts

Fire scars are found to be prevalent in Yankari, indicating both high level of fire activities and frequent burning. Although fire is known to be synonymous with savannahs, fire has been reported to have negative impacts on vegetation in some studies (Hobbs, 1992; Bond and Midley 2001; Bond and Keeley, 2005; Sankaran, 2008). Yankari, has very few fire breaks, and the impacts of fire is clearly seen on the trees in particular and the landscape generally. Furthermore in drought-prone environments, fire does not work in isolation, fire and droughts work in combination to negatively impact the vegetation (Jurisch *et al.,* 2013). There are success stories elsewhere that Yankari can learn from. In Kimberly, Australia for example, various studies have reported on the success of the Australian Wildlife

Conservancy's (AWC) Eco fire project (see, Legge *et al,* 2009, 2011). The EcoFire project aimed at reducing the incidence of intense fires, and to increase the amount of long - unburnt habitat in the landscape (Legge and Fleming, 2012). Prescribed burning was done very early in the dry season because fires are less intense, less thorough, much smaller, and are more likely to leave a lot of unburnt patches of fire scar footprint. The EcoFire project was done in collaboration between pastoralists, indigenous communities and government agencies. Major outcomes of the projects are: i) a measurable positive change in fire patterns on a large scale was evident; ii) a cost-effective way of tackling a key threat to biodiversity; and iii) the importance of private-public partnerships in which the traditional role of government, and non-government sectors is re-assessed (Legge and Fleming, 2012).

6.2.4. Patterns, extent of harvest rates of fodder plants from Yankari to local communities

The patterns of harvests of fodder plants do not strictly follow some of the known Fulani patterns like the Sopoodu as reported by other studies (Sinsin *et al.,* 1989; Petit, 2003; Gaoue and Ticktin, 2007, Gaoue and Ticktin 2009), such traditional management of trees are known to enhance tree survival. Additionally, the extent of the harvest of fodder plants was found to differ between species. The herders seemed to have preference for some for their livestock. These species that are severely harvested have been reported in the 1980s to be preferred and highly harvested by the herders (Green, 1986). Furthermore, the close proximity of the local communities surrounding Yankari to the boundary of Yankari may be a contributing factor to high harvests rates in some of these fodder plants. Additionally, various types of incursions encountered have also supported the fact that there are negative impacts from the local communities on Yankari. Finally, there is a connectivity in this system that must be considered: the livelihoods of these local communities is strongly tied to seasonal rainfall (for the farmers) and the availability of foliage and fodder (for the herders) and there are limited or absence of alternative means of livelihoods. The present challenges to find feed for their livestock will only escalate causing further declines in these fodder plants in the future.

It is general knowledge now that the mission of protected areas has evolved from biodiversity conservation to improving human welfare, resulting in a shift in favour of protected areas allowing local resource use (Naughton-Treves *et al.,* 2005). Buffer zones can serve as one area for protected areas to promote this mission. Many initiatives have linked protected areas to local socioeconomic development and have been successful (see, Usongo and Nkanje 2004; Andrade and Rhodes, 2012). In Lobeke Park, Cameroon for example, the buffer zone served as community hunting areas allowing local residents to generate substantial financial resources which are used to sponsor community development activities, such as community farms, purchasing medical supplies, and promoting education programs. Whereas other initiatives such as in Nepal, have suffered major challenges, for example, lack of local community empowerment in decision-making, transparency and inadequate benefit-sharing among others in buffer zone programs (see, Budhathoki 2004). Hence Yankari can take a cue from those successful initiatives and create a buffer zone that can meet the conservation goals of the reserve as well as be beneficial to the local communities.

6.2.5. Decline in fodder trees, and temporary migration

Chapter 5 aimed at understanding the social aspects of conservation from the local communities' perspective. Consequently the perceptions of the herders were explored to help understand their awareness on the trends in their herds and the availability of fodder plants. Results from this section have not been easy to collect as the herders' recollection of dates and events seemed inconsistent. Additionally, to get the exact numbers of their livestock was challenging. Nevertheless, the responses from the survey have helped us to establish that there has been additional pressure of grazing in Yankari because Fulani migrants who have settled in all the local communities surrounding Yankari since the late 1960s but mostly in the 1980s and 1990s. Furthermore, the study found that fodder plants preferred by cattle are the same as those reported to be the rarest fodder plants, but this may not be so for sheep and goats. Outside Yankari these fodder plants are rarely seen, the tendency therefore is for the local communities to harvest the fodder plants from Yankari to a large extent during the driest periods. This is not conclusive as the fodder plants in Yankari are insufficient and inadequate to cater for their herds (averaging 40 and above per household) (see chapter 5) and the abundance of the fodder plants may be inadequate for the herds.

Additionally, there are reports and evidence of influx of nomadic Fulani, also referred to as seasonal herders, to the local communities and all areas surrounding Yankari. This yearly migration add pressure on the limited fodder plants. The Seasonal herders are reported to have larger herds numbering hundreds and they are usually focused only on getting food for their herds. Therefore, they are known to over-graze and completely loop off these fodder plants for their livestock. The sedentary herders have devised temporary migration to more luxuriant areas to the south of Yankari (short and long distances) as a means of coping with the harsh and difficult periods in the dry season. This may not be the best alternative for the overall good of conserving the fodder plants because the decline recorded in Yankari now will eventually be the same story in Taraba, Plateau, and all other areas they are migrating to during the dry periods.

To reduce the impacts of heavy harvests by additional pressure from the seasonal herders, the following recommendations are proposed. First, the migrant herders could be educated and empowered to protect their homesteads during the periods that the seasonal herders arrive. This will require careful planning and gradual training but it is worth exploring (see, Hazzah and Dolrenry, 2007). Second, instead of embarking on temporary migrations during the dry season, a parkland can be created in Yankari to enable the herders' harvests and feed their livestock with the fodder plants they need during the dry season (see Petit 2003).

6.2.6. Patrols, law enforcement and governance

The findings of this study have pointed us to the facts that the Wildlife Conservation Society (WCS) and A. P. Leventis Ornithological Research Institute (APLORI) have continuously supported anti-poaching activities through cyber-tracking, monitoring and improving the allowances of rangers in Yankari since 2009. Yet, culprits are caught regularly, penalties such as payments of fines and imprisonment are enforced but the poachers and herdsmen never stop; instead they are getting more and more desperate for the resources within the reserve (Haruna, 2011; Tende, *et al.,* 2011). The conflicts between the local communities and the park rangers have escalated. Only two years ago, some of the park rangers lost their lives in these conflicts (WCS, 2013; Tende, *et al.,* 2011).

Last year the Bauchi State Government and WCS signed a memorandum of understanding making WCS to be responsible for managing/governing all the affairs of Yankari, not just the anti-poaching activities alone from 2014 -2018. The efforts of WCS have resulted in good initiatives (collaring of elephants, use of cyber trackers, training and equipping the park rangers) and APLORI (providing two power chutes for monitoring activities throughout the park) but are grossly inadequate for a reserve as big as Yankari. WCS is underfunded, have very few patrol vehicles, threats from poachers and cattle herders' men are some of the challenges that they face. Given the challenges, it is necessary for WCS to begin exploring the possibility of participatory conservation initiatives with the local communities, this to a large extent is a much more sustainable option of conserving the biodiversity of Yankari compared to the traditional governance model that Yankari has practiced since its inception.

6.3 Further research and recommendations

Despite extensive research that has been undertaken on vegetation composition, the trends in the drivers of woody vegetation change in Yankari, focusing on herders' impacts and herder perception on fodder trees, there is still scope for further work to investigate the drivers such as fire, elephant population and climate change individually (e.g. make projections) and collectively (determine their synergies in the system). Furthermore, it will be interesting to model the changes in vegetation vis-à-vis trends in drivers of the woody vegetation and see whether there is a correlation or connection between the changes in vegetation and trends in the drivers of the woody vegetation based on co-occurrence or the pattern of change. Consequently, further research is recommended to ascertain the cause and effects of these relationships.

Discussions on conservation and management initiatives for monitoring should be initiated where the local communities will be involved and form an integral part of the conservation project in Yankari (i. e the bottom up approach conservation model, or the Love and Steward Model (Apfelbaum *et al.,* 2013). Initially, short-term projects can be initiated and investigated so as to find suitable and relevant methods that can be realistically implemented in Yankari and other protected areas with similar changes.

Most habitats that were earlier referred to as *Afzelia* tree savannah (Geerling 1973; Green 1986) do not qualify to be named as such as much of the habitats have been changed by increase in Combretacaea species. Therefore, the vegetation classification of Yankari needs to be revisited and studies using up-to-date methods and techniques be undertaken to reclassify the vegetation of Yankari. This should reduce all biases and ambiguity in handling the results.

Findings from Chapter 5 can be used to further explored working with the local communities. Which seem as an interesting area to look into, therefore new initiatives for conservation should focus on this area for the benefit of Yankari and the local communities. Globally, there are several local communities that are actively engaged in managing protected areas (see, Leach *et al.,* 1999; Porter-Bollard *et al.,* 2012 and Lockwood *et al.,* 2012). Furthermore, there are some notable success stories achieved in some places like the joint forest management in India and the CAMPFIRE in Zimbabwe, which is considered as Africa's best example of community-based resource management and development (see, Dougill *et al.,* 2012; Chimire *et al.,* 2013; Leach and Mearns, 2013). In West Africa there are a few success stories in local community engagement as seen in the W-Arly-Pendjari WAP complex which straddles the borders between Benin, Burkina Faso, Niger and Togo, (see, IUCN, 2014) but it is still in its' infancy, therefore, time will tell if it is a suitable example for other protected areas in West Africa. Hence it can be introduced as a trial in all or just parts of the reserve, with research as a component, so that changes can be monitored and quantified.

Yankari is at a very close proximity to the local communities. There is no fence or buffer zone in Yankari; where the boundary of the reserve stops, the farmlands begin. This study has also found that encroachment has extended into the reserve recently (from the satellite image of 2013, see chapter 3). Therefore a conservation strategy is urgently required to stop any further encroachment, to protect the species and the many other endangered taxa found in Yankari and more importantly, to protect the habitats. The World Commission on Protected Areas (WCPA) is set to contribute to strengthening the governance of protected areas in future by analysing the range of governance models of protected areas and then distilling and widely communicating the outcomes (IUCN, 2014). Attention needs to be given to the role of indigenous and local communities in protected areas and the equitable sharing of benefits. The IUCN (2014) guidelines on co-management and community managed protected areas should be promoted and applied in Yankari.

This study has revealed the vulnerabilities of the herders and their herds to harsh conditions especially during the driest period. The Fulani are much immersed in their beliefs and protective of their livestock. Projects that will directly involve them need to be thought out carefully and implemented gradually. The Fulani have strong ties to traditional beliefs; therefore, they will need to see proof of any benefits to them and their livestock before they can cooperate with authorities or the managers of Yankari and other protected areas alike.

In order to enhance conservation there is the need for participatory research or monitoring with the Fulani engagement and cooperation. This study has demonstrated the importance of traditional leadership in Fulani communities. Fulani have their leaders they refer to as 'Hardo'. In each local community, the head was visited who then invited the Hardo and instructed him to send message to the Fulani requesting them to come and see him and that was done. Therefore, both the local community head and the Hardo can convince the Fulani to cooperate with relevant authorities or accept any conservation strategy if and when initiated.

References

Abdullahi, M.B., Sanusi, S.S., Abdul, S.D, and Sawa, F.B.J., 2009. "An Assessment of the Herbaceous Species Vegetation of Yankari Game Reserve, Bauchi, Nigeria." *American-Eurasian Journal of Agricultural & Environmental Sciences* 6 (1): 20-25.

Achoundong, G. and Onana, J.M., 1998. “Allexis Zygomorpha (Violaceae): A New Species from the Littoral Forest of Cameroon.” *Kew Bull* 53 (4): 1009–10.

Adele, A, and Todd, A C. 2011. “Impacts of Climate Change on Smallholder Farmers in Africa and Their Adaptation Strategies: What Are the Roles for Research?: International Symposium and Consultation (29-31 March, 2010, Arusha, Tanzania).

Adriansen, H. K. 2008. “Understanding Pastoral Mobility: The Case of Senegalese Fulani.” *The Geographical Journal*, *174*(3):207-222.

Afolayan, A. A, and Adelekan, I. O. 1999. “The Role of Climatic Variations on Migration and Human Health in Africa.” *Environmentalist* 18 (4): 213–18.

Afolayan, T. A., and Ajayi, S. S. 1980. “The Influence of Seasonality on the Distribution of Large Mammals in the Yankari Game Reserve, Nigeria.” *African Journal of Ecology* 18 (1): 87–96.

Agbelusi, E. A. 1994. “Wildlife Conservation in Ondo State.” *The Nigerian Field* 59(1-2): 73–83.

Agustino, S., Mataya, B, Senelwa, K, and Achigan-Dako, E.G. 2011. “Non-Wood Forest Products and Services for Socio-Economic Development.” In *A Compendium for Technical and Professional Forestry Education. The African Forest Forum, Nairobi*.

Ahouangonou, S. and Bris, B. 1997. Afzelia africana. Le Flamboyant n° 42 - Juin 1997: 7–10

Aide, T.M., Clark, M.L., Grau, H.R., López-Carr, D., Levy, M.A., Redo, D., Bonilla-Moheno, M., Riner, G., Andrade-Núñez, M.J. and Muñiz, M., 2013." Deforestation and reforestation of Latin America and the Caribbean (2001–2010)". *Biotropica*, *45*(2): 262-271.

Akoegninou, A., Adjanohoun, E. V., Adjakidje, M. R. A., Ahyi, L., Ake Assi, A., Akoegninou, J., d'Almeida, F., Apovo, K., Boukef, M., Chadare, G., Gusset, K., Dramane, J., Eyme, J., Gassita, N., Gbaguidi, E., Goudote, S., Guinko, P., Houngnon, Issa Lo., Keita, A., Kiniffo, H. V. 1989. "Contribution aux études ethnobotaniques et floristiques en République Populaire du Bénin". Médecine traditionnelle et pharmacopée. Agence de coopération culturelle et technique,(A.C.C.T.), Paris: 895

Akinpelu, D.A., Adegboye, M. F., Adeloye, O.A. and Okoh. A.I. 2008. “Bioc.idal Activity of Partially Purified Fractions from Methanolic Extract of Garcinia Kola (Heckel) Seeds on Bacterial Isolates.” *Biological research*, *41*(3):277-287.

Anadu, P A. 1987. “Wildlife Conservation in Nigeria: Problems and Strategies.” *Environmentalist* 7 (3): 211–20.

Andersen, A. N., Cook, G. D., Corbett, L. K., Douglas, M. M., Eager, R. W., Russell-smith., J, and Woinarski, J. C. Z. 2005. “Fire Frequency and Biodiversity Conservation in Australian Tropical Savannas: Implications from the Kapalga Fire Experiment.” *Austral Ecology* 30 (2): 155–67

Andary, C., Doumbia, B., Sauvan, N., Olivier, M., Garcia, M., Jansen, P.C.M. and Cardon, D., 2005. Anogeissus leiocarpa (DC.) Guill. & Perr.*PROTA*, *3*.

Apfelbaum, J.L., Hagberg, C.A., Caplan, R.A., Blitt, C.D., Connis, R.T., Nickinovich, D.G., Benumof, J.L., Berry, F.A., Bode, R.H., Cheney, F.W. and Guidry, O.F., 2013. "Practice Guidelines for Management of the Difficult AirwayAn Updated Report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway". *The Journal of the American Society of Anesthesiologists*, *118*(2) :.251-270.

Arbonnier, M. 2004. *Trees, Shrubs and Lianas of West African Dry Zones*. Editions Quae.

Archer, S., Schimel, D.S., and Holland, E. A. 1995. “Mechanisms of Shrubland Expansion: Land Use, Climate or CO2?” *Climatic Change* 29 (1): 91–99.

Archibald, S., Lehmann, C. E. R., Gómez-Dans, J. L. and Bradstock, R.A. 2013. “Defining Pyromes and Global Syndromes of Fire Regimes.” *Proceedings of the National Academy of Sciences* 110 (16): 6442–47.

Arditi, M, Manogue, K.R, Caplan, M and Yogev, R. 1990. “Cerebrospinal Fluid Cachectin/Thmor Necrosis Factor-α and Platelet-Activating Factor Concentrations and Severity of Bacterial Meningitis in Children.” *Journal of Infectious Diseases* 162 (1): 139–47.

Arditi, R. and Akçakaya, H.R., 1990. “Underestimation of Mutual Interference of Predators.” *Oecologia* 83 (3): 358–61.

Aubréville, A .1950 "Flore forestière soudano-guinéenne". *Soc Ed Geogr Mar Coll*, Paris: 523

Awogbade, M. 1983.” *Pastoral Fulani Reaction to Grazing Reserve Development: The Gaae of Ruma-Kukar-Jangarai, Kaduna State, Nigeria". Pastoral Development Network. Oversea Development Institute*.

Ayantunde, A.A., Kango, M., Hiernaux, P., Udo, H.M. and Tabo, R., 2007. “Herders’ Perceptions on Ruminant Livestock Breeds and Breeding Management in Southwestern Niger.” *Human Ecology* 35 (1): 139–49.

Ayantunde, A. A, Williams,T.O, Udo, H.M., Fernández-Rivera, S, Hiernaux, P and Van Keulen, H. 2000. “Herders’ Perceptions, Practice, and Problems of Night Grazing in the Sahel: Case Studies from Niger.” *Human Ecology* 28 (1): 109–29.

Balmford, A, Moore, J.L, Brooks,T., Burgess, N., Hansen, L.A., Williams, P, and Rahbek.

C. 2001. “Conservation Conflicts across Africa.” *Science* 291 (5513): 2616–19.

Barbier, B., Yacouba, H., Karambiri, H., Zoromé, M, and Somé, B. 2009. “Human Vulnerability to Climate Variability in the Sahel: Farmers’ Adaptation Strategies in Northern Burkina Faso.” *Environmental Management* 43 (5): 790–803.

Barbosa, P.M., Stroppiana, D., Gregoire, J.M. and Pereira, J.M.C., 1999. “An Assessment of Vegetation Fire in Africa (1981–1991): Burned Areas, Burned Biomass, and Atmospheric Emissions.” *Global Biogeochemical Cycles* 13 (4) : 933–50.

Barnes, R.F. W. 1999. *African Elephant Database 1998*. IUCN.

Barratt, D. G, and Hall-Martin, A. 1991. “The Effect of Indigenous Browsers on Valley Bushveld in the Addo Elephant National Park.” In *Proceedings of the First Valley Bushveld Symposium. Grassland Society of South Africa. Howick*, 14–16.

Bartholomé, E., and Belward, A. S. 2005. “GLC2000: A New Approach to Global Land Cover Mapping from Earth Observation Data.” *International Journal of Remote Sensing* 26 (9): 1959–77.

Bassett, T. J. 2009. “Mobile Pastoralism on the Brink of Land Privatization in Northern Côte d’Ivoire.” *Geoforum* 40 (5): 756–66.

Bassett, T. J, and Turner, M.D 2007. “Sudden Shift or Migratory Drift? Fulbe Herd Movements to the Sudano-Guinean Region of West Africa.” *Human Ecology* 35 (1) : 33–49.

Bates, D.G, and Conant, F. P 1981. “Livestock and Livelihood: A Handbook for the 1980s.” In *Conference on the Future of Pastoral Peoples, Nairobi (Kenya), 4-8 Aug 1980*. IDRC.

Batterbury, S, and Warren, A. 2001. “The African Sahel 25 Years after the Great Drought: Assessing Progress and Moving towards New Agendas and Approaches.” *Global Environmental Change* 11 (1): 1–8.

Bawa, K.S, Seidler, R, and Raven, P. H. 2004. “Reconciling Conservation Paradigms.” *Conservation Biology* 18 (4): 859–60.

BBC News - Lions 'facing extinction in West Africa' (2014): www.bbc.co.uk/news/world-BBC News - Lions 'facing extinction in West Africa' (2014): www.bbc.co.uk/news/world-africa-25722058

Behrens, K, and Thisse, J.T 2007. “Regional Economics: A New Economic Geography Perspective.” *Regional Science and Urban Economics* 37 (4). Elsevier: 457–65.

Belbin, L, and Collins, A. 1995. *PATN*. CSIRO Division of Wildlife and Ecology, Canberra.

Belem, B., Nacoulma, B.M.I., Gbangou, R., Kambou, S., Hansen, H.H., Gausset, Q., Søren Lund., Raebild, A., Lompo, D, and Ouedraogo, M. 2007. “Use of Non Wood Forest Products by Local People Bordering the‘ Parc National Kaboré Tambi’, Burkina Faso.”

Journal for Transdisciplinary Environmental Studies 6 (1).

Benjaminsen, T. A, and Boubacar, Ba. 2009. “Farmer–herder Conflicts, Pastoral Marginalisation and Corruption: A Case Study from the Inland Niger Delta of Mali.” *The Geographical Journal* 175 (1): 71–81.

Bergl, R.A., Dunn, A., Haruna, S., Mshelbwala, J, and Nyanganji, G. 2011. "Aerial Survey of Elephantsand Other Large Mammals at Yankari Game Reserve, Bauchi State, Nigeria". Unpublished report to Bauchi State Government

Bernardet, P. 1984. “Pour Une étude Des Modes de Transmission. La Technologie Du Manche Court En Afrique Noire in Les Instruments Aratoires En Afrique Tropicale. La Fonction et Le Signe.” *Cahiers ORSTOM (Office de La Recherche Scientifique et Technique d’Outre-Mer). Série Sciences Humaines Bondy* 20 (3-4): 375–98.

Bernardet, P. 1999. “Peuls En Mouvement, Peuls En Conflits En Moyenne et Haute Côte d’Ivoire, de 1950 à 1990.” *Figures Peules, Paris, Karthala*, 407–44.

Bierschenk, T, and Pierre-Yves Le Meur. 1997. *Trajectoires Peules Au Benin: Six Etudes Anthropologiques*. KARTHALA Editions.

Bin, Y., Ye, W., Muller-Landau, H.C., Wu, L., Lian, J. and Cao, H., 2012. Unimodal tree size distributions possibly result from relatively strong conservatism in intermediate size classes. *PloS one*, *7*(12):.e52596.

Boko, M., Niang, I, and Nyong, A 2007. "Africa. In:Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change(eds Parry ML, Canziani OF,Palutikof JP, van der Linden PJ, Hanson CE)"Cambridge University Press, Cambridge, UK : 433–467

Blanc-Pamard, C. and Boutrais, J., 1994. "Eleveurs, bétail et environnement. In Dynamique des systèmes agraires: A la croisée des parcours, pasteurs, éleveurs, cultivateurs". Coll. colloques et séminaires, Ed. Orstom: 303–319.

Botha, J., Witkowski, E.T.F., and Shackleton, C.M., 2004a. Market profiles and trade in medicinal plants in the Lowveld, South Africa. Environmental conservation, 31(01):38–46.

Botha, J., Witkowski, E.T.F., and Shackleton, C.M., 2004b. The impact of commercial harvesting on Warburgia salutaris (“pepper-bark tree”) in Mpumalanga, South Africa. Biodiversity & Conservation, 13(9):1675–1698.

Blanc, J. J. 2003. African Elephant Status Report 2002: *African elephant status report 2002: An update from the African elephant database* (No. 29). IUCN.

Blanc, J.J., Barnes, R.F.W., Craig, G.C., Dublin, H.T., Thouless, C.R. and Douglas-Hamilton, I. 2007. African elephant status report 2007: an update from the African elephant database. Gland, Switzerland: IUCN

Blench, R., 2001. *'You Can't Go Home Again': Pastoralism in the New Millennium* (p. 103). London: Overseas Development Institute.

Bloor, J. M. G., Leadley, P.W, and Barthes, L 2008. "Responses of Fraxinus Excelsior Seedlings to Grass-Induced above-and below-Ground Competition." *Plant Ecology* 194 (2): 293–304.

Bobbink, R., Hornung, M and Roelofs, J.G.M. 1998. "The Effects of Air-borne Nitrogen Pollutants on Species Diversity in Natural and Semi-natural European Vegetation." *Journal of Ecology* 86 (5): 717–38.

Bond, N. R., Lake, P. S, and Arthington, A. H. 2008. "The Impacts of Drought on Freshwater Ecosystems: An Australian Perspective." *Hydrobiologia* 600 (1) : 3–16.

Bond, W J., Midgley, G. F, and Woodward, F. I. 2003. "The Importance of Low Atmospheric CO2 and Fire in Promoting the Spread of Grasslands and Savannas." *Global Change Biology* 9 (7): 973–82.

Bond, W J, and Van Wilgen, B. W. 1996. "Fire and Plants (population and Community Biology Series 14)." *Population and Community Biology* 263.

Bond, W. J, and Keeley, J. E. 2005. "Fire as a Global 'herbivore': The Ecology and Evolution of Flammable Ecosystems." *Trends in Ecology & Evolution* 20 (7): 387–94.

Bond, W. J., and Midgley, G. F, 2000. "A Proposed CO_2-Controlled Mechanism of Woody Plant Invasion in Grasslands and Savannas." *Global Change Biology* 6 (8): 865–69.

Bourlière, F. 1983. Ecosystems of the world. 13. Tropical savannas., Elsevier Scientific Publishing.

Bourlière F, Hadley, M.1983. "Present-day savannas: an overview. In: Bourlière F (ed) Tropical savannas," *Elsevier, Amsterdam*, 13:1–17

Boshoff, A F., Kerley, G. I .H and Cowling, R. M. 2001. "A Pragmatic Approach to Estimating the Distributions and Spatial Requirements of the Medium-to Large-sized Mammals in the Cape Floristic Region, South Africa." *Diversity and Distributions* 7 (1-2): 29–43.

Botkin, D. B., Saxe, H., Araujo, M. B., Betts, R., Bradshaw, R. H W., Cedhagen, T., Chesson, P., Dawson, T. P., Etterson, J. R, and Faith, D. P. 2007. "Forecasting the Effects of Global Warming on Biodiversity." *Bioscience* 57 (3): 227–36.

Bouché, P, Iain Douglas-Hamilton, Wittemyer, G, Nianogo, A. I, Doucet, J.L, Lejeune, P and Vermeulen. C. 2011. "Will Elephants Soon Disappear from West African Savannahs?"

PloS One 6 (6): 20619.

Bowman, D.M.J.S., Walsh, A and Milne, D.J 2001. “Forest Expansion and Grassland Contraction within a Eucalyptus Savanna Matrix between 1941 and 1994 at Litchfield National Park in the Australian Monsoon Tropics.” *Global Ecology and Biogeography* 10 (5): 535–48.

Brandt, M., Romankiewicz, C, Spiekermann, R and Samimi, C. 2014. “Environmental Change in Time Series – An Interdisciplinary Study in the Sahel of Mali and Senegal.” *Journal of Arid Environments*, *105*:52-63.

Breshears, D. D., Cobb, N.S., Rich, P. M., Price, K. P., Allen, C. D., Balice, R D., Romme, W. H., Kastens, J. H., Floyd, M. L, and Belnap, J. 2005. “Regional Vegetation Die-off in Response to Global-Change-Type Drought.” *Proceedings of the National Academy of Sciences of the United States of America* 102 (42): 15144–48.

Briggs, J. M., Knapp, A. K., Blair, J .M., Heisler, J. L., Hoch, G. A., Lett, M, T, and McCarron, J . K. 2005. “An Ecosystem in Transition: Causes and Consequences of the Conversion of Mesic Grassland to Shrubland.” *BioScience* 55 (3): 243–54.

Brook, B. W, and David, M. J, Bowman, S. 2006. “Postcards from the Past: Charting the Landscape-Scale Conversion of Tropical Australian Savanna to Closed Forest during the 20th Century.” *Landscape Ecology* 21 (8): 1253–66.

Brown, J R, and Archer, S. 1989. “Woody Plant Invasion of Grasslands: Establishment of Honey Mesquite (Prosopis Glandulosa Var. Glandulosa) on Sites Differing in Herbaceous Biomass and Grazing History.” *Oecologia* 80 (1): 19–26.

Budhathoki, P. 2004. “Linking Communities with Conservation in Developing Countries: Buffer Zone Management Initiatives in Nepal.” *Oryx* 38 (03). Cambridge Univ Press: 334–41.

Bufford, J. L, and Gaoue. O.G. 2014. “Defoliation by Pastoralists Affects Savanna Tree Seedling Dynamics by Limiting the Facilitative Role of Canopy Cover.” *Ecological Applications*, *25*(5):1319-1329.

Buitenwerf, R., Swemmer, A. M, and Peel, M.J.S. 2011. “Long-term Dynamics of Herbaceous Vegetation Structure and Composition in Two African Savanna Reserves.” *Journal of Applied Ecology* 48 (1): 238–46.

Carr, D. 2009. “Population and Deforestation: Why Rural Migration Matters.” *Progress in Human Geography* 33 (3). SAGE Publications: 355–78.

Carpenter, S. R., Harold, A . M., Agard, J, Capistrano, D., Defries, R. S., Díaz, S, and Dietz, T. 2009. “Science for Managing Ecosystem Services: Beyond the Millennium Ecosystem Assessment.” Proceedings of the National Academy of Sciences of the United States of America 106 (5): 1305–12

Castaño-Santamaría, J., Crecente-Campo, F., Fernández-Martínez, J.L., Barrio-Anta, M. and Obeso, J.R., 2013. "!Tree height prediction approaches for uneven-aged beech forests in northwestern Spain". *Forest Ecology and Management, 307*:63-73.

Chapin, F S, Zavaleta, E. S, Eviner, V. T, Naylor, R.L, Vitousek, P .M, Reynolds, H.L, Hooper. D.U 2000. "Consequences of Changing Biodiversity." *Nature* 405 (6783). Macmillan Magazines Ltd.: 234–42.

Chase, J. M. 1999. "Food Web Effects of Prey Size Refugia: Variable Interactions and Alternative Stable Equilibria." *The American Naturalist* 154 (5): 559–70.

Chazdon, R. L. 2008. "Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Lands." *Science* 320 (5882). American Association for the Advancement of Science: 1458–60.

Christensen, J. H, and Christensen, O.B, 2007. "A Summary of the PRUDENCE Model Projections of Changes in European Climate by the End of This Century." *Climatic Change* 81 (1): 7–30.

Cissé, B. 1988. "Les Systèmes D'élevage Dans Les Villages Riverains Des Forêts Classées de Tissé et Du Sourou." *Ouagadougou/Burkina Faso, Université de Ouagadougou.(mémoire de Fin D'études)*.

Cissé, M. I. 1980. "The Browse Production of Some Trees of the Sahel: Relationships between Maximum Foliage Biomass and Various Physical Parameters." In *Browse in Africa*, 205–210.

Clerici, N. B, A., Eva, H., Grégoire, J.M., Dulieu, D and Paolini, C. 2007. "Increased Isolation of Two Biosphere Reserves and Surrounding Protected Areas (WAP Ecological Complex, West Africa)." *Journal for Nature Conservation* 15 (1): 26–40.

Collins, J. M. 2011. "Temperature Variability over Africa." *Journal of Climate* 24 (14): 3649–66.

Collins, S. L, and Calabres, L.B. 2012. "Effects of Fire, Grazing and Topographic Variation on Vegetation Structure in Tallgrass Prairie." *Journal of Vegetation Science* 23 (3) : 563–75.

Condit, R, Sukumar., R, Hubbell, S . P, and Foster, R. B. 1998. "Predicting Population Trends from Size Distributions: A Direct Test in a Tropical Tree Community." *The American Naturalist* 152 (4) : 495–509.

Conway, G. 2009. "The Science of Climate Change in Africa: Impacts and Adaptation." *Grantham Institute for Climate Change Discussion Paper* 1: 24.

Conybeare, A M. 2004. "Elephant Impacts on Vegetation and Other Biodiversity in the Broadleaved Woodlands of S-Central Africa." *Biodiversity of the Four Corners Area: Technical Reviews Volume Two. Biodiversity Foundation for Africa, Bulawayo/Zambezi Society, Harare, Zimbabwe*, 477–508.

Cordeiro, N. J., Burgess, N. D., Dovie, D.B.K., Kaplin, B. A., Plumptre, A. J, and Marrs, R. 2007. "Conservation in Areas of High Population Density in Sub-Saharan Africa."

Biological Conservation 134 (2) : 155–63.

Cottam, G, and Curtis, J. T. 1956. “The Use of Distance Measures in Phytosociological Sampling.” *Ecology*: 451–60.

Coulibaly, S., Gregory, J. A, and Piché, V. 1980. *T. 1: Importance et Ambivalence de La Migration Voltaïque*. Ottawa: Centre de recherches pour le développement international.

Crick, H. Q. P, and Marshall, P. J. 1981. " The birds of Yankari Game Reserve, Nigeria: their abundance and seasonal occurance". *Malimbus* 3: 103-113

Cumming, D.H., Fenton, M.B., Rautenbach, I.L., Taylor, R.D., Cumming, G.S., Cumming, M.S., Dunlop, J.M., Ford, A.G., Hovorka, M.D., Johnston, D.S. and Kalcounis, M., 1997. “Elephants, Woodlands and Biodiversity in Southern Africa.” *South African Journal of Science* 93 (5): 231–36.

Cunningham, A B, and F T Mbenkum. 1993. “Sustainability of Harvesting Prunus Africana Bark in Cameroon.” *People and Plants Working Paper* 2: 28.

Cunningham, A. B. 2001. *Applied Ethnobotany: People, Wild Plant Use and Conservation*. Earthscan.

D’Agostino, M., Cook, N., Rodriguez-Lazaro, D, and Rutjes, S. 2011. “Nucleic Acid Amplification-Based Methods for Detection of Enteric Viruses: Definition of Controls and Interpretation of Results.” *Food and Environmental Virology* 3 (2): 55–60.

Dai, A. 2011. “Drought under Global Warming: A Review.” *Wiley Interdisciplinary Reviews: Climate Change* 2 (1): 45–65

Dai, A. 2013. “Increasing Drought under Global Warming in Observations and Models.” *Nature Climate Change* 3 (1). Nature Publishing Group: 52–58.

Dai, A, Trenberth, K.E and Qian, T. 2004. “A Global Dataset of Palmer Drought Severity Index for 1870-2002: Relationship with Soil Moisture and Effects of Surface Warming.” *Journal of Hydrometeorology* 5 (6): 1117–30.

Dale, V. H, and Beyeler, S. C. 2001. “Challenges in the Development and Use of Ecological Indicators.” *Ecological Indicators* 1 (1): 3–10.

De Bie, S. 1991. *Wildlife Resources of the West African Savanna.*

De Bie S., Ketner, P., Paase, M, and Geerling , C. 1998. Woody plant phenology in the West African savanna. J Biogeogr 25:883–900

Delgado, C, and Staatz. J. 1980. “Livestock and Meat Marketing in West Africa. Volume III. Ivory Coast and Mali.” *Center for Research and Economic Development, University of Michigan, Michigan, USA.*

Delvaux, C., Sinsin, B., Darchambeau, F, and Van Damme, P. 2009. “Recovery from Bark Harvesting of 12 Medicinal Tree Species in Benin, West Africa.” *Journal of Applied*

Ecology 46 (3): 703–12.

Desta, S, and Coppock, D. L. 2002. “Cattle Population Dynamics in the Southern Ethiopian Rangelands, 1980-97.” *Journal of Range Management*, 439–51.

Desta, S. 2004. “Pastoralism under Pressure: Tracking System Change in Southern Ethiopia.” *Human Ecology* 32 (4): 465–86.

Desta, S., Coppock, D .L, and Barrett, C. B 1999. “Opportunities for Asset Diversification in a Livestock System: The Case of the Pastoral Boran of Southern Ethiopia.” In *Proceedings of the VI International Rangeland Congress, Townsville, Australia, July*.

Diallo, D. 2000. “Ethnopharmacological Survey of Medicinal Plants in Mali and Phytochemical Study of Four of Them:‘ Glinus Oppositifolius’(Aizoaceae),‘ Diospyros Abyssinica’(Ebenaceae),‘ Entada Africana’(Mimosaceae),‘ Trichilia Emetica’(Meliaceae).” (Doctoral dissertation).

Diallo, B.O., Joly, H.I., McKEY, D., Hosaert-McKey, M. and Chevallier, M.H., 2007. Genetic diversity of Tamarindus indica populations: Any clues on the origin from its current distribution?. African Journal of Biotechnology, 6(7).

Dombois, D. M, and Ellenberg, H. 1974. *Aims and Methods of Vegetation Ecology*. John Wiley &Sons.http://books.google.co.uk/books/about/Aims_and_Methods_of_Vegetation_Ecology.html?id=amFKT9AEQiUC&pgis=1

Dongmo, A L. P., Djamen, E., Vall, M. O., Coulibaly, K. D, and Lossouarn. L. 2007. “Space Is Finished! Would Settlement Prevail? Innovations and Sustainable Development at Stake for Pastors of the Cotton Zone of West and Central Africa.” In *14 èmes Recontres Autour Des Recherches Sur Les Ruminants, Paris, Les 5 et 6 Décembre 2007.*, 153–60. Institut National de la Recherche Agronomique (INRA).

Dongmo, A.L., Vall, E., Diallo, M. A., Dugue, A.N, and Lossouarn, J. 2012. “Herding Territories in Northern Cameroon and Western Burkina Faso: Spatial Arrangements and Herd Management.” *Pastoralism* 2 (1): 1–21.

Donovan, D. G, and Puri, R. K. 2004. “Learning from Traditional Knowledge of Non-Timber Forest Products: Penan Benalui and the Autecology of Aquilaria in Indonesian Borneo.” *Ecology and Society* 9 (3): 3.

Dougill, A. J., Stringer, L. C., Leventon, J., Riddell, M., Rueff, H., Spracklen, D. V., & Butt, E. 2012. Lessons from community-based payment for ecosystem service schemes: from forests to rangelands. Philosophical Transactions of the Royal Society B: Biological Sciences, 367(1606), 3178-3190.

Dupire, B. 1996. “A Unified Theory of Volatility.” *Derivatives Pricing: The Classic Collection*, 185–96.

Dyson-Hudson, R, and Dyson-Hudson, N. 1980. “Nomadic Pastoralism.” *Annual Review of Anthropology*: 15–61.

Elvidge, C. D, Baugh, K. E, Dietz, J. B, Bland, T, Sutton, P. C and Kroehl, H.W 1999. “Radiance Calibration of DMSP-OLS Low-Light Imaging Data of Human Settlements.” *Remote Sensing of Environment* 68 (1) : 77–88.

Erb, Karl-Heinz, H, H, Krausmann, F, Lauk, C, Plutzar, C, Steinberger, J.K, Müller, C, Bondeau, B, Waha, K and Pollack, G. 2009. *Eating the Planet: Feeding and Fuelling the World Sustainably, Fairly and Humanely: A Scoping Study*. Inst. of Social Ecology, IFF-Fac. for Interdisciplinary Studies, Klagenfurt Univ.

Ermert, V., Fink, A.H., Jones, A.E, and Morse, A . P. 2011. “Development of a New Version of the Liverpool Malaria Model. I. Refining the Parameter Settings and Mathematical Formulation of Basic Processes Based on a Literature Review.” *Malar J* 10 (1): 35.

Ezealor, A.U. 2002. *Critical Sites for Biodiversity Conservation in Nigeria*. Nigerian ConservationFoundation.http://books.google.com.au/books/about/Critical_Sites_for_Biodiversity_Conserva.html?id=J5YfAQAAIAAJ&pgis=1.

Faith, D. P. and Walker, P. A.1996 "Environmental diversity: on the best-possible use of surrogate data for assessing the relative biodiversity of sets of areas." *Biodiversity & Conservation* 5, (4): 399-415.

Falade, O. 1999. *Understanding Tourism in Nigeria*. JIS Printing Press.

Fandohan, A. B, Assogbadjo, A . E, Kakaï, R. L. G, Sinsin, B and Van Damme, P. 2010. “Impact of Habitat Type on the Conservation Status of Tamarind (Tamarindus Indica L.) Populations in the W National Park of Benin.” *Fruits* 65 (01): 11–19.

FAO, 1995. Forest resources assessment 1990. Global Synthesis. FAO, Rome

Fensham, R. J. 2008. “Leichhardt’s Maps: 100 Years of Change in Vegetation Structure in Inland Queensland.” *Journal of Biogeography* 35 (1) : 141–56.

Fensham, R J, Fairfax, R J and Archer, S .R. 2005. “Rainfall, Land Use and Woody Vegetation Cover Change in Semi-arid Australian Savanna.” *Journal of Ecology* 93 (3): 596–606.

Flannigan, M. D, Stocks, B. J and Wotton, B. M. 2000. “Climate Change and Forest Fires.” *Science of the Total Environment* 262 (3): 221–29.

Flannigan, M., Stocks, B., Turetsky, M. and Wotton, M., 2009. “Impacts of Climate Change on Fire Activity and Fire Management in the Circumboreal Forest.” *Global Change Biology* 15 (3): 549–60. Flannigan, M., Stocks, B., Turetsky, M. and Wotton, M., 2009. Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global Change Biology*, *15*(3), pp.549-560.

Foley, J. A, DeFries, R, Asner, G .P, Barford, C, Bonan,G, Carpenter, S, R, Chapin, F. S,

M. T. Coe, Daily, G. C and Gibbs, H. K. 2005. “Global Consequences of Land Use.” *Science* 309 (5734) : 570–74.

Fraser, D .J., Coon, T., Prince, M. R., Dion, R, and Bernatchez, L. 2006. "Integrating Traditional andEvolutionary Knowledge in Biodiversity Conservation: A Population Level Case Study" Ecology and Society, 11(2):4

Fricke, H. W. 1979. “Mating System, Resource Defence and Sex Change in the Anemonefish Amphiprion Akallopisos.” *Zeitschrift Für Tierpsychologie* 50 (3) : 313–26.

Galli, A. W, T, Ercin, E, Knoblauch, D, Ewing, B and Giljum, S. 2012. “Integrating Ecological, Carbon and Water Footprint into a ‘footprint Family’ of Indicators: Definition and Role in Tracking Human Pressure on the Planet.” *Ecological Indicators* 16 : 100–112.

Gandah, M. B, J Brouwer, J, Hiernaux, P and N Van Duivenbooden. 2003. “Strategies to Optimize Allocation of Limited Nutrients to Sandy Soils of the Sahel: A Case Study from Niger, West Africa.” *Agriculture, Ecosystems & Environment* 94 (3) : 311–19.

Gaoue, O. G., Horvitz, C. C, and Ticktin, T 2011. “Non-Timber Forest Product Harvest in Variable Environments: Modeling the Effect of Harvesting as a Stochastic Sequence.” *Ecological Applications* 21 (5) : 1604–16.

Gaoue, O. G., and Ticktin, T. 2007. “Patterns of Harvesting Foliage and Bark from the Multipurpose Tree Khaya Senegalensis in Benin: Variation across Ecological Regions and Its Impacts on Population Structure.” *Biological Conservation* 137 (3): 424–36.

Gaoue, O. G. 2009. “Fulani Knowledge of the Ecological Impacts of Khaya Senegalensis (Meliaceae) Foliage Harvest in Benin and Its Implications for Sustainable Harvest.” *Economic Botany* 63 (3): 256–70.

Gauch Jr, Hugh G. 1982. “Noise Reduction by Eigenvector Ordinations.” *Ecology*. JSTOR, 1643–49.

Gautier D., Bonnerat A., Njoya A. 2005 2005. The relationship between herders and trees in space and time in northern Cameroon. *The geographical journal*, *171*(4), pp.324-339.

Geerling, C. 1973a. *The Vegetation of Yankari Game Reserve: Its Utilization and Condition*. Department of Forestry, University of Ibadan.

Geerling, C. 1973b. “Vegetation of Yankari Game Reserve.” Dept. of Forestry, University of Ibadan.

Geerling, C.1985. “The Status of the Woody Species of the Sudan and Sahel Zones of West Africa.” *Forest Ecology and Management* 13 (3-4): 247–55.

Geldenhuys, C. J. 1992. “ The use of diameter distributions in sustained use management of forest: examples from Southern Africa. Paper presented at the SAREC/Zimbabwe Forestry Commission Symposium: Ecology and Management of Indigenous Forest in Southern Africa, Victoria Falls, July 199 Livestock Grazing NCF/RES Field Document

Richness".

Green A.A. 1989. “Avifauna of Yankari Game Reserve, Nigeria: New records and observations” Green, A.A., 1989. Avifauna of Yankari Game Reserve, Nigeria:. *Malimbus*, *5*, pp.17-30.

Green, A. A. 1986. Baseline data: vegetation cover monitoring system, Yankari game reserve, NCF Technical Report NO.1 Nigerian Conservation Foundation, Lagos Typescript and photocopy.

Green, A. A. 1987. The Human Onslaught on Yankari Game Reserve: Hunting and Livestock Grazing NCF/RES Field Document 5.

Green, A.A. and Amance, M.S. 1987. Management Plan for Yankari Game Reserve, Bauchi State, Nigeria. WWF Project 3632, NCF Technical Report 2, Lagos

Grellier S, Barot S, Janeau J-L, Ward D .2012 "Grass competition is more important than seed ingestion by livestock for *Acacia* recruitment in South Africa". *Plant Ecol* 213:899–908

Ghimire, S. K., McKey, D, and Aumeeruddy-Thomas, Y. 2004. “Heterogeneity in Ethnoecological Knowledge and Management of Medicinal Plants in the Himalayas of Nepal: Implications for Conservation.” *Ecology and Society* 9 (3): 6.

Giglio, L., Descloitres, J., Justice, C. O, and Kaufman.Y. J. 2003. “An Enhanced Contextual Fire Detection Algorithm for MODIS.” *Remote Sensing of Environment* 87 (2-3): 273–82. doi:10.1016/S0034-4257(03)00184-6.

Glantz, M. H. 1988. “Societal Responses to Regional Climatic Change.” Westview Press.

Goldammer, J. G, and Price, C. 1998. “Potential Impacts of Climate Change on Fire Regimes in the Tropics Based on MAGICC and a GISS GCM-Derived Lightning Model.” In *Potential Impacts of Climate Change on Tropical Forest Ecosystems*, 133–56.Springer Netherlands.

González, A. D., Frostell, B, and Carlsson-Kanyama, A. 2011. “Protein Efficiency per Unit Energy and per Unit Greenhouse Gas Emissions: Potential Contribution of Diet Choices to Climate Change Mitigation.” *Food Policy* 36 (5): 562–70.

Gonzalez, P. 2001. “Desertification and a Shift of Forest Species in the West African Sahel.” *Climate Research* 17 (2): 217-228.

Gonzalez, P., Compton. J .T, and H Sy. 2012. “Tree Density and Species Decline in the African Sahel Attributable to Climate.” *Journal of Arid Environments* 78: 55–64.

Goudie, A. S. 2013. *The Human Impact on the Natural Environment: Past, Present, and Future*. John Wiley & Sons.

Gouwakinnou, G. N., Kindomihou, V., Assogbadjo, A. E and Sinsin, B. 2009. “Population Structure and Abundance of Sclerocarya Birrea (A . Rich) Hochst Subsp . Birrea in Two Contrasting Land-Use Systems in Benin.” *International Journal of Biodiversity* *and Conservation* 1 (6): 194–201.

Greve, M., Lykke, A.M., Blach-Overgaard, A, and Svenning, J. C. 2011. “Environmental and Anthropogenic Determinants of Vegetation Distribution across Africa.” *Global Ecology and Biogeography* 20 (5): 661–74.

Grimm, N. B., Stanley H. F., Golubiewski, N. E., Redman, C.L., Wu, J, Bai, X and Briggs, J. M 2008. “Global Change and the Ecology of Cities.” *Science (New York, N.Y.)* 319 (5864): 756–60.

Grime, J.P., Hodgson, J.G. and Hunt, R., 2014. "*Comparative plant ecology: a functional approach to common British species"*. Springer.

Guinko, S., & Pasgo, L. J. 1992. “Harvesting and Marketing of Edible Products from Local Woody Species in Zitenga, Burkina Faso.” *Unasylva* 43 (168): 16–19.

Gulliver, P. H. 1955. *The Family Herds: A Study of Two Pastoral Tribes in East Africa, the Jie and Turkana*. Routledge & K. Paul. 1992. Harvesting and marketing of edible products from local woody species in Zitenga, Burkina Faso. Unasylva, 43(168):16–19.

Haberl, H., Erb, K. H., Krausmann, F., Gaube,V., Bondeau, A., Plutzar,C., Gingrich, S., Lucht, W, and Fischer-Kowalski, M. 2007. “Quantifying and Mapping the Human Appropriation of Net Primary Production in Earth’s Terrestrial Ecosystems.” *Proceedings of the National Academy of Sciences* 104 (31) : 12942–47.

Halpern, B. S., Walbridge, S., Selkoe, K.A., Kappel, C. V., Micheli, F., D’Agrosa, C., Bruno, J.F., Casey, K. S., Ebert, C, and Fox, H. E. 2008. “A Global Map of Human Impact on Marine Ecosystems.” *Science* 319 (5865) : 948–52.

Hamilton, A. C. 2004. “Medicinal Plants, Conservation and Livelihoods.” *Biodiversity & Conservation* 13 (8) : 1477–1517.

Hampshire, K. R, and Smith, M.T, 2001. “Consanguineous Marriage among the Fulani.” *Human Biology* 73 (4) : 597–603.

Hannah, L., Lohse, D., Hutchinson, C., Carr, J. L, and Lankerani. A 1994. “A Preliminary Inventory of Human Disturbance of World Ecosystems.” *Ambio*. JSTOR, 246–50.

Hao, W. M, and Mei Liu. 1994. “Spatial and Temporal Distribution of Tropical Biomass Burning.” *Global Biogeochemical Cycles* 8 (4) : 495–503.

Hao, Wei Min, Mei-Huey Liu, and Paul J Crutzen. 1990. “Estimates of Annual and Regional Releases of CO2 and Other Trace Gases to the Atmosphere from Fires in the Tropics, Based on the FAO Statistics for the Period 1975–1980.” In *Fire in the Tropical Biota,* 440–62. Springer.

Haruna.S., 2011."Interview with author in Yankari Game Reserve."

Hayward, M. W, and Zawadzka, B. 2010. “Increasing elephantLoxodonta Africana Density Is a More Important Driver of Change in Vegetation Condition than Rainfall.” *Acta*

Theriologica 55 (4) : 289–98.

Hazzah, L, and Dolrenry, S. 2007. “Coexisting with Predators.” In *SEMINAR-NEW DELHI-*, 577:21. MALYIKA SINGH.

Hennenberg, K. J., Goetze, D., Kouamé, L., Orthmann, B, and Porembski. S 2005. “Border and Ecotone Detection by Vegetation Composition along Forest-savanna Transects in Ivory Coast.” *Journal of Vegetation Science* 16 (3) : 301–10.

Henschel, P., Azani, D., Burton, C., Malanda, G., Saidu,Y., Sam, M, and Hunter, L. 2010. “Lion Status Updates from Five Range Countries in West and Central Africa.” *Cat News* 52: 34–39.

Henshaw, J. 1979. “Notes on Habitat Relationships of Ungulates in Yankari Game Reserve, Nigeria.” *Mammal Review* 9 (1): 47–52.

Henshaw J. 1975. "The Ecology and Management of Yankari Game Reserve" F. A. O. Technical Report Rome:106

Herrmann, S. M, and Hutchinson, C. F .2005. “The Changing Contexts of the Desertification Debate.” *Journal of Arid Environments* 63 (3) : 538–55.

Hertwich, E. G, and Peters, G.P. 2009. “Carbon Footprint of Nations: A Global, Trade-Linked Analysis.” *Environmental Science & Technology* 43 (16) : 6414–20.

Higgins, S.I., Bond, W.J., February, E.C., Bronn, A., Euston-Brown, D.I., Enslin, B., Govender, N., Rademan, L., O'Regan, S., Potgieter, A.L. and Scheiter, S., 2007. "Effects of four decades of fire manipulation on woody vegetation structure in savanna". *Ecology*, *88*(5):1119-1125.

Higgins, S.I., Bond, W. J, and Trollope,W.S.W. 2000. “Fire, Resprouting and Variability: A Recipe for Grass–tree Coexistence in Savanna.” *Journal of Ecology* 88 (2): 213–29.

Hobbs, R. J. 1992. “The Role of Corridors in Conservation: Solution or Bandwagon?” *Trends in Ecology & Evolution* 7 (11) : 389–92.

Hobby, M., Gascoyne, M., Marsham, J.H., Bart, M., Allen, C., Engelstaedter, S., Fadel, D.M., Gandega, A., Lane, R., McQuaid, J.B. and Ouchene, B., 2013. "The Fennec automatic weather station (AWS) network: Monitoring the Saharan climate system". *Journal of Atmospheric and Oceanic Technology*, *30*(4):709-724.

Hoffman, M .T., Cousins, B., Meyer, T., Petersen, A, and Hendricks, H. 1999. “Historical and Contemporary Land Use and the Desertification of the Karoo.” *The Karoo: Ecological Patterns and Processes*. Cambridge University Press Cambridge, 257–73.

Hoffman, M.T, and Simon .T. 2000. “A National Review of Land Degradation in South Africa: The Influence of Biophysical and Socio-Economic Factors.” *Journal of Southern African Studies* 26 (4) : 743–58.

Hoffmann, W. A., Bazzaz, F. A., Chatterton, N . J., Harrison, P. A, and Jackson, R .B 2000. “Elevated CO2 Enhances Resprouting of a Tropical Savanna Tree.” *Oecologia*

123 (3): 312–17.

Hogben, S. J. 1930. “The Mohammedan Emirates of Northern Nigeria.” Oxford: The University Press.

Houghton, R. A. 1999. “Greenhouse effectGreenhouse Effect.” In *Environmental Geology*, Springer :303–6

House, J. I., Archer, S., Breshears, D. D, and Scholes, R . J 2003. “Conundrums in Mixed Woody–herbaceous Plant Systems.” *Journal of Biogeography* 30 (11) : 1763–77.

Hovenden, M. J., Newton, P.C.D., Carran, R.A., Theobald, P, Wills, K. E. Vander Schoor, J. K, Williams, A. L and Osanai.Y. 2008. “Warming Prevents the Elevated CO2-induced Reduction in Available Soil Nitrogen in a Temperate, Perennial Grassland.” *Global Change Biology* 14 (5) : 1018–24.

Hubbell, S. P. 2001. *The Unified Neutral Theory of Biodiversity and Biogeography (MPB-32)*. Vol. 32. Princeton University Press.

IPCC, 2014. Climate change 2014: impacts, adaptation, and vulnerability. Vol. 1. 2014.

IPCC, 2014 Climate change 2014: impacts, adaptation, and vulnerability. Vol. 1.

Ikhimioya, I, and Imasuen, J. A. 2007. “Blood Profile of West African Dwarf Goats Fed Panicum Maximum Supplemented with Afzelia Africana and Newbouldia Laevis.” *Pakistan Journal of Nutrition* 6 (1): 79–84.

Iro, I. 2009. “Grazing Reserve Development: A Panacea to the Intractable Strife between Farmers and Herders.” *Crisis Group International*.

Iro, I. 2008. The characteristics of the Fulani. http://www.gamji.com/fulani3.htm

IUCN 2010.“Red List of Threatened Species: Nigeria”. http://www.iucnredlist.org/apps/redlist/search. Accessed on 17/05/2014

IUCN 2014 @ http://www.iucn.org/about/work/programmes/gpap_home/gpap_biodiversity/

Jabbar, M A, Reynolds, L and Francis.P.A 1995. “Sedentarisation of Cattle Farmers in the Derived Savannah Region of South-West Nigeria: Results of a Survey.” *Tropical Animal Health and Production* 27 (1) : 55–64.

James, R, and Washington, R 2013. “Changes in African Temperature and Precipitation Associated with Degrees of Global Warming.” *Climatic Change* 117 (4) : 859–72.

Jensen, R., Gatrell, J., Boulton, J., & Harper, B. 2004. “Using Remote Sensing and Geographic Information Systems to Study Urban Quality of Life and Urban Forest Amenities.” Ecologyand Society 9 (5): 5. http://www.ecologyandsociety.org/vol9/iss5/art5/main.html.

Jeltsch, F, Weber, G. E and Grimm, V. 2000. “Ecological Buffering Mechanisms in Savannas: A Unifying Theory of Long-Term Tree-Grass Coexistence.” *Plant Ecology* 150 (1-2). Springer: 161–71.

Jin, S, and Sader,S.A 2005. “MODIS Time-Series Imagery for Forest Disturbance Detection and Quantification of Patch Size Effects.” *Remote Sensing of Environment* 99 (4) : 462–70.

Joshi, M., Hawkins, Ed Sutton, R., Lowe, J, and Frame, D. 2011. “Projections of When Temperature Change Will Exceed 2 [deg] C above Pre-Industrial Levels.” *Nature Climate Change* 1 (8). Nature Publishing Group: 407–12.

Juul, K.,2005. Transhumance, tubes and telephones: drought-related migration as a process of innovation. Beyond Territory and Scarcity: Exploring Conflicts over Natural Resource Management. Stockholm: Elanders Gotab, Stockholm, 112–134.

Juul, K., 1999. Tubes, Tenure and Turbulence: The Effects of Drought Related Migration on Tenure Is-sues and Resource Management in Northern Senegal.Ph.D. Dissertation, Roskilde: Roskilde University Centre.

Jung, M., Henkel, K., Herold, M, and Churkina,G. 2006. “Exploiting Synergies of Global Land Cover Products for Carbon Cycle Modeling.” *Remote Sensing of Environment* 101 (4): 534–53.

Jurisch, K., Hahn, K, Wittig, R, and Bernhardt-Römermann, M. 2012. “Population Structure of Woody Plants in Relation to Land Use in a Semi-arid Savanna, West Africa.” *Biotropica* 44 (6) : 744–51.

Jurisch. 2013. “Land-use Impact on the Growth and Survival of Seedlings and Saplings in West African Savannas.” *Journal of Vegetation Science* 24 (1) : 101–12.

Justice, C.O., Dugdale, G., Townshend, J.R.G., Narracott, A.S. and Kumar, M., 1991. Synergism between NOAA-AVHRR and Meteosat data for studying vegetation development in semi-arid West Africa. *International Journal of Remote Sensing*, *12*(6): 1349-1368.

Justice, C.O., Townshend, J.R.G., Holben, B.N. and Tucker, E.C., 1985. Analysis of the phenology of global vegetation using meteorological satellite data. *International Journal of Remote Sensing*, *6*(8):1271-1318.

Juul, K. 2005. “Transhumance, Tubes and Telephones: Drought-Related Migration as a Process of Innovation.” *Beyond Territory and Scarcity: Exploring Conflicts over Natural Resource Management. Stockholm: Elanders Gotab, Stockholm*, 112–34.

Kalema, V. N. "Diversity, use and resilience of woody plants in a multiple land-use equatorial African savanna, Uganda." PhD diss., Ph. D. Thesis, Johannesburg: University of the Witwatersrand, 2010.

Kankare, V., Holopainen, M., Vastaranta, M., Puttonen, E., Yu, X., Hyyppä, J., Vaaja, M., Hyyppä, H. and Alho, P., 2013. "Individual tree biomass estimation using terrestrial laser scanning." *ISPRS Journal of Photogrammetry and Remote Sensing*, *75*:.64-75.

Karl, T. R, and Melillo, J . M 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press.

Kasperson, J. X, Kasperson, R . E and Turner, B.L. 1995. “Regions at Risk.” United Nations University Press.

Keay, R .W. J. 1950. “The Systematic Position of Suffrutescent Species of Combretum Loeffl.” *Kew Bulletin* 5 (2): 255–57.

Keay, R. W. J. 1989. "Trees of Nigeria". Clarendon Press.

Kerley, G. I. H, and Landman, M . 2006. “The Impacts of Elephants on Biodiversity in the Eastern Cape Subtropical Thickets: Elephant Conservation.” *South African Journal of Science* 102 (9 & 10) : 395–402.

Kiéma, S 2007 Élevage extensif et conservation de la diversité biologique dans les aires protégées de l’Ouest burkinabé: arrêt sur leur histoire, épreuves de la gestion actuelle, état et dynamique de la végétation, PhD. Université d’Orléans Paris, Paris

Kiéma, S, and Fournier, A 2007. “Utilisation de Trois Aires Protégées Par L’élevage Extensif Dans L'ouest Du Burkina Faso.”

Kloos, H, and Zein, Z.A. 1993. *The Ecology of Health and Disease in Ethiopia*. Vol. 53. Westview Press Oxford.

Koadima, M. 2008. “Inventaire Des Espèces Ligneuses Utilitaires Du Parc W et Terroirs Riverains Du Burkina Faso et état Des Populations de Trois Espèces a Grande Valeur Socio-économique.” *Mémoire de DEA En Sciences Biologiques Appliquées. Université de Ouagadougou, Burkina Faso, 39p*.

Komwihangilo, D. Sendalo, F. Lekule, L. Mtenga, W.K. Temu 2001 Farmers' knowledge in the utilisation of indigenous browse species for feeding of goats in semi arid central Tanzania Livestock Research for Rural Development.13: 1–7

Konczacki, Z A. 1978. “Some Speculations on the Prospects of the Pastoral Mode of Production.” *The Economics of Pastoralism: A Case Study of Sub-Saharan Africa*, 150–71.

Krausmann, F. G, S., Eisenmenger, N, Erb, K.H., Haberl, H, and Fischer-Kowalski, M. 2009. “Growth in Global Materials Use, GDP and Population during the 20th Century.” *Ecological Economics* 68 (10): 2696–2705.

Krohmer J, Hahn-Hadjali K, and Wittig R. 2006. Use of wild populations by Fulani in Burkina Faso and Benin. Studies on the flora and vegetation of Burkina Faso, 10: 33-48.

Kristensen, M, and Balslev, H. 2003. “Perceptions, Use and Availability of Woody Plants among the Gourounsi in Burkina Faso.” *Biodiversity & Conservation* 12 (8): 1715–39.

Kumar, K., Dasgupta, C.N., Nayak, B., Lindblad, P. and Das, D., 2011. “Development of Suitable Photobioreactors for CO_2 Sequestration Addressing Global Warming Using Green Algae and Cyanobacteria.” *Bioresource Technology* 102 (8): 4945–53.

Kumar, P. 2010. *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. UNEP/Earthprint.

Lambin, E, F., Turner, B.F., Geist, H . J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O.T., 2001. “The Causes of Land-Use and Land-Cover Change: Moving beyond the Myths.” *Global Environmental Change* 11 (4): 261–69.

Lambin, E. F., Geist, H. J., & Lepers, E. 2003. “Dynamics of Land-Use and Land-Cover Change in Tropical Regions.” *Annual Review of Environment and Resources* 28 (1). Annual Reviews 4139 El Camino Way, PO Box 10139, Palo Alto, CA 94303-0139, USA: 205–41.

Landman, M, and Kerley, G. 2006. “Threats to Important Plants in the Addo Elephant National Park, South Africa–evaluating the Role of Elephant Herbivory.” in *proceedings of the second eastern cape elephant conservation and management workshop*.

Laris, P. 2002. “Burning the Seasonal Mosaic: Preventative Burning Strategies in the Wooded Savanna of Southern Mali.” *Human Ecology* 30 (2): 155–86.

Le Houérou, H N. 1980. “Chemical Composition and Nutritive Value of Browse in Tropical West Africa.” *Browse in Africa, the Current State of Knowledge. Le Houerou, HN (ed.), ILCA, Addis Ababa*, 261–89.

Leach, M, Mearns, R and Scoones, I. 1999. “Environmental Entitlements: Dynamics and Institutions in Community-Based Natural Resource Management.” *World Development* 27 (2) : 225–47.

Leach, G. and Mearns, R. 2013. Beyond the woodfuel crisis: people, land and trees in Africa. Routledge

Legge, S and Atticus F. 2012. "Fire management in the central Kimberley (EcoFire): delivering measurable results by integrating science and land management in a cost-effective model." Innovation for 21st Century Conservation (124)

Legge, S. S. A., Murphy, B., Maher, R., Kingswood, D., Swan, J. Axford, R. Faulkner and G. Basnett. 2009 EcoFire 2008. 24. Australian Wildlife Conservancy Report to the Western Australian Department of Environment and Conservation, Perth. http://www.eksa.com.au/rangelandsbmpwiki/GetFile.aspx?File=Ecofire_2008_Report.pdf

Legge, S. S. A., Murphy, R. Kingswood, B. Maher and D. Swan 2011. EcoFire: restoring the biodiversity values of the Kimberley region by managing fire. Ecol. Mmt. Restor., 12: 84-92. https://cgspace.cgiar.org/bitstream/handle/10568/35109/RPL_WA_2013_technical_report.pdf?sequence=22

Lehmann, C. E R., Anderson, T. M., Sankaran, M., Higgins, S. I., Archibald, S., Hoffmann,W.S., Hanan, N.P., Williams, R..J., Fensham, R.J, and Felfili, J. 2014. “Savanna Vegetation-Fire-Climate Relationships Differ among Continents.” *Science* 343 (6170). American Association for the Advancement of Science: 548–52.

Liu, O, and Bråkenhielm. S. 1996. “Variability of Plant Species Diversity in Swedish Natural Forest and Its Relation to Atmospheric Deposition.” *Vegetatio*. http://link.springer.com/article/10.1007/BF00045205.

Lockwood, M, Worboys, G and Kothari, A. 2012. *Managing Protected Areas: A Global Guide*. Routledge.

Lombard, A. T., Johnson, C . F., Cowling, R . M, and Pressey, R . L. 2001. “Protecting Plants from Elephants: Botanical Reserve Scenarios within the Addo Elephant National Park, South Africa.” *Biological Conservation* 102 (2): 191–203.

López-Hoffman, L, Monroe, I . A, Narváez, E, Martínez-Ramos, M and Ackerly, D. A. 2006. “Sustainability of Mangrove Harvesting: How Do Harvesters’ Perceptions Differ from Ecological Analysis.” *Ecology and Society* 11 (2): 14.

Lopoukhine, N, N Crawhall, N Dudley, P Figgis, C Karibuhoye, D Laffoley, J Miranda Londoño, K MacKinnon, and T Sandwith. 2012. “Protected Areas: Providing Natural Solutions to 21st Century Challenges.” *SAPI EN. S. Surveys and Perspectives Integrating Environment and Society*, no. 5.2. Institut Veolia Environnement.

Loveland, T., Merchant, J., Ohlen, D, and Brown, J. 1991. “Development of a Land-Cover Characteristics Database for the Conterminous U.S.” *Photogrammetric Engineering and Remote Sensing* 57 (1): 1453–63.

Ludwig, J. A., Wilcox, B.P., Breshears, D.D., Tongway, D. J, and Imeson, A.C. 2005. “Vegetation Patches and Runoff-Erosion as Interacting Ecohydrological Processes in Semiarid Landscapes.” *Ecology* 86 (2): 288–97.

Lunetta, R. S., Johnson, D.M., Lyon, J.G, and Crotwell. J. 2004. “Impacts of Imagery Temporal Frequency on Land-Cover Change Detection Monitoring.” *Remote Sensing of Environment* 89 (4): 444–54.

Lunetta, R. S., Knight, J.F., Ediriwickrema, J., Lyon, J .G, and Worthy, L. D. 2006. “Land-Cover Change Detection Using Multi-Temporal MODIS NDVI Data.” *Remote Sensing of Environment* 105 (2): 142–54.

Lutz, J. A., van Wagtendonk, J.W., Thode, A. E., Miller, J . D, and Franklin, J. F. 2009. “Climate, Lightning Ignitions, and Fire Severity in Yosemite National Park, California, USA.” *International Journal of Wildland Fire* 18 (7). CSIRO PUBLISHING: 765.

Lykke, A M, Kristensen, M. K and Ganaba, S. 2004. “Valuation of Local Use and Dynamics of 56 Woody Species in the Sahel.” *Biodiversity & Conservation* 13 (10). Springer: 1961–90.

Lykke, A.M. 2000. “Local Perceptions of Vegetation Change and Priorities for Conservation of Woody-Savanna Vegetation in Senegal.” *Journal of Environmental Management* 59 (2): 107–20. doi:10.1006/jema.2000.0336.

Lykke, A.M. 1998. “Assessment of Species Composition Change in Savanna Vegetation by Means of Woody Plants’ Size Class Distributions and Local Information.” *Biodiversity*

& Conservation 1275: 1261–75.

Lykke, A. M. 1998. “Assessment of Species Composition Change in Savanna Vegetation by Means of Woody Plants’ Size Class Distributions and Local Information.” *Biodiversity and Conservation* 7 (10): 1261–75. doi:10.1023/A:1008877819286.

Mace, G. M., Collar, N.J., Gaston, K.J., Hilton-Taylor, C., Akçakaya, H.R..,Leader-Williams, N Milner-Gulland, E.J, and Stuart,S. N. 2008. “Quantification of Extinction Risk: IUCN’s System for Classifying Threatened Species.” *Conservation Biology* 22 (6):1424–42.

Martínez-Meyer, Enrique, A Townsend Peterson, and William W Hargrove. 2004. “Ecological Niches as Stable Distributional Constraints on Mammal Species, with Implications for Pleistocene Extinctions and Climate Change Projections for Biodiversity.” *Global Ecology and Biogeography* 13 (4) : 305–14.

Marshall, P.J. 1985. "A new method of censusing, Elephants and hippopotamus on Yankari Game Reserve". Nigeria Field 50: 5-11

Mayle, F. E., Langstroth, R.P., Fisher, R.A, and Meir. P. 2007. “Long-Term Forest–savannah Dynamics in the Bolivian Amazon: Implications for Conservation.” *Philosophical Transactions of the Royal Society B: Biological Sciences* 362 (1478): 291–307.

McDowell, N., Pockman,W.T., Allen, C.D., Breshears, D.D., Cobb, N., Kolb, T, and Plaut, J. 2008. “Mechanisms of Plant Survival and Mortality during Drought: Why Do Some Plants Survive While Others Succumb to Drought?” *The New Phytologist* 178 (4): 719–39.

Meduna, A. J., Ogunjinmi, A.A, and Onadeko, S. A. 2009. Biodiversity Conservation Problems and their Implications on Ecotourism in Kainji Lake National Park, Nigeria. Journal of Sustainable Development in Africa(10) 4: 59-73

Meyer, W. B, and Turner, B.L 1994. *Changes in Land Use and Land Cover: A Global Perspective*. Vol. 4. Cambridge University Press.

Midgley, J.J and Joubert. D, 1991. “Mistletoes, Their Host Plants and the Effects of Browsing by Large Mammals in Addo Elephant National Park.” *Koedoe* 34 (2): 149–52.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Desertification Synthesis*. *Ecosystems and Human Well-Being*. http://library.wur.nl/WebQuery/clc/1785684.

Milner-Gulland, E. J. 2008. “New Perspectives on Harvesting as One Driver of Ecosystem Dynamics.” *Journal of Applied Ecology* 45 (1). Wiley Online Library: 1–3.

Mitchard, E. T, and Flintrop, C.M. 2013. “Woody Encroachment and Forest Degradation in Sub-Saharan Africa’s Woodlands and Savannas 1982-2006.” *Philosophical Transactions of the Royal Society B: Biological Sciences* 368: 20120406.

Mitchell, K., 2010. "Quantitative analysis by the point-centered quarter method". *arXiv preprint arXiv:1010.3303*.

Mohammed, I., Shehu., A.I, Adamu., M.B, and Saleh, U.F. 2010. “Comparative Analysis of Fauna Numerical Characteristic of Yankari Game Reserve from 1980-2008.” *Environmental Research Journal* 4 (2): 177–81.

Moolman, H.J. and Cowling, R.M 1994. “The Impact of Elephant and Goat Grazing on the Endemic Flora of South African Succulent Thicket.” *Biological Conservation* 68 (1): 53–61.

Moore, R D., Fleming, S.W., Menounos, B., Wheate, A., Fountain, K., Stahl, K., H, and Jakob, M. 2009. “Glacier Change in Western North America: Influences on Hydrology, Geomorphic Hazards and Water Quality.” *Hydrological Processes* 23 (1): 42–61.

Monod. T (Ed.), 1975a Pastoralism in tropical Africa, Oxford University Press, London, Ibadan, Nairobi: 455–467

Monod . T (Ed.), 1975b Pastoralism in tropical Africa, Oxford University Press, London, Published for the International African Institute by Oxford University Press. 387–405

Moreno, C. E, and Halffter, G. 2000. “Assessing the Completeness of Bat Biodiversity Inventories Using Species Accumulation Curves.” *Journal of Applied Ecology* 37 (1). Wiley Online Library: 149–58.

Morgan G, J., Cadenasso, M , J., Burch, W. R. Jr., Pickett, S.T. A., Schwarz, K., O’Neil-Dunne, J., Wilson, M., Troy, A, and Boone, C. 2006. “Data and Methods Comparing Social Structure and Vegetation Structure of Urban Neighborhoods in Baltimore, Maryland.” *Society and Natural Resources* 19 (2): 117–36.

Moritz, M A., Parisien, E., Batllori, M . A., Krawchuk, J Van Dorn, D J Ganz, and K Hayhoe. 2012. “Climate Change and Disruptions to Global Fire Activity". *Ecosphere* 3 (6): 49.

Mortimore, M. 1989. *Adapting to Drought: Farmers, Famines, and Desertification in West Africa*. Cambridge University Press.

Mortimore, M. 2010. “Adapting to Drought in the Sahel: Lessons for Climate Change.” *Wiley Interdisciplinary Reviews: Climate Change* 1 (1): 134–43.

Müller, S. C., Overbeck, G. E., Pfadenhauer, P, and Pillar, V. D. 2007. “Plant Functional Types of Woody Species Related to Fire Disturbance in Forest–grassland Ecotones.” *Plant Ecology* 189 (1) : 1–14.

Mwavu, E. N, and Witkowski. Ed.T.F 2009. “Population Structure and Regeneration of Multiple-Use Tree Species in a Semi-Deciduous African Tropical Rainforest: Implications for Primate Conservation.” *Forest Ecology and Management* 258 (5) : 840–49.

Nantel, P., Gagnon, D, and Nault, A 1996. “Population Viability Analysis of American

Ginseng and Wild Leek Harvested in Stochastic Environments.” *Conservation Biology* 10 (2): 608–21.

Nations, Food and Agriculture Organization of the United. 2010. *Global Forest Resources Assessment 2010: Main Report*. Food and Agriculture Organization of the United Nations.

Naughton-Treves, L., Holland, M.B, and Brandon, K. 2005. “The Role of Protected Areas in Conserving Biodiversity and Sustaining Local Livelihoods.” *Annu. Rev. Environ. Resour.* 30. Annual Reviews: 219–52.

Neelo, J., Teketay, D., Masamba, W, and Kashe, K. 2013. "Diversity, Population Structure and Regeneration Status of Woody Species in Dry Woodlands Adjacent to Molapo Farms in Northern Botswana." *Open Journal of Forestry* 3 (4): 138.

Newmark, W. D. 2008. “Isolation of African Protected Areas.” *Frontiers in Ecology and the Environment* 6 (6) : 321–28.

Niamir, M. 1990. “Community Forestry: Herders’ Decision-Making in Natural Resources Management in Arid and Semi-Arid Africa.” *FAO Community Forestry Note*, no. 4.

Niamir-Fuller, M. 1998. “The Resilience of Pastoral Herding in Sahelian Africa.” *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge University Press Cambridge, 250–84.

Nicholas, A. 1999. Yankari National Park, Nigeria: Aerial total count of elephants (Loxodonta africana Africana) and Buffalo (Syncerus caffer brachyceros).March-April 1999. Abuja: Abuja Nigeria National Parks

Nicholson SE. 2001. Climatic and environmental change in Africa during the last two centuries. Clim. Res. 17: 123–144.

Nicholson, F., Chambers, B., Alloway, B., Hird, A., Smith, S., Carlton-Smith, C., 1998. An inventory of heavy metal inputs to agricultural soils in England and Wales. In: Proceedings of the 16th World Congress of Soil Science. Montpellier, France.

Nicholson, N. 1980."Modelling of dynamical systems".1:256.

Nihotours 2000. "A Bulleting of the National Institute for Hospitality and tourism Studies, Kano," Nigeria. 1 (1):8-9.

Nielsen, I. 1991. “Keay, R. W. J. 1989. Trees of Nigeria. Clarendon Press Oxford.” *Nordic Journal of Botany* 11 (3): 322–322.

Nilsson, C, and Berggren, K. 2000. “Alterations of Riparian Ecosystems Caused by River Regulation Dam Operations Have Caused Global-Scale Ecological Changes in Riparian Ecosystems. How to Protect River Environments and Human Needs of Rivers Remains One of the Most Important Questions of Our.” *BioScience* 50 (9). Oxford University Press: 783–92.

Nogués-Bravo, D., Rodríguez, J., Hortal, J., Batra, P, and Araújo, M.B. 2008. “Climate

Change, Humans, and the Extinction of the Woolly Mammoth." *PLoS Biology* 6 (4). Public Library of Science: e79.

Noss, R. F. 1990. "Indicators for Monitoring Biodiversity: A Hierarchical Approach." *Conservation Biology* 4 (4): 355–64.

N.P.D.L. record, 1992: www.gamji.com/fulani4.htm

Nyanganji, G, Saidu,Y, Henschel, P and Dunn, A. 2012. "2011 Survey of Lion (Plantshera Leo) in Yankari Game Reserve and Kainji Lake National Park, Nigeria,":1–16. http://www.plantshera.org/sites/default/files/Nyanganji_et_al_2012_Nigeria_lion_survey_report.pdf.

O'Connor, Timothy G, Goodman, P.S and Clegg, A. 2007. "A Functional Hypothesis of the Threat of Local Extirpation of Woody Plant Species by Elephant in Africa." *Biological Conservation* 136 (3) : 329–45.

O'Connor, T.G., 1985. A synthesis of field experiments concerning the grass layer in the savannah regions of southern Africa. National Scientific Programmes Report No. 114. CSIR, Pretoria.

Obiri, J, Lawes, M and Mukolwe, M. 2002. "The Dynamics and Sustainable Use of High-Value Tree Species of the Coastal Pondoland Forests of the Eastern Cape Province, South Africa." *Forest Ecology and Management* 166 (1-3): 131–48.

Odunlami, S.S.S., 2000. "Parks: Vanguard of Ecotourism Promotion". *The Host Magazine*, *2*(1):.25.

Oldfield, F, Dearing, J.A, G, Marie-Jose, and Bugmann, H 2000. "Ecosystem Processes and Human dimensions–The Scope and Future of HITE (Human Impacts on Terrestrial Ecosystems)." *Pages Newsletter* 2000 (3): 21–23.

Olokesusi, F. 1990. "Assessment of the Yankari Game Reserve, Nigeria." *Tourism Management* 11 (2): 153–63.

Olsson, L, Eklundh, L and Ardö, J, 2005. "A Recent Greening of the Sahel—trends, Patterns and Potential Causes." *Journal of Arid Environments* 63 (3): 556–66.

Omondi, P, R Mayienda, Mshelbwala, J.H and Massalatchi, M.S. 2006. "Total Aerial Count of Elephants , Buffaloes , Roan Antelope and Other Wildlife Species in Yankari," *For CITES MIKE programme*.

Omotoriogun, T.C, Onoja, J.D, Tende,T, Manu, S, and Ottosson, U. 2011. "Density and Diversity of Birds in the Wetlands of Yankari Game Reserve Bauchi Nigeria." *Journal of Wetlands Ecology* 5: 48–58.

Onana, J. 1998. Sur l'utilisation et la régénération naturelle de Afzelia africanaSmith ex Person. Le Flamboyant 8: 33

Onana J, Devineau JL .2002. "*Afzelia africana* Smithex Persoon in North Cameroon. Current status of populations and pasture use". *J. Ani. Husbandry Vet. Med. Trop*. Countries, 55:

39-45

Ouédraogo, A, and Thiombiano, A. 2012. “Regeneration Pattern of Four Threatened Tree Species in Sudanian Savannas of Burkina Faso.” *Agroforestry Systems* 86 (1): 35–48.

Ouédraogo, A, Thiombiano, A, Hahn-Hadjali, K and Guinko, S. 2006. “Diagnostic de L’état de Dégradation Des Peuplements de Quatre Espèces Ligneuses En Zone Soudanienne Du Burkina Faso.” *Science et Changements Planétaires / Sécheresse* 17 (4): 485–91.

Ouédraogo-Koné, S, C Y Kaboré-Zoungrana, and I Ledin. 2006. “Behaviour of Goats, Sheep and Cattle on Natural Pasture in the Sub-Humid Zone of West Africa.” *Livestock Science* 105 (1): 244–52.

Ouédraogo-Koné, S, Kaboré-Zoungrana, C.Y and Ledin.I. 2007. “Important Characteristics of Some Browse Species in an Agrosilvopastoral System in West Africa.” *Agroforestry Systems* 74 (2): 213–21.

Owen-Smith, N. 1982. “Factors Influencing the Consumption of Plant Products by Large Herbivores.” In *Ecology of Tropical Savannas,* 359–404. Springer Berlin Heidelberg.

Owen-Smith, N, and Cooper, S. M. 1988. “Plant Palatability Assessment and Its Implications for Plant-herbivore Relations.” *Journal of the Grassland Society of Southern Africa* 5 (2) : 72–75.

Parmesan, C, and Yohe, G. 2003. “A Globally Coherent Fingerprint of Climate Change Impacts across Natural Systems.” *Nature* 421 (6918). Nature Publishing Group: 37–42.

Parry, M. L. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Vol. 4. Cambridge University Press.

Pausas, J. G, Bradstock, R. A, Keith,D.A and Keeley, J. N. 2004. “Plant Functional Traits in Relation to Fire in Crown-Fire Ecosystems.” *Ecology* 85 (4) : 1085–1100.

Pausas, J. G, and Keeley, J. E. 2014. “Evolutionary Ecology of Resprouting and Seeding in Fire-prone Ecosystems.” *New Phytologist* 204 (1) : 55–65.

Paradis G. and Houngnon P. 1997. "La végétation de l'aire classée de la Lama dans la mosaïque forêtsavane du Sud-Bénin" (ex Sud Dahomey). Bulletin du Muséum National d'Histoire Naturelle, 3é série, n° 503.

Pare, S, Savadogo, P, Tigabu, M, Oden, PC, Ouadba, JM .,2009. "Regeneration and spatial distribution of seedling populations in Sudanian dry forests in relation to conservation status and human pressure". *Trop Ecol* 50:339-353

Penzhorn, B L, Robbertse, P J and Olivier, M. C. 1974. “The Influence of the African Elephant on the Vegetation of the Addo Elephant National Park.” *Koedoe* 17 (1): 137–58.

Peres, C. A, Baider,C, Zuidema, P. A, Wadt, L.H.O, Kainer, K. A, Gomes-Silva, D.A.P, Salomão, R.P. Simões, L.L, Franciosi, E. R. N and Valverde, F. C. 2003. "Demographic Threats to the Sustainability of Brazil Nut Exploitation." *Science* 302 (5653): 2112–14.

Peters, C.M. 1994. "Sustainable Harvest of Non - Timber Plant Resources in Tropical Moist Forest". An Ecological Primer. USAID Biodiversity Support Programme, Washington DC.

Petit, S. and Mallet, B. 2001. "L'émondage d'arbres fourragersdétail d'une pratique pastorale. Bois et Forêt des Tropiques" 4:35-45.

Petit, R. J, Bialozyt, R. Garnier-Géré, P and Hampe, A 2004. "Ecology and Genetics of Tree Invasions: From Recent Introductions to Quaternary Migrations." *Forest Ecology and Management* 197 (1): 117–37.

Petit, S. 2003. "Parklands with Fodder Trees: A Fulße Response to Environmental and Social Changes." *Applied Geography* 23 (2-3): 205–25.

Pielke, R.A. 2001. "Influence of the Spatial Distribution of Vegetation and Soils on the Prediction of Cumulus Convective Rainfall." *Reviews of Geophysics* 39 (2): 151–77.

Polcher, J, P, Amadou Gaye D . J, Diedhiou, A, Eymard, L, Fierli, F, Genesio, L 2011. "AMMA's Contribution to the Evolution of Prediction and Decision-Making Systems for West Africa." *Atmospheric Science Letters* 12 (1): 2–6.

Polley, H.W. 1997. "Implications of Rising Atmospheric Carbon Dioxide Concentration for Rangelands." *Journal of Range Management Archives* 50 (6): 562–77.

Polley, H .W, Mayeux, H.S, Johnson, H. B and Tischler, C. R. 1997. "Viewpoint: Atmospheric CO2, Soil Water, and Shrub/grass Ratios on Rangelands." *Journal of Range Management*: 278–84.

Porter-Bolland, L, Ellis, E.A, Guariguata, M, A. Ruiz-Mallén, I, Negrete-Yankelevich, S and Reyes-García, V. 2012. "Community Managed Forests and Forest Protected Areas: An Assessment of Their Conservation Effectiveness across the Tropics." *Forest Ecology and Management* 268: 6–17.

Pouillon, F. 1988. "Cens et Puissance, Ou Pourquoi Les Pasteurs Nomades Ne Peuvent Pas Compter Leur Bétail (Census and Power, or Why Nomadic Pastors Cannot Count Their Cattle)." *Cahiers d'Etudes Africaines*: 177–205.

Poupon H, Bille, J.C.1974. "Recherches ecologiques sur une savane sahelienne du Ferlo septentrional, Senegal: influence de la secheresse de l'annee 1972–1973 sur la strate ligneuse. *La Terre et la Vie*, 28; 49–75.

Prins, H. H. T, and van der Jeugd, H. P. 1993. "Herbivore Population Crashes and Woodland Structure in East Africa." *Journal of Ecology*: 305–14.

Prudhomme, C, Crooks, S, Kay, A.L and Nick Reynard. 2013. "Climate Change and River Flooding: Part 1 Classifying the Sensitivity of British Catchments." *Climatic Change* 119 (3-4): 933–48.

Raman, T R, Rawat, G.S and Johnsingh.A.J.T. 1998. "Recovery of Tropical Rainforest Avifauna in Relation to Vegetation Succession Following Shifting Cultivation in Mizoram, North-east India." *Journal of Applied Ecology* 35 (2) : 214–31.

Ratnam, J, Bond,W.J. Fensham, R. J, Hoffmann,W.A, Archibald, S, Lehmann,C.E.R, Anderson, M.T, Higgins,S.I and Sankaran, M. 2011. "When Is a 'forest'a Savanna, and Why Does It Matter?" *Global Ecology and Biogeography* 20 (5) : 653–60.

Reisman, P. 1977. "Freedom in Fulani Social Life." *Chicago: University of ChicagoPress*.

Reserve, Yankari Game. 2009. "An Assessment of the Herbaceous Species Vegetation of." *Science* 6 (1): 20–25.

Rhemtulla, J. M, Mladenoff, D . J and Clayton, M .K 2009. "Historical Forest Baselines Reveal Potential for Continued Carbon Sequestration." *Proceedings of the National Academy of Sciences of the United States of America* 106 (15): 6082–87.

Ripple, W. J. and Beschta, R. L. 2004. "Wolves, Elk, Willows, and Trophic Cascades in the Upper Gallatin Range of Southwestern Montana, USA." *Forest Ecology and Management* 200: 161–81.

Roy, D, P, Y Jin, Lewis,P.E and Justice, C.O. 2005. "Prototyping a Global Algorithm for Systematic Fire-Affected Area Mapping Using MODIS Time Series Data." *Remote Sensing of Environment* 97 (2): 137–62.

Roy, D. P, Lewis, P. E and Justice, C.O. 2002. "Burned Area Mapping Using Multi-Temporal Moderate Spatial Resolution data—A Bi-Directional Reflectance Model-Based Expectation Approach." *Remote Sensing of Environment* 83 (1) : 263–86.

Roy, D. P. 1999. "Multi-Temporal Active-Fire Based Burn Scar Detection Algorithm." *International Journal of Remote Sensing* 20 (5) : 1031–38.

Saha. 2006. "Stature of Juvenile Trees in Response to Anthropogenic Fires in a Tropical Deciduous Forest of Central India." *Conservation and Society*. 4(4): 619

Sala, O. E. 2000. "Global Biodiversity Scenarios for the Year 2100 ." *Science* 287 (5459): 1770–74.

Salzman, C.P., 1980. When Nomads Settle., Praeger.

Sanderson, M.G., Hemming, D.L. & Betts, R.A., 2011. "Regional Temperature and Precipitation Changes under High-End (≥ 4 C) Global Warming." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 369 (1934). The Royal Society: 85–98.

Sankaran, M, Hanan, N.P, Scholes, R . J, Ratnam, J. Augustine, D.J, Cade, B.S, Gignoux,J S Higgins,S.I, Le Roux, X and Ludwig, F. 2005. "Determinants of Woody Cover in African Savannas." *Nature* 438 (7069). Nature Publishing Group: 846–49.

Sankaran, M, Ratnam, J and Hanan, N. 2008. "Woody Cover in African Savannas: The Role of Resources, Fire and Herbivory." *Global Ecology and Biogeography* 17 (2): 236–45.

Sankaran, M, Ratnam, J and Hanan, N.2004. “Tree–grass Coexistence in Savannas Revisited–insights from an Examination of Assumptions and Mechanisms Invoked in Existing Models.” *Ecology Letters* 7 (6): 480–90.

Sarmiento, G., and Monasterio, M. 1983. “Life Forms and Phenology.” *Ecosystems of the World* 13: 79–108.

Scheiter, S., and Higgins.S.I. 2009. “Impacts of Climate Change on the Vegetation of Africa: An Adaptive Dynamic Vegetation Modelling Approach.” *Global Change Biology* 15 (9). Wiley Online Library: 2224–46.

Scholes, R. J., and Archer, S.R. 1997. “Tree-Grass Interactions in Savannas.” *Annual Review of Ecology and Systematics*. JSTOR, 517–44.

Schumann, K., Wittig, R, Thiombiano., A, Becker,U, and Hahn, K. 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 Savanna, West Africa.” *Forest Ecology and Management* 260 (11). Elsevier: 2035–44.

Scoones, I. 1995. “Exploiting Heterogeneity: Habitat Use by Cattle in Dryland Zimbabwe.” *Journal of Arid Environments* 29 (2). Elsevier: 221–37.

Shackleton, C. M., Guthrie, G and Main.R 2005. “Estimating the Potential Role of Commercial Over-harvesting in Resource Viability: A Case Study of Five Useful Tree Species in South Africa.” *Land Degradation & Development* 16 (3). Wiley Online Library: 273–86.

Shackleton, S., Shackleton, C, and Shanley, P eds. 2011. *Non-Timber Forest Products in the Global Context*. Vol. 7. Tropical Forestry. Berlin, Heidelberg: Springer Berlin Heidelberg.

Shahidian, S., and Serralheiro. R. P. 2011. “Development of an Adaptive Surface Irrigation System.” *Irrigation Science* 30 (1): 69–81.

Shannon, G., Druce, D.J., Page, B.R., Eckhardt, H.C, Grant, R, and Slotow, R 2008. “The Utilization of Large Savanna Trees by Elephant in Southern Kruger National Park.” *Journal of Tropical Ecology* 24 (03): 281–89.

Sheffield, J, Wood, E. F and Roderick, M . L. 2012. “Little Change in Global Drought over the Past 60 Years.” *Nature* 491 (7424). Nature Publishing Group: 435–38.

Shuttleworth, W. J. 2007. “Stakeholder-Driven, Enquiry-Driven, or Stakeholder-Relevant, Enquiry-Driven Science?” In *Integrated Assessment of Water Resources and Global Change*, 63–77. Springer Netherlands.

Siebert, S. F. 2000. “Abundance and Growth of Desmoncus Orthacanthos Mart.(Palmae) in Response to Light and Ramet Harvesting in Five Forest Sites in Belize.” *Forest Ecology and Management* 137 (1) : 83–90.

Sikes, S. 1964. “A Game Survey for the Yankari Reserve of Northern Nigeria.” *Niger. Fld*

29: 127–41.

Sikes, S. K. 1964. “Elephant, Loxodonta Africana (32) [in A Game Survey of the Yankari Reserve of Northern Nigeria].” *The Nigerian Field* 29 (2): 73.

Sinclair, J. and Garwood, E.A. 1979. Use of water by six grass species. 2. Root distribution and use of soil water. The Journal of Agricultural Science, 93(01):25–35.

Sinha, A., and Solange., B. 2005. “Assessing Sustainability of Nontimber Forest Product Extractions: How Fire Affects Sustainability.” *Biodiversity and Conservation* 14 (14): 3537–63.

Sinsin, B., Matig, O.E., Assogbadjo, A.E., Gaoué, O.G. and Sinadouwirou, T., 2004.2004. “Dendrometric Characteristics as Indicators of Pressure of Afzelia Africana Sm. Dynamic Changes in Trees Found in Different Climatic Zones of Benin.” *Biodiversity and Conservation* 13 (8): 1555–70.

Sitch, S, Smith, B, Prentice, C, Arneth, A, Bondeau, A, Cramer,W, Kaplan, J.O, Samuel Levis, W Lucht, and Sykes, M.T. 2003. “Evaluation of Ecosystem Dynamics, Plant Geography and Terrestrial Carbon Cycling in the LPJ Dynamic Global Vegetation Model.” *Global Change Biology* 9 (2): 161–85.

Sitrit, Y, Loison, S, Ninio, R., Dishon, E., Bar, E., Lewinsohn, E., & Mizrahi, Y. 2003. "Characterization of monkey orange (Strychnos spinosa Lam.), a potential new crop for arid regions". *Journal of agricultural and food chemistry*, 51(21):6256-6260

Sokpon, N, and Biaou, B.H.2002. “The Use of Diameter Distributions in Sustained-Use Management of Remnant Forests in Benin: Case of Bassila Forest Reserve in North Benin.” *Forest Ecology and Management* 161 (1-3): 13–25.

Speedy, A, and Pierre-Luc Pugliese. 1992. *Legume Trees and Other Fodder Trees as Protein Sources for Livestock*. FAO.

Spiekermann, R., Brandt, M. and Samimi., C. 2015. “Woody Vegetation and Land Cover Changes in the Sahel of Mali (1967–2011).” *International Journal of Applied Earth Observation and Geoinformation* 34: 113–21.

Srivastava, P., and Garg, A. 2013. “Forest Fires in India: Regional and Temporal Analyses.” *Journal of Tropical Forest Science*. 228–39.

Staver., A. C, Archibald., S. and Levin., S.A. 2011. “The Global Extent and Determinants of Savanna and Forest as Alternative Biome States.” *Science (New York, N.Y.)* 334 (6053): 230–32.

Stenning., D.J., 1959. *Savannah nomads:" a study of the Wodaabe pastoral Fulani of Western Bornu Province Northern region" Nigeria*. LIT Verlag Münster.

Stocks., B. J, M A Fosberg, T J Lynham, L Mearns, B M Wotton, Q Yang, J Z Jin, K Lawrence, G R Hartley, and J A Mason. 1998. “Climate Change and Forest Fire Potential in Russian and Canadian Boreal Forests.” *Climatic Change* 38 (1) : 1–13.

Stuart-Hill., G. C. 1992. “Effects of Elephants and Goats on the Kaffrarian Succulent Thicket of the Eastern Cape, South Africa.” *Journal of Applied Ecology*. 699–710.

Sutter, J. W. 1987. “Cattle and Inequality: Herd Size Differences and Pastoral Production among the Fulani of Northeastern Senegal.” *Africa* 57 (02). Cambridge Univ Press: 196–218.

Swann., A. L. S, Fung, I.Y and Chiang, J.C.H. 2012. “Mid-Latitude Afforestation Shifts General Circulation and Tropical Precipitation.” *Proceedings of the National Academy of Sciences* 109 (3): 712–16.

Swift, J, Leach, M. and Mearns., R. 1996. “Desertification. Narratives, Winners & Losers.” *The Lie of the Land: Challenging Received Wisdom on the African Environment.* James Currey Ltd, 73–90.

Tata. 2001: www.gamji.com/article5000/NEWS5846.htm

Tchamba, M.N. and Mahamat., H. 1992. “Effects of Elephant Browsing on the Vegetation in Kalamaloue National Park, Cameroon.” *Mammalia* 56 (4).

Tézenas du Montcel., H. 1994. “L’avenir Appartient à L’immatériel Dans L’entreprise.” *Revue Française de Gestion*, no. 100.

Tende., T. Onoja, J. D, Ulf, O and Manu,S .2011 "The State of Yankari Game Reserve, Nigeria": http://www.aplori.org/research/oj1html.html

Thomson., M. C, Connor., S. J, Zebiak., S. E, Jancloes., M. and Mihretie, A 2011. “Africa Needs Climate Data to Fight Disease.” *Nature* 471 (7339). Nature Publishing Group: 440–42.a Population Level Case Study

Ticktin., T. 2005. “Applying a Metapopulation Framework to the Management and Conservation of a Non-Timber Forest Species.” *Forest Ecology and Management* 206 (1). Elsevier: 249–61.

Ticktin., T. and Nantel., P. 2004. “Dynamics of Harvested Populations of the Tropical Understory Herb Aechmea Magdalenae in Old-Growth versus Secondary Forests.” *Biological Conservation* 120 (4): 461–70.

Ticktin., T, and Dalle., S. P. 2005. “Medicinal Plant Use in the Practice of Midwifery in Rural Honduras.” *Journal of Ethnopharmacology* 96 (1-2): 233–48.

Ticktin., T, and Johns., T. 2002. “Chinanteco Management ofAechmea Magdalenae: Implications for the Use of TEK and TRM in Management Plans.” *Economic Botany* 56 (2): 177–91.

Tiseer., F.A 2009. "Floristic and Vegetation Study of Yankari Game Reserve: A Report Submitted to A.P. Leventis ornithological Research Institute (APLORI), Jos Nigeria

Tieguhong., J C, O Ndoye, P Vantomme, S Grouwels, J Zwolinski, and J Masuch. 2009. “Coping with Crisis in Central Africa: Enhanced Role for Non-Wood Forest Products.” *Unasylva* 233 (60): 49–54.

Tishkoff, S. A, Reed, F.A. Friedlaender,F. A, Ehret, C, Ranciaro, A, Froment, A, Hirbo, J.A, Awomoyi, A . A, Bodo, J . M and Doumbo, O. 2009. “The Genetic Structure and History of Africans and African Americans.” *Science* 324 (5930) : 1035–44.

Tolba, M. K, Osama A El-Kholy, E El-Hinnawi, M W Holdgate, D F McMichael, and R E Munn. 1992. “The World Environment 1972-1992.” *Two Decades of Challenge. London Ua*.

Townshend, J. R. G., and Justice.C.O. 1986. “Analysis of the Dynamics of African Vegetation Using the Normalized Difference Vegetation Index.” *International Journal of Remote Sensing* 7 (11) : 1435–45.

Toupet., C. 1975."Le nomade, conservateur de la nature? L’exemple de la Mauritanie centralT Monod (Ed.), Pastoralism in tropical Africa," Oxford University Press, London, Ibadan, Nairobi, pp. 455–467

Trollope, W. S. W. 1984. “Fire in Savanna.” In *Ecological Effects of Fire in South African Ecosystems*, 149–75. Springer Berlin Heidelberg.

Turner, B. L. 2008. “Resource Partitioning for Soil Phosphorus: A Hypothesis.” *Journal of Ecology* 96 (4): 698–702.

Turner, M.G., Gardner, R.H. and O'neill, R.V., 20012001. *Landscape ecology in theory and practice* (Vol. 401). New York: Springer.

Turner., M.D, Hiernaux., P. and Schlecht, E. 2005. "The distribution of grazing pressure in relation to vegetation resources in semi-arid West Africa: the role of herding" Ecosystems 8: pp. 668-681

Usongo., L, and Nkanje., B.T. 2004. “Participatory Approaches towards Forest Conservation: The Case of Lobéké National Park, South East Cameroon.” *The International Journal of Sustainable Development & World Ecology* 11 (2): 119–27.

Vall., E, and Diallo, M.A. 2009. Savoirs techniques locaux et pratiques: la conduite des troupeaux aux pâturages (Ouest du Burkina Faso). Natures Sciences Sociétés 17:122-135

Van Langevelde, F., Van De Vijver, C.A., Kumar, L., Van De Koppel, J., De Ridder, N., Van Andel, J., Skidmore, A.K., Hearne, J.W., Stroosnijder, L., Bond, W.J. and Prins, H.H., 2003. “Effects of Fire and Herbivory on the Stability of Savanna Ecosystems.” *Ecology* 84 (2). Eco Soc America: 337–50.

Van Wyk, G. F., Everard., D A, Midgley, J. J. and Gordon., I. G. 2006. “Classification and Dynamics of a Southern African Subtropical Coastal Lowland Forest.” Bureau for Scientific Publishers.

Van Wyk., P, and Fairall, N. 1969. “The Influence of the African Elephant on the Vegetation of the Kruger National Park.” *Koedoe* 12 (1): 57–89.

Verhoef., E. T, Richard H M Emmerink, Peter Nijkamp, and Piet Rietveld. 1996.

“Information Provision, Flat and Fine Congestion Tolling and the Efficiency of Road Usage.” *Regional Science and Urban Economics* 26 (5): 505–29.

Veron., S. R, Paruelo, J. M. and Oesterheld., M. 2006. “Assessing Desertification.” *Journal of Arid Environments* 66 (4) : 751–63.

Vigaud, N, Pohl, B and Crétat, J. 2012. “Tropical-Temperate Interactions over Southern Africa Simulated by a Regional Climate Model.” *Climate Dynamics* 39 (12). Springer: 2895–2916.

Wackernagel, M., Schulz, N.B., Deumling, D., Linares, A.C., Jenkins, M., Kapos, V., Monfreda, C., Loh, J., Myers, N., Norgaard, R. and Randers, J., 2002.. “Tracking the Ecological Overshoot of the Human Economy.” *Proceedings of the National Academy of Sciences* 99 (14): 9266–71.

Wakeling, J. L., Staver, A.C. and Bond.W.J. 2011. “Simply the Best: The Transition of Savanna Saplings to Trees.” *Oikos* 120 (10): 1448–51.

Walker, D.H., and Sinclair, F.L. 1998. “Acquiring Qualitative Knowledge about Complex Agroecosystems. Part 2: Formal Representation.” *Agricultural Systems* 56 (3). Elsevier Masson: 365–86.

Walker, J. and Peet, R.K. 1984. “Composition and Species Diversity of Pine-Wiregrass Savannas of the Green Swamp, North Carolina.” *Vegetatio* 55 (3): 163–79.

Walker, R. 2012. “The Scale of Forest Transition: Amazonia and the Atlantic Forests of Brazil.” *Applied Geography* 32 (1) : 12–20.

Walshe, M. J., Grindle, J., Nell, A. and Bachmann, M. 1991. *Dairy Development in Sub-Saharan Africa: A Study of Issues and Options*. Vol. 23. World Bank.

Waters-Bayer, A, and Taylor-Powell., E. 1986. “Settlement and Land Use by Fulani Pastoralists in Case Study Areas.” ILCA.

Waters-Bayer, A. 1986. “Modernizing Milk Production in Nigeria: Who Benefits?” *Ceres. FAO Review on Agriculture and Development (FAO)*.

Werner, P. A. 2012."Growth of juvenile and sapling trees differs with both fire season and understorey types: trade-offs and transitions out of the fire trap in an Australian savanna". *Austral Ecol* 37:644–657

Wezel, A. 2006. “Variation of Soil and Site Parameters on Extensively and Intensively Grazed Hillslopes in Semiarid Cuba.” *Geoderma* 134 (1): 152–59.

Wezel, A, and Lykke.A.M. 2006. “Woody Vegetation Change in Sahelian West Africa: Evidence from Local Knowledge.” *Environment, Development and Sustainability* 8 (4). Springer: 553–67.

Wezel, A. 2004. “Local Knowledge of Vegetation Changes in Sahelian Africa-Implications for Local Resource Management.” *The Sahel (eds. Lykke AM, Due MK, Kristensen M. & Nielsen I.),* 37–52.

White, F. 1983. “The Vegetation of Africa. A Descriptive Memoir to Accompany the Unesco/AETFAT/UNSO Vegetation Map of Africa.” *Clinical and Experimental Allergy* : 75: 356.

Whitney, G.G. and DeCant, J.P., 2001. Government land office surveys and other early land surveys. "*The Historical Ecology Handbook, a Restorationist’s Guide to Reference Ecosystems". Island Press, Washington, DC*:147-172.

Whittaker, R. H. 1972. “Evolution and Measurement of Species Diversity.” *Taxon* : 213–51.

Wiggins, J. S. 1996. *The Five-Factor Model of Personality: Theoretical Perspectives*. Guilford Press.

Wiggins, S. 1995. “Change in African Farming Systems between the mid-1970s and the mid-1980s.” *Journal of International Development* 7 (6): 807–48.

Wigley, B.J., Bond, W.J. and Hoffman, M., 2010. “Thicket Expansion in a South African Savanna under Divergent Land Use: Local vs. Global Drivers?” *Global Change Biology* 16 (3): 964–76.

Williams, E. 2002. “Contrasting Convective Regimes over the Amazon: Implications for Cloud Electrification.” *Journal of Geophysical Research* 107 (D20): 8082.

Williams, S. E., Marsh, H. and Winter. J. 2002. “Spatial Scale, Species Diversity, and Habitat Structure: Small Mammals in Australian Tropical Rain Forest.” *Ecology* 83 (5): 1317–29.

Willis, K. J, and Van Andel, T.H. 2004. “Trees or No Trees? The Environments of Central and Eastern Europe during the Last Glaciation.” *Quaternary Science Reviews* 23 (23): 2369–87

Willott, S.J. 2001. “Species Accumulation Curves and the Measure of Sampling Effort.” *Journal of Applied Ecology* 38 (2): 484–86.

Wilson, H. R. 1985. “Discrimination of Contour Curvature: Data and Theory.” *JOSA A* 2 (7). Optical Society of America: 1191–99.

Wittemyer, G., Elsen, P., Bean, W.T., Burton, A.C.O. and Brashares, J.S., 2008. “Accelerated Human Population Growth at Protected Area Edges.” *Science* 321 (5885): 123–26.

Zelazowski, P., Malhi, Y., Huntingford, C., Sitch, S. and Fisher, J.B., 2011. “Changes in the Potential Distribution of Humid Tropical Forests on a Warmer Planet.” *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 369 (1934): 137–60.

Appendix 1: Summary of the report on human activitiest in Yankari by Green (1987). This report is the NCF/RES field document No 5. Based on 1985 and 1986 activities within Yankari. Track refers to game tracks within the reserve. Most of the ones mentioned in the report are situated in Afzelia tree/woodland savannah formation. KI = Kassim Ibrahim track; AB =Ahmadu Bello Road; SM = Sha'aman

S/No	Track	Period	Species	Incursion by:	Activity	Comment
1	Buri	June	Afzelia africana	Herders	lopping and chopping	Big piles of branches of Afzelia, road was blocked by them Devastation caused by herdsmen ranks those of poaching, fire and drought. Worse year of scourge of Afzelia mutilation
2	Wala Kerol	July	Afzelia africana	Herders	lopping and chopping	All trees fewer than 15cm were chopped at breast height. Old trees have died from lopping, fire and drought. High competition.
3	N. Sha'aman	Feb – Aug.	Grasses. Afzelia africana	Cattle Herders	Grazing Lopping and chopping	Main route between villages. Encountered 1000 cattle,200-300 sheep near Sha'aman hill
4	J. of Gale, TG, Randall, SM & KI	March	Afzelia africana	Herders	Attacking	No evidence of past activity. Many arrests were made Sheep also seen grazing
5	Kariyo hill	April	Afzelia africana	Herders	lopping and chopping	Piles of branches of Afzelia. Dilapidated shape of trees
6	Duguri	March	Afzelia africana	Cattle	Grazing	Track impassable due to erosion
7	Dagudi	March, June & July	Grasses	Cattle	Grazing	Tonglong gorge is used for water supply
8	Area Surrounded by loopline 4, Lipji , KIb &AB road	March	Afzelia africana	Herders, sheep, camels and asses	Lopping and cutting	6 men lopping and feeding flocks for at least 3 weeks. They also cut trees which indicated their presence. Subsequent to this was three days of patrol, but only some of their sheep were captured.

Appendix 2

Themes for focus group discussions:

1) What are the main occupations of household heads in this LC
2) Who are those involved in active herding?(sex/age)
3) Do you have migrant herders in your LC
4) Can you recall the periods; you had an influx of migrants?
5) Do you know why your community is an attraction to herder migrants?
6) How do you (as people) relate with migrant herders? Do you like/hate them/None
7) Do you have to compete for scarce resources with them? (list resources)
8) When is the competition most severe?
9) Do you think water sources are declining /increasing? Why?
10) Do you think trees (fodder) are declining /increasing? Why

What are your main challenges in your occupation(s) now?

Appendix 3

Questionnaires on Herder's experiences and perspectives of fodder species:

I am Salamatu Fada, an indigene of Gombe State but raised in Bauchi. This study is an aspect of my PhD at Bangor University, United Kingdom. We are working to understand the use of fodder trees common to this area and therefore feel your experiences are vital to this study. We have sought permission from your community leader to talk with you, but you are not under any obligation to participate in this exercise. No names will be recorded and no one will be able to trace you in any way.

Village ☐ Respondent Age ☐ Years in School ☐ Age ☐

SECTION A: GENERAL INDICATORS

Q1. What is the total size of your hearth hold? ☐

Q2. If SH, what was your household number the year you came here/NA? ☐

Q3. If SH, which year did you come here/NA? ☐

Q4. Why did you move here/NA? ☐

Q5. What is the current number of your livestock?

Livestock ID	Livestock type	Livestock number
1	Cattle	
2	Sheep	
3	Goats	

Q6. Have the number of your livestock increased/decreased/stable since then?

Livestock ID	Livestock type	Livestock status
1	Cattle	
2	Sheep	
3	Goats	

Q7.What water sources (sites) are available for your livestock during the dry season? ☐

Q8. Are these sources also used for domestic purposes and by other livestock? Yes/No

Q9. Have some water sources disappeared since the year you relocated? Yes/No

Q10. If yes, can you list them?

Q11. Are the available water sources enough to cater for your livestock and others? Yes/No

Q12. Do your livestock move somewhere else during the dry season? Yes/No

Q13. If yes, why do they move during the dry season? Can list

Q14. If yes, where do they go to?

Q15. What is their main diet during the dry season? Can list

Q16. Have their diet changed since you moved here? Yes/No

Q17. If yes, what was their diet before you moved? Can list

Q18. And, what do they feed on now? Can list

SECTION B: PLANT BASE INDICATORS

Q19.What is the local/common names of these species?

Fadi sunayen itatuwan nan da yaren ka/ke

Species ID	Species names	Answer/Response
1	Afzelia africana	
2	Balanite aegytiaca :	
3	Strychnos spinosa:	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

Q20. Can you rank these species according to category of use(s) 1 -5?

a) Medicinal b) Food c) Fodder d) Furniture e) Other

(1.Never 2. Seasonally 3.Forth nightly 4.Weekly 5.Daily)

Species ID	Species names	Answer/Response
1	Afzelia africana	
2	Balanite aegytiaca :	
3	Strychnos spinosa:	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

Q21. Which season are these species harvested?

A wane wata ne ake samun/jirbe itatuwan da dama?

Species ID	Species names	Answer/Response
1	Afzelia africana	
2	Balanite aegytiaca :	

3	Strychnos spinosa:	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

Q22. Which fodder tree is most preferred by which livestock group(s)?

a) Cattle   b) Goats   c) Sheep d) Other

Wane dabobi ne suka fi anfani da itatuwan nan?

Species ID	Species names	Answer/Response
1	Afzelia africana	
2	Balanite aegytiaca :	
3	Strychnos spinosa:	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

Q23. On a category 1 – 5, how often do you encounter these species on an average herding day?

a) Very common b) Common c) Average d) Rare e) Very rare
1) >50 2) 30 -50 3) 20 - 30 4) 10 – 20 5) <10

Species ID	Species names	Answer
1	Afzelia africana	
2	Balanite aegytiaca :	
3	Strychnos spinosa:	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

Q24. Do you think these trees have declined/increased in since you relocated here? Yes/No

Species ID	Species names	Answer
1	Afzelia africana	
2	Balanite aegytiaca :	
3	Strychnos spinosa:	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

Q25. If yes, why do you think so?

Q26. On a category 1 – 5, can you estimate the rate of decrease/increase?

a) Very high b) High c) Average d) Low e) Very Low

Species ID	Species names	Answer
1	Afzelia africana	
2	Balanite aegytiaca :	
3	Strychnos spinosa:	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

Q27. What do you think is responsible for the decline/increase in the availability of these trees?

a) Fire b) Droughts c) Harvest by herders d) Other havests e) Other

Species ID	Species names	Answer
1	Afzelia africana	
2	Balanite aegytiaca	
3	Strychnos spinosa	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

Q29. Why do you think so?

Species ID	Species names	Answer
1	Afzelia africana	
2	Balanite aegytiaca	
3	Strychnos spinosa	
4	Tamarindus indica	
5	Pericarpus erinaceus	
6	Khaya senegalensis	

SECTION B: LIVESTOCK BASED INDICATORS

Q30. Which trees provide the best fodder for milk production when eaten by your lactating cows?

Species ID	Species names	Answer
1	Afzelia africana	
2	Balanite aegytiaca :	
3	Strychnos spinosa:	
4	Tamarindus indica	
5	Pericarpus erinaceus	

6	Khaya senegalensis	

Q31. Do you think milk yields have decreased/increased since you relocated here? Decreased/increased/neither

Q32.If changed, why do you think/say so?

Q33. Have the calving rates of your cattle decreased/increased since you relocated? Decreased/increased/neither

Q34. What do you think is responsible for the changes?

Q35. At what period are your livestock healthiest?

a) Early wet season b) Late wet season c) Early dry season d) Late dry season