REPUBLIQUE DE CÔTE D'IVOIRE
UNION-DISCIPLINE-TRAVAIL

MINISTÈRE DE L'EDUCATION SUPERIEURE ET DE LA RECHERCHE SCIENTIFIQUE

UNIVERSITÉ FELIX HOUPHOUET-BOIGNY

WASCAL
West African Science Service Centre on Climate Change and Adapted Land Use

Federal Ministry of Education and Research

GRP Climate Change and Biodiversity

Document number: 5

Academic year: 2015-2016

THESIS

Presented to obtain the grade of **Doctor of Philosophy** at Félix Houphouët-Boigny University

Speciality: Climate change and Biodiversity

Ecological characteristics of Elephant (*Loxodonta africana* Blumenbach, 1797) Habitat within Protected Areas Network Oti-Keran-Mandouri in Togo

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Publicly defended on 18th November 2016

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DEDICATION

To My Family:
my Mom **Akouavi Amedetonou,**
my Dad **Sankpaté Akpisso Polo,**
and my young Sister **Nassi Polo-Akpisso,**
for their love and unconditional support.

To all those who thrive in new ways and leave their steps for the new generation.

ACKNOWLEDGEMENTS

This study has been conducted with the full scholarship of the German Federal Ministry of Education and Research (BMBF) through the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) initiative. However, it would not be completed without the active contribution of many people.

I am also grateful to the Togolese Ministry Department of Environment and Forest Resources and park rangers who facilitate my access to the complex of protected areas Oti-Keran-Mandouri.

All my gratitude to the staff of the GRP Climate change and Biodiversity in Bingerville, the Headquarters of WASCAL in Accra for all the paperwork they were doing to enable the progress of my work.

I cannot imagine being able to write the whole of my dissertation in English after just three months of training. This was possible with the rigorous work of the lecturers and all the staff of the Department of English at the University of Cape Coast. I am grateful for all the effort they made for me to be proficient in English.

My gratitude to all the members of the Laboratory of Botany and Plant Ecology of the University of Lomé for their constant availability to help.

I express my gratitude to the Environmental System Research Institute (ESRI) that granted me with one of the most exciting experience of my life by funding my participation to the ESRI Users' Conference in San Diego through its branch ESRI France and provided me with a Home use license for ArcGIS Desktop.

I would like to express my gratitude to Prof. Paul Vlek, former Director of WASCAL who approved my application to the PhD research program on Climate change and Biodiversity.

Many thanks to Dr. Mamadou Ouattara, former Director of WASCAL Capacity Building Program. You acted as a father for me. I was impressed by your availability and your willingness to help whenever there is a problem.

I am also grateful to Mrs. Melissa Vlek, former Project Assistant at WASCAL. You give me your help when I needed most.

Thanks to Prof. Ramata Bakayoko-Ly, Minister of Education and Research of Côte d'Ivoire, former President of the University Felix Houphouët Boigny for her hospitality and for all the facilities especially the accommodation she granted to our batch.

I would like to express all my gratitude to Dr. Laurent Sédogo, current Executive Director of WASCAL for his support especially when I needed to travel abroad to complete part of my research work.

All my gratitude to Prof. Janet Adelegan, current Director of WASCAL Capacity Building program for her encouragement and the scholarship extension she made possible for us to complete our thesis in acceptable condition.

Thanks to Prof. Daouda Kone, Director of WASCAL Graduate Research Studies on Climate Change and Biodiversity, Director of the Centre of Excellence of Climate change, Biodiversity and Sustainable Agriculture. Your receptive attitude, your solicitude and availability save me from troubles many times. Thank you for your support, your advices and your continuous effort to make everything work for the best for all your students.

May Dr. François N'Guessan Kouamé, Vice Director and Program Coordinator of WASCAL Graduate Research Studies on Climate Change and Biodiversity, receive my gratitude for your advices and critics that guided me. Thank you for all the literature you made available to help me deepen my topic.

Prof. Yao Tano, President of the University of Nangui Abrogoua, receive my deepest gratefulness for accepting to supervise my research work. Your calm, understanding and your receptive attitude have inspired me.

I would like to express all my gratitude to my local supervisor Dr. Kpérkouma Wala, Associate Professor and Vice Director of the Cooperation office at the University of Lomé. You have been a model for me since my fourth year of study at the Faculty of Sciences. Thank you for your lead, your insightful thoughts and your guidance from the design of the study to the writing of my thesis dissertation.

I am very thankful to Dr. Ouattara Soulemane, lecturer at the Department of Animal Biology of the University Felix Houphoët Boigny and expert of large Mammal Biology. Thank you for your time, your advices and your effort to make me progress though there were lot of difficulties. Thank you for reviewing our manuscripts and this dissertation. Your rigor and love for the good work inspired me.

Please, Dr. Emmanuel Hema, receive all my gratitude for your availability and your help at the early stage of this study. Your advices and critics during the elaboration of our research proposal were very useful.

All my gratitude to all the lecturers who thought us during the coursework of our GRP in Bingerville especially Dr. Soulemane Konate, Associate Professor at the University Nangui Abrogoua and Prof. Adjima Thiombiano for their help, availability and suggestions that were of great use for me.

Thanks to Prof. Stefan Porembski, responsible of the Botanical Garden of the University of Rostock, for his interest in my study and all the advices he provided during my research activities.

All my gratefulness to Prof. Koffi Akpagana, Director of the Laboratory of Botany and Plant Ecology of the University of Lomé. Thank you for accepting me into your dynamic research team since my Master degree enabling me to develop useful skills to conduct the current research work.

Many thanks to Prof. Komlan Batawila, 1st Vice President and Director of Human Resources of the University of Lomé. You guided me in my first step into scientific research during my Master degree and since then you always involved me in your research activities. As a team manager, you always create conviviality in your work environment that always inspired me.

All my gratitude to Dr. Yao Agbéléssessi Woegan, Associate Professor, member of the Laboratory of Botany and Plant Ecology of the University of Lomé. Your advices were very useful for my research activities and in real life. Thank for your help in the identification of my plant specimen every time I come from field campaigns.

Thanks to Dr. Abalo Atato, Assistant Professor at the University of Kara for making yourself available for my fieldworks and for all your advices during this work.

I would like to express my sincere gratitude to Dr. Mamadou Coulibaly, Associate Professor at the University of Wisconsin, Oshkosh (WI, USA). Thank you for hosting me at your institution and providing me with your time and all I needed for my stay in Oshkosh and for my study at the Department of Geography and Urban Planning. Special thanks to your family who have been really friendly.

Thanks to Prof. Colin Long, Chair of the Department of Geography and Urban Planning for making all the facilities needed for my stay at your University.

All my gratitude to Prof. Kazimierz Zaniewski, Prof. Elizabeth Barron, and Dr. Angela Subulwa and to all their colleagues of the Department of Geography and Urban Planning of the University of Wisconsin-Oshkosh for the insightful discussion we had and critics I received that were very useful.

Thanks to my elders Dr. Fouséni Folega, Dr. Wouyo Atakpama, Dr. Hèou Maléki Badjana, Dr. Hodabalo Pereki, Dr. Badabate Diwediga Assistants at the University of Lomé and Mr. Kangbeni Dimobe, Ph.D. student for all their advices and help during my data collection and data analysis.

I am grateful to Mr. Limbila Nayabi, Regional Director of Environment in Région des Savanes, for all his help and assistance during field works.

Many thanks to Mrs. Melissa Casper, Mr. Breck Speers, and Dr. Paul Strait for the English editing and the moral support during my stay in Oshkosh.

All my gratitudes to Micheal Gould, Ph.D., Global Education Manager at ESRI Redlands and Mr. Stanislas Pachulski, Responsible for Education and Research at ESRI France who provided me with an extra student licence of ArcGIS to complete my work.

I am very grateful to all my colleagues in WASCAL Climate change and Biodiversity, in the Laboratory of Botany and Plant Ecology and in Laboratory of Zoology and Animal Ecology Koutchoukalo Aleza, Nassifa Tittikpina, Mariama Camara, Ceesay Adam, Patricia Leabo, Isimemem Osemwegie, Achille Hounkpevi, Emmanuel Amoah Boakye, Issiaka Issaharou Matchi, Kapoury Sanogo, Dabitora Koumantiga, Dazimwai Simza, M'Tékounm Nare, Alphonse Kouassi Yao and Cyrille Joseph Atta for the mutual support and cheerful moment we have shared.

Thanks to all my family and friends especially Emile N'Guissan, Naya N'Guissan and Nakome N'Guissan, Steve Sossah-Tado, Marc Essodomdoo Makpawo, Komlan Assimadi, Ramatou Bouari, Massama Tchaou, Djibril Hassan, Karamoko Kroman, and Nabissan Kenkou for their absolute support.

Many thanks to all the visited local communities for their hospitality.

I am really gratefull to all the members of the defence jury for their comments and suggestions that improve this document.

Above all, to God be the glory. He has strengthened me and led me in very difficult times. I am very grateful for His mercy and grace upon my life.

FOREWORD

With regard to the effects of climate change, it has been proposed that the management of protected areas has to be considered at the landscape level. According to the Convention on Biological Diversity (CBD), managing resources by taking in the whole ecosystem into consideration is a key way of ensuring ecological resilience. This is particularly important for large-bodied mammals such as the African savanna elephant that depends on large areas of suitable habitat to meet its dietary demands. Conservation planning at the landscape scale implies maintaining corridors for species. These corridors are of critical importance for maintaining the viability of isolated populations and conserving ecosystem functionality. The complex of protected areas Oti-Keran-Mandouri in Togo is considered as part of one of the most important of the 18 transboundary ranges or conservation corridors of elephant in West Africa designed as part of the conservation strategy of elephant population in West Africa. This complex because of highly diverse wetlands has been listed as Ramsar site and as International Bird Area.

Most of the studies in elephant research and conservation efforts in West Africa have mainly focused on estimating elephant densities, distribution and human elephant conflict. But there is an urgent need of scientific-based data on the dynamic and quality of habitats within elephant's current range. With the assumption that conservation planning of an umbrella species such as the elephant provides protection to many other species, there is a need for research in all the aspects of habitat dynamics, habitat integrity, habitat quality and habitat modelling in the current context of climate change. All these aspects could only be assessed by applying tools and methods from landscape ecology, remote sensing, GIS, botany and even social science.

Our study is a contribution for a better understanding of the drivers of natural habitat degradation within a key conservation area at the national scale: the complex of protected areas Oti-Keran-Mandouri. The study explored the occurrence of elephants within Oti-Keran-Mandouri. The current state of habitats was described through vegetation sampling. A model of elephant habitat suitability was performed using a multicriteria evaluation to account for the suitable habitat remaining in the area. The directions and magnitude of changes in land cover and the different landscapes processes using moderate resolution Landsat images from different missions 1987, 2000 and 2013 were assessed. The socio-ecological system including perceptions of climate change was also assessed among resident communities through a social survey. From 1987 to 2013, natural habitats regressed to the profit of croplands with wetlands being the main contributor to the increase in croplands. Three main habitat change processes leading to landscape anthropization were identified. These are attrition in forests and savannas, dissection in wetlands and creation in croplands. Two ecological gradients influencing the distribution of plant species and seven plant communities were described. There are still patches of suitable habitats but resident communities expressed no interest in the conservation of this area and suggested its release for them to increase their agricultural land. Population growth, former and current management inadequacy and climate change are the main drivers of habitat fragmentation and biodiversity loss in this region. The restauration of this complex of protected areas will be only successful if resident communities are put at the heart of the conservation system.

Though our study may be basic in the fields of conservation biology and landscape ecology, it has been performed in a geographical area where capacities in conservation biology, landscape ecology and related fields is still to be built especially on big mammals.

This study has been conducted within the framework of the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) a research initiative funded by the German Federal Ministry of Education and Research (BMBF) aiming at enhancing the information and building capacities on climate change and its impacts on ecosystems. Currently, six graduate research studies covering different fields have been launched and this study is related to the graduate research on Climate Change and Biodiversity. Outputs such as this study from WASCAL can be considered as first steps for a promising journey in research/applications in Climate Change and related impacts in West Africa that will definitively enhance the resilience of people and ecosystems in West Africa to the projected impacts of climate change and provide useful information needed for a sustainable development of countries of this part of the world.

TABLE OF CONTENTS

ABSTRACT

The complex of protected areas Oti-Keran-Mandouri (OKM) is a key biodiversity area in Togo. It is listed as Ramsar site, as International Bird Area and considered as conservation corridor for the African savanna elephant. However, its habitats are under increasing anthropogenic pressure. Therefore, social survey, remote sensing, geographic information system and vegetation sampling were combined to assess the occurrence frequency of elephant from 2010 to 2013, the potential elephant habitat, the dynamics of different land cover within this habitat from 1987 to 2013 and its vulnerability to anthropogenic pressure and climate change. Presence of elephants (one to three or four and even eleven) was reported to occur in villages surrounding OKM with some located more than 10 km away from the borders of OKM. However, the potential elephant habitat is about 30 % the current area of OKM and it is 81.81% fragmented. From 1987 to 2013, natural habitats regressed to the profit of croplands with wetlands being the main contributor. Three main habitat change processes leading to landscape anthropization were identified. These are attrition in forests and savannas, dissection in wetlands and creation in croplands. Two ecological gradients influencing the distribution of plant species and seven plant communities were identified. The analysis of the socio-ecological system revealed that some adaptive strategies to climate change like recessional agriculture are detrimental to biodiversity conservation. Moreover, resident communities expressed no interest in the conservation of this area and suggested its release for them to increase their agricultural land. Population growth, former and current management inadequacy and climate change appeared to be the main drivers of habitat fragmentation and biodiversity loss in this region. The restoration of this complex of protected areas will be only successful if resident communities are put at the heart of the conservation system.

Key words: Biodiversity, Conservation, Habitat suitability, Landscape process, Socio-ecological system.

RÉSUMÉ

Le complexe d'aires protégées Oti-Kéran-Mandouri (OKM) est un refuge de biodiversité au Togo. Il est classé comme site Ramsar. C'est une aire d'importance internationale pour les oiseaux et considérée comme un corridor de conservation pour l'éléphant de savane en Afrique de l'Ouest. Cependant, ses habitats sont sous l'emprise croissante de la pression anthropique. Aussi, l'évaluation de la présence des éléphants sur cette aire et ses environs de 2010 à 2013, l'habitat potentiel des éléphants, sa dynamique de 1987 à 2013 et sa vulnérabilité au changement climatique et aux pressions antropiques a-t-elle été faite en assossiant les enquêtes sociales, la télédétection, le système d'information géographique et les relevés de végétation. La presence d'éléphants (un à 11) a été rapportée dans les villages environnant OKM avec certains localisés à plus de 10 km des limites de OKM. Toutefois, l'habitat potentiel de l'éléphant est à 81,81% fragmenté et occupe environ 30% de l'aire actuelle de OKM. De 1987 à 2013, les habitats naturels ont regressé au profit de terres cultivées avec les terres humides etant le principal contributeur. Environ 17% des terres humides ont été converties en terres cultivées alors qu'environ 13% et 2% des savanes et des forêts respectivement ont été converties. Trois principaux processus de changement des habitats entrainant l'anthropisation ont été identifiés. Il s'agit de l'attrition au niveau des forêts et dans les savanes, la dissection au niveau des terres humides et la création au niveau des terres cultivées. Deux gradients écologiques influençant la distribution des plantes et sept communautés de plantes ont été identifiées. L'analyse du système socio-écologique a montré que certaines stratégies d'adaptation au changement climatique comme l'agriculture de contre saison, ne sont pas favorables à la conservation de la biodiversité. En plus, les communautés riveraines disent n'avoir aucun intérêt dans la conservation de cette aire et suggèrent sa liberation pour leur permettre d'augmenter la superficie de leur champ. La croissance démographique, l'inadéquate gestion et le changement climatique paraissent être les facteurs principaux de la fragementation des habitats et de la perte de la biodiversité dans cette région. La restoration effective de ce complexe ne pourra être faite qu'en plaçant les populations riveraines au centre du système de conservation.

Mots clés: Biodiversité, Conservation, Habitat potentiel, Processus paysager, système socio-économique.

LIST OF ACRONYMS

BMBF		German Federal Ministry of Education and Research
CBD	:	Convention on Biological Diversity
CCA	:	Canonical Correspondence Analysis
CMS	:	Convention on the Conservation of Migratory Species of Wild Animals
DEM	:	Digital Elevation Model
ESRI		Environmental Systems Research Institute
ETM+	:	Landsat 7 Enhanced Thematic Mapper Plus
GloVis	:	USGS Global Visualization Viewer
HEC	:	Human Elephant Conflict
IPCC	:	Intergovernmental Panel on Climate Change
IUCN	:	International Union for Conservation of Nature
LandSat	:	Land + Satellite
LCLU		Land Cover and Land Use
NDVI	:	Normalized Difference Vegetation Index
NIR	:	Near Infra-Red
NPP	:	Net Primary Productivity
OKM	:	Oti-Keran-Mandouri
OLI	:	Landsat 8 Operational Land Imager
PONASI	:	Po-Nazinga-Sisili
REDD+		Reducing emissions from deforestation and forest degradation
SRTM	:	Shuttle Radar Topography Mission
TBCL/S	:	Transboundary Conservation Landscape and/or Seascape
TBMCA	:	Transboundary Migration Conservation Area
TBPA	:	Trans-Boundary Protected Area
TM	:	Landsat 4-5 Thematic Mapper
TWINSPAN	:	Two Ways INdicator SPecies Analysis
UNEP	:	United Nations Environment Programme
UNESCO		United Nations Educational, Scientific and Cultural Organization
USGS	:	United State Geological Survey
WAP	:	W”-Arly-Pendjari

WAPOK : W”-Arly-Pendjari-Oti-Mandori-Keran

WASCAL West African Science Centre on Climate Change and Adapted Land Use

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Biodiversity as defined by **Konaté and Linsenmair (2010)** is a dynamic phenomenon connected to the evolution of life on Earth. It is constituted by the variety and variability of organisms living on the planet and their interactions. It encompasses all levels of variation of living beings, from genes to species, and communities to ecosystems **(Konaté and Linsenmair, 2010)**. Apart from its intrinsic value, the biological diversity is essential for all natural processes on which anthropogenic activities rely on. It provides services such as food, fiber and medicines for people all over the world and even has a cultural value. The ecosystems services delivered by biodiversity are essential for life on Earth. However, as human population grows there is an increasing pressure on the biological diversity. It becomes critical to conserve part of this natural asset to maintain the ecosystem services in the nature and for the use of human being.

The formal conservation of natural resources started by the creation of natural reserves. These are portions of territory with valuable terrestrial or aquatic ecosystems put under protection with law enforcement. They are also called protected areas and they have been distinguished in different categories according to their goals **(Dudley, 2008)**. So far, protected areas become the main tool for biodiversity conservation around the world. There are more than 100 000 protected areas worldwide covering about 12% of the Earth's surface **(CBD, 2008)**. In developing countries, especially in Africa, the formal conservation started during the period of colonization. However, before the colonial period there were sacred groves which were a form of indigenous natural reserves established on the basis of traditional rules **(Kokou and Sokpon, 2006)**. Many of these sacred groves were enlarged during the colonial period to constitute the current national network of protected areas in many African countries. Unfortunately, many of these protected areas failed to conserve effectively species and their natural habitat leading to species extinction or extirpation from many areas. For instance there have been a continent-wide halving in the abundance of large mammals in African protected areas since the 1970s **(Craigie *et al.*, 2010)**. The overarching causes of the decrease are thought to be over-hunting and habitat conversion, both driven by rapid growth in human population and resource consumption **(Baillie *et al.*, 2004)**. In some others areas, the failure was caused by the negative impact of fortress conservation on residents who took revenge by degrading the conserved resources inside protected areas **(Tchamié, 1994)**. Aside of the negative impact of fortress conservation there are others complex causes of the failure of biodiversity conservation in protected areas among which the condition of their creation and management **(Muhumuza and Balkwill, 2013)**. Nevertheless, protected areas are expected to play an important role in the adaptation of local communities to the projected impacts of climate change. Protected areas can serve to both mitigate and help adapt to climate change **(Dudley *et al.*, 2010)**.

Mitigation is achieved by storing carbon in natural vegetation and adaptation is achieved through the provision of environmental goods and services to residents.

With regard to the effects of climate change, it has been proposed that the management of protected areas has to be considered at the landscape level including planning for dynamics in concert with the surrounding matrix and other protected areas **(Lovejoy and Hannah, 2005)**. Managing resources by taking in the whole ecosystem into consideration is a key way of ensuring ecological resilience **(CBD, 2008)**. While isolated protected areas are vulnerable to habitat change which may disrupt connectivity and increase extinction risk, the African protected area network has the potential to act as a set of functionally interconnected patches that conserve meta-populations of mammal species **(Wegmann *et al.*, 2014)**. Particularly, large-bodied mammals depend on large areas of suitable habitat to meet their dietary demands. Conservation planning at the landscape scale implies maintaining corridors for species. These corridors could reverse the consequences of habitat fragmentation. They are of critical importance for maintaining the viability of isolated populations and conserving ecosystem functionality **(Beier and Noss, 1998)**. For wildlife, corridors are important for balancing conservation and human development needs in increasingly modified landscapes **(Kikoti *et al.*, 2010)**. For instance in West Africa, the twentieth century witnessed a decline of 90% of elephant *(Loxodonta africana*, Blumenbach, 1797*)* range **(Roth and Douglas-Hamilton, 1991)**. The historical range of the African elephant is converted into small patches of habitat. Therefore, the West African strategy to conserve African elephant designed several transboundary protected areas and conservation corridors to enable the conservation and the seasonal migration of groups of elephant population **(Sebogo and Barnes, 2003)**.

There are 18 transboundary ranges or conservation corridors of elephant in West Africa and the most important one is the complex of protected areas in eastern Burkina Faso, including W National Park in Niger and Benin, and the protected areas of northern Togo **(Sebogo and Barnes, 2003)**. This site comprises several adjacent protected areas, including the tripartite W Park, the Pendjari Park, and Arly Park, the wildlife reserve of Oti-Mandouri and Keran National Park. The two latter constitute the complex Oti-Keran-Mandouri (OKM) in Togo. At a wider range, OKM can be considered as a link between PONASI and WAP including many protected areas (Po, Nazinga, Sissili and W, Arly, Pendjari) that constitutes the most vast and important eco-geographical region for the African elephant migration in West Africa **(Bouché *et al.*, 2011)**. While reducing human impacts (e.g. illegal killing) is critical to the persistence of elephants across this range, conserving links and establishing corridors between the largest populations and largest blocks of protected areas should be of a primary management objective particularly in West Africa where poaching is better controlled **(Bouché *et al.*, 2011)**.

The African savanna elephant is considered as a keystone and an umbrella species of the savanna ecosystem **(Hoare and Du Toit, 1999)** with the status of a vulnerable species **(Blanc, 2008)**. Before 1990, elephant population was ranged from 100 to 400 in Togo **(Douglas-Hamilton *et al.*, 1992)**. Elephants were then common and permanent in Togo and OKM was considered as their largest and continuous habitat. Unfortunately, because of the fortress conservation implemented at the creation of protected areas, natural resources within protected areas were the target of huge anthropogenic pressure from 1990. A great number of elephants were killed. The remaining extirpated to the neighboring countries **(Okoumassou *et al.*, 1998)**. Nowadays, It has been reported that they just occur occasionally within OKM and remain there just for few months **(IUCN, 2008)**. Whereas other authors reported that they used this area as a corridor to move between Burkina Faso, Ghana, and Togo **(Okoumassou *et al.*, 2004)**. Currently, the habitats in this area have been degraded due to continuous anthropogenic pressure **(Dimobe *et al.*, 2012; Dimobe *et al.*, 2014; Folega *et al.*, 2012a)**. However, OKM is still listed in the top ten priority protected areas currently under rehabilitation process in Togo **(Posner, 2008)**. Therefore, there is a need of scientific-based data on the dynamic and the current characteristics of habitats in this area. Furthermore, the investigation of the socio-ecological system in this area can give better understanding of the threats to biodiversity and insights for its sustainable management.

Most of the studies in elephant research and conservation efforts in West Africa have mainly focused on estimating elephant densities, distribution and human elephant conflict **(Roth and Douglas-Hamilton, 1991; Okoumassou *et al.*, 1998; Barnes, 2001; Blake *et al.*, 2003; Boafo *et al.*, 2009; Hema *et al.*, 2010; Ouattara *et al.*, 2010; Bouché, 2012; Danquah and Oppong, 2013; Hema *et al.*, 2013; Vermeulen *et al.*, 2013)**. Some studies assessed the ecology of the species and the interactions between elephant and some plant species in its habitat **(Tehou and Sinsin, 2000; Danquah and Oppong, 2007; Tehou *et al.*, 2012; Kassa *et al.*, 2013; Salako *et al.*, 2015)**. These studies have been proven to be useful to monitor elephant population trends but they rose the problem of the management of elephant habitat. Since the habitat of the elephant in West Africa is currently converted into fragmented patches, most populations are now completely isolated genetically **(Barnes, 1999)**. There is a need for the design of corridor as suggested by the Action Plan for Elephant conservation in West Africa **(Sebogo and Barnes, 2003)**. But the first action to take is to gain better understanding of the habitat condition in the potential or designated corridors. However, there are few studies focusing on the integrity of the habitat in such corridors allowing them to be effective. In theory, the conservation of an umbrella species provides protection to many other targets **(Craighead and Convis, 2013)**.

Apart from being part of the historical range of the savanna elephant and one of the priority corridor to be established, Oti-Keran-Mandouri is also listed as Ramsar site and as Important Bird Area (IBA001 and IBA002) **(Cheke, 2001)**. Therefore, this study aims at improving biodiversity conservation in Togo by providing data on the characteristics of OKM's habitats taking elephant as the focal species. Data on OKM's habitats are important for a sustainable management of this area in the current context of a changing climate. The specific objectives of this study are:

1. assess the occurrence frequency of elephant within Oti-Keran-Mandouri from 2010 to 2013;
2. analyze the habitats of elephants within Oti-Keran-Mandouri;
3. assess the dynamics of habitats from 1987 to 2013;
4. assess the vulnerability of the habitats to climate induced anthropogenic pressure.

Here are the hypotheses of each of these specific objectives:

- there is occurrence of elephants within Oti-Keran-Mandouri regardless of anthropogenic activities;
- habitats for elephant exist within Oti-Keran-Mandouri;
- habitats are reduced in area within Oti-Keran-Mandouri;
- anthropogenic pressure accentuated by climate change impacts stresses habitat vulnerability.

This dissertation is subdivided in four parts that are:

- overview: where background information on climate change and conservation planning are debated;
- materials and methods: where the study area and the methods used during this study are described;
- results: where the results are presented;
- discussion: where each result is discussed.

A conclusion pulling out the main findings and recommendations and perspectives are given at the end.

I. OVERVIEW: BIOLOGICAL DIVERSITY CONSERVATION IN THE MIDST OF GLOBAL CHANGING

1.1. Climate change and its impacts on biodiversity

The atmospheric concentrations of greenhouse gases mostly carbon dioxide (CO2), methane, nitrous oxide, chlorofluorocarbon have increased since the pre-industrial era due to human activities, primarily the combustion of fossil fuels and land-use and land-cover change. For instance, having started at preindustrial levels of 280 ppm (parts per million) **(Sodhi and Ehrlich, 2010)**, current atmospheric levels are more than 400 ppm of CO2, and are still increasing. These and natural forces have contributed to changes in the Earth's climate over the 20th century: Land and ocean surface temperatures have warmed, the spatial and temporal patterns of precipitation have changed, and sea level has risen. The current levels of greenhouse gas concentration have already led to an overall rise in global temperature of 0.75 degree Celsius. In addition, because there is a lag between attaining a concentration level and the consequent trapping of heat energy, the planet is slated for an additional 0.5 degree (for a total of 1.25 degrees Celsius) even if greenhouse gas concentrations were to cease to increase immediately **(Lovejoy, 2010)**.

There is a wide recognition of the impacts of climate change on biodiversity **(Gitay *et al.*, 2002; Perrings, 2010)**. According to **Gitay *et al.* (2002)**, the warmer regional temperatures, is projected to affect the timing of reproduction in animals and plants and/or migration of animals, the length of the growing season, species distributions and population sizes, and the frequency of pest and disease outbreaks. Some coastal, high-latitude, and high-altitude ecosystems have also been affected by changes in regional climatic factors. The 4th Intergovernmental Panel on Climate Change (IPCC) Assessment Report described the evidence for these effects and concluded that the implications of the impacts are significant for the long-term stability of the natural world and for the many benefits and services that humans derive from it **(IPCC, 2007)**. Species are expected to shift their current geographical range following latitudinal and altitudinal gradients. Tropical species are shifting to higher elevations in response to warming temperatures **(Colwell *et al.*, 2008; Forero-Medina *et al.*, 2011; Freeman and Class Freeman, 2014)**.

In West Africa, local perception and climatic data are consistent for the increase of temperature across all the region while there is inter- and intra-seasonal variation in rainfall patterns **(Mertz *et al.*, 2012)**. Since natural environment is the main source of income and subsistence for population in West Africa **(Mertz *et al.*, 2001)**, this region would be therefore more impacted by climate induced change in biodiversity. Income growth depends on the extensive growth of agriculture resulting in the expansion of agricultural lands into more 'marginal' areas that are otherwise habitat for wild species **(Perrings,**

2010). Thus, the expected impacts will be large and more complex in the tropics due to the combined impacts of land use change.

1.2. Global trends in biodiversity conservation

The conservation of biodiversity is often implemented based on the values ascribed to nature. Indeed, the economic, biological or cultural values of a given species or habitat oriented most of the natural resources' conservation projects. Two main concepts had driven conservation actions so far. First, the intrinsic values of nature - the nature is conserved because of its own right to exist. For this concept human is considered as a threat to biodiversity and removed from the conservation system. Second, the ecosystem services that is a human centered concept. Considering ecosystem services, the nature is conserved according to its role in sustaining human wellbeing.

In the modern world, there seems to be a disconnection between human and the natural world. However, whether, conservation is implemented based on human needs or because of the right of natural resources to exist, biodiversity is important to humanity. According to the **Millenium-Ecosystem-Assessment (2005)**, human wellbeing is inextricably linked to biodiversity. The same report provides the scientific evidences of the contribution of biodiversity to people's livelihood in many ways by providing security, resiliency, social relations, health, and freedom of choices and actions. But, biodiversity degradation due to anthropogenic activities is so catastrophic these last decades that **Kolbert (2014)** argues that we are now in the midst of a sixth extinction, one distressingly of our own making.

The contemporary concerns about environmental degradation due to anthropogenic activities started after the Second World War with the foundation of the World Conservation Union (IUCN) in 1948. The aims of IUCN is to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable. This concern about environmental degradation was emphasized by the publication of the Silent Spring by **Carson (1962)** and the development of new scientific fields such us landscape ecology **(Troll, 1950)** and conservation biology **(Soulé and Wilcox, 1980; Soulé, 1985)**. The concerns for biological diversity was made more popular by the National Forum on BioDiversity, held in Washington, DC in September 1986 where the rapidly alteration and destruction of the environment was debated and the word biodiversity was used for the first time **(Wilson and Peter, 1988)**. In response to this growing recognition of the alarming rate of threats to ecosystems, the United Nations Environment

Programme (UNEP) convened the Ad Hoc Working Group of Experts on Biological Diversity in November 1988 to explore the need for an international convention on biological diversity. The Convention was opened for signature on June 5, 1992 at the United Nations Conference on Environment and Development (the Rio "Earth Summit").

But then, in a world of limited resources **(Wilson *et al.*, 2006)** and an uneven distribution of human population and biodiversity **(Brooks *et al.*, 2006)**, there is a choice to make on what species and where to conserve. Therefore, there was a need of conservation planning and prioritization in the framework of irreplaceability and vulnerability. While irreplaceability measures the spatial conservation options, vulnerability measures temporal conservation options **(Margules and Pressey, 2000)**.

The prioritization was applied at two main scales. First, at global scale where nine templates of global biodiversity conservation priority were identified covering from less than one-tenth to more than a third of Earth's land surface **(Brooks *et al.*, 2006)**. The most common measure of irreplaceability used is plant or bird endemism, often supported by terrestrial vertebrate endemism overall **(Mittermeier *et al.*, 1997; Stattersfield *et al.*, 1998; Myers *et al.*, 2000; Mittermeier *et al.*, 2003)**. Whereas, vulnerability is assessed based on four types of measures: environmental and spatial variables, land tenure, threatened species, and expert opinion **(Wilson *et al.*, 2005)**. Of these, environmental and spatial variables have been used most frequently in global conservation prioritization, measured as proportionate habitat loss **(Myers *et al.*, 2000; Sanderson *et al.*, 2002; Mittermeier *et al.*, 2003; Hoekstra *et al.*, 2005)**. Species-area relationships provide justification that habitat loss translates into biodiversity loss **(Pimm *et al.*, 1995)**. Though much work has been done, the remaining research priorities for global conservation prioritization concern the use of data from all other taxa such as data from the megadiverse invertebrate, the incorporation of freshwater and marine biodiversity, the evolutionary history and process of species, the intersection with human values and finally the incorporation of conservation cost **(Sodhi and Ehrlich, 2010)**.

Second, at local scale, prioritization is considered at three levels of ecological organization: species, sites and sea/landscapes. Planning at much finer scales is necessary to allow conservation implementation **(Brooks *et al.*, 2006)**. The IUCN Red List is used in the assessment of vulnerability at the species level, specifically in estimation of extinction risk. Phylogenetic, rather than geographic, space provided the dimension over which irreplaceability is measured. This concept is referred to as "phylogenetic irreplaceability" and lead to the creation of the 'edge of existence' (EDGE) prioritisation scheme **(Isaac *et al.*, 2007)**. This prioritisation scheme identifies species that are both isolated on the tree of life and at imminent risk of extinction as defined by the World Conservation Union (IUCN) **(Redding and Mooers, 2015)**. Habitat destruction is the overwhelming driver, threatening 90% of threatened species **(Baillie *et al.*, 2004)**. The logical implication of this is that the cornerstone of conservation action must be conserving the habitats in which these species live by establishing protected areas **(Bruner *et al.*, 2001)**. According to **Brooks *et al.* (2006)** sites' vulnerability criterion is derived directly from the IUCN Red List, through the identification of sites regularly holding threshold populations of one or more threatened species. The irreplaceability criterion is based on regular occurrence at a site of a significant proportion of the global population of a species. This is divided into sub-criteria to recognize the various situations under which this could occur, namely for restricted range species, species with clumped distributions, congregatory populations (species that concentrate during a portion of their life cycle), source populations, and biome-restricted assemblages. This is because site vulnerability interacts with irreplaceability: where irreplaceability is high, the most threatened sites are priorities, while where irreplaceability is lower, the least vulnerable sites should be prioritized. This is particularly important in considering resilience (i.e. low vulnerability) of sites in the face of climate change. However, the recent growth of the field of landscape ecology **(Turner, 2005)** sounds a warning that while species and site planning are essential for effective biodiversity conservation, they are not sufficient. Effective management requires a large scale view of systems. The first recommendations of how conservation planning might address persistence at landscape scales were generic design criteria for the connectivity of protected areas **(Diamond, 1975)**. Conservation agencies were quick to pick up the concept, and over the last twenty years a number of large scale conservation corridors have been designed **(Sebogo and Barnes, 2003; Crooks and Sanjayan, 2006)**, for example, the "Yellowstone to Yukon" **(Raimer and Ford, 2005)**, Mesoamerican Biological Corridor **(Kaiser, 2001)**, and the conservation corridor of elephant in West, Central and in South Africa **(Parren and Sam, 2003; Van Aarde *et al.*, 2006; GEF, 2010)**. There is no doubt that the implementation of corridors benefits biodiversity **(Tewksbury *et al.*, 2002)**.

Recent work has demonstrated that changes in the nature and intensity of threats over time have important consequences for the prioritization of conservation actions among sites **(Turner and Wilcove, 2006)**. Such dynamism introduces particular complications when considered at the landscape scale, the implications of which are only just beginning to be addressed **(Pressey *et al.*, 2007)**. Climate change is one such threat that will very likely require extensive landscape scale response **(Hannah *et al.*, 2002; Lovejoy and Hannah, 2005)**. The largest open research challenge for sea/landscape conservation planning is to move from maintaining current biodiversity towards restoring biodiversity that has already been lost **(Hobbs and Norton, 1996)**. However, restoration is much more expensive and much less likely to succeed than is preservation of biodiversity before impacts occur, and so explicit planning towards the specific biodiversity targeted to be restored is essential **(Miller and Hobbs, 2007)**. Current explosive growth in markets for carbon as mechanisms for climate change mitigation will likely make the restoration of forest landscapes increasingly viable in the near future **(Laurance, 2008)**. Ultimately, planning should move from simple restoration to designing landscapes that allow the sustainability of both biodiversity and human land uses, envisioned as "countryside biogeography" **(Daily *et al.*, 2001)** or "reconciliation ecology" **(Rosenzweig, 2003)**.

1.3. Habitat conservation in a changing world

Habitats are the foundation of natural resource management and conservation **(Van Horne and Wiens, 2015)**. The term habitat is very common in ecology and in general it refers to a place where an organism lives at a given time. Nevertheless, habitat remains a complex concept with confusing meaning. In general, it is accepted that habitat is an area with a combination of resources (e.g. food, cover, water) and environmental conditions (temperature, precipitation, presence or absence of predators and competitors) that promotes coccupancy by individuals of a given species (or population) and allows those individuals to survive and reproduce **(Morrison *et al.*, 2006)**. As defined, habitat is recognized as a species specific. Therefore, the ability of a habitat to provide conditions appropriate for individual and population persistence, based on the provision of resources for survival, reproduction, and population persistence determines the habitat quality **(Morrison, 2009)**. At the most fundamental root, habitat is a binary determination: an area, and its associated conditions, either is or is not habitat **(Mathewson and Morrison, 2015)**. In this sense, a phrase such as "unsuitable habitat" has no meaning **(Hall *et al.*, 1997; Garshelis, 2000)**. However, subtle impacts by human activities transform habitat to become a continuum from high quality to low quality. Thus habitat suitability should often be viewed along a continuum of quality rather than a paradigm that categorizes areas as inhabitable versus uninhabitable **(Francis, 2015)**.

Increasing human pressure on natural resources leads to habitat loss and habitat fragmentation. In general, habitat loss has strong negative effects on biodiversity, whereas the influence of habitat fragmentation appears to be much weaker and may range from negative to positive. Habitat loss refers to the reduction in the overall area of a particular land cover type **(Francis, 2015)**. Meanwhile habitat fragmentation is described as a disruption of the linkages among patches that exchange ecologically important resources **(Karr, 1994)**. Ultimately, what separates habitat fragmentation from simple habitat loss is the disproportionate reduction in numerical capacity of the remaining habitat of the same net area **(Smallwood, 2015)**. The principal countermeasure to habitat fragmentation is maintaining and improving habitat connectivity. Natural or constructed corridors have often been promoted to mitigate the effects of habitat fragmentation by maintaining or improving animal movement and gene flow between habitat patches **(Smallwood, 2015)**.

Beier and Noss (1998) defined corridor as linear habitat connecting habitat patches of the same type and separated by a dissimilar matrix. **Gilbert-Norton *et al.* (2010)** distinguished between natural and constructed corridors. **Simberloff and Cox (1987)** characterized conservation corridors as constructed corridors intended to connect habitat reserves to facilitate immigration and genetic exchange. Another two types of corridor were defined by **Forman and Godron (1981)**. These are strip corridor: a protected strip of landscape that is wide enough to include interior conditions typical of the interior conditions of habitat patches being connected by the strip, and line corridor: a protected strip of landscape that is too narrow to include interior conditions typical of the interior conditions of habitat patches being connected by the strip but instead includes edge conditions that are typical of the edge conditions of the connected habitat patches. Long term fragmentation experiment indicates that habitat fragmentation reduces biodiversity by 13 to 75% and impairs key ecosystem functions by decreasing biomass and altering nutrient cycles **(Haddad *et al.*, 2015)**. The same experimentes advocate for an urgent need for conservation and restoration measures to improve landscape connectivity, which will reduce extinction rates and help maintain ecosystem services. However, habitat management for conservation is often restricted to areas designated for biodiversity protection such as reserves or protected areas with the primary goal to manage species (endangered) or communities **(Van Horne and Wiens, 2015)**.

1.4. Transboundary conservation areas

The global biodiversity is not confined in political boundaries. Therefore, transboundary conservation has emerged as a practical way to encourage cooperative working across international boundaries so as to achieve shared conservation goals **(Vasilijević *et al.*, 2015)**. Their importance was stressed at the 5th IUCN World Parks Congress, held in Durban, South Africa, in 2003. They are considered as more socially-oriented approach to protected areas, with more emphasis on local communities, indigenous peoples, sustainable development, the establishment of partnerships, and related management and governance issues.

Though the conservation of nature has been the primary purpose, transboundary conservation initiatives were established with many other purposes. These are the commemoration of peace, striving to establish peaceful relationships, ensuring political stability, encouraging economic development and facilitating socio-cultural integration **(Vasilijević *et al.*, 2015)** and they fit well in the current conservation paradigm of ‘’people and nature’’ as defined by **Mace (2014)** as well as an adaptation to climate change impacts on biodiversity **(Hannah, 2010)**. The first transboundary protected areas were established in Europe, Central Africa and North America: the Krakow Protocol between Poland and Czechoslovakia in 1924, Albert National Park in 1925 to protect mountain gorilla populations on the boundary between the colonies of Ruanda-Urundi and the Congo and the Glacier-Waterton International Peace Park on the Canadian-US border in 1932 **(Rüster and Simma, 1975; van der Linde *et al.*, 2001; Schoon, 2015)**. Transboundary conservation initiatives have grown steadily. There were about 70 border parks recorded in 1990 but this number reached 169 in 2001 and 227 in 2007 **(Thorsell and Harrison, 1990; Sandwith *et al.*, 2001; Lysenko *et al.*, 2007)**.

According to **Vasilijević *et al.* (2015)**, there are three types of transboundary conservation areas. These are Transboundary Protected Area (TBPA), Transboundary Conservation Landscape and/or Seascape (TBCL/S), and Transboundary Migration Conservation Area (TBMCA). Park of Peace is a special designation that could be applied to any of the three types. It is dedicated to the promotion, celebration and/or commemoration of peace and cooperation.

1.4.1. Transboundary protected area (TBPA)

A Transboundary Protected Area is a clearly defined geographical space that includes protected areas that are ecologically connected across one or more international boundaries and involves some form of cooperation. The constituent parts of a TBPA could be two or more contiguous as well as a cluster of protected areas located in two or more countries. The latter could be separated by areas that are not protected.

1.4.2. Transboundary conservation landscape and/or seascape (TBCL/S)

A Transboundary Conservation Landscape and/or Seascape is an ecologically connected area that includes both protected areas and multiple resource use areas across one or more international boundaries and involves some form of cooperation. TBCL/S includes protected areas, but also other areas which support conservation objectives through sustainable management which is compatible with the objectives of the protected areas and helps to integrate them into broader landscapes/seascapes. A TBCL/S could take one of the following forms:

- two or more contiguous protected areas across international boundary and including adjoining intervening land;
- a cluster of protected areas in two or more countries and the intervening land;
- a protected area in one country alongside a proposed protected area in a neighbouring country;
- a protected area in one country alongside an area with sympathetic land use over the border.

The ‘W’ Regional Park of Benin, Burkina Faso, and Niger and the Greater Virunga Landscape are examples of Transboundary Conservation Landscape.

1.4.3. Transboundary migration conservation area (TBMCA)

Transboundary Migration Conservation Areas are wildlife habitats in two or more countries that are necessary to sustain populations of migratory species and involve some form of cooperation. It is essential for a TBMCA to meet the necessary ecological requirements for a migratory species, the importance of key habitat areas, and the protection of intermediate stop-over habitats for migratory species. TBMCAs may include protected areas, but they are not essential, as long as there is effective cooperation in the conservation of migratory species or their associated habitats. TBMCAs are corridors that could be continuous linear corridor made up of a narrow forest strip or of a river with its riverside habitat; landscape corridors consisting of a mosaic of interlinked landscapes; and corridors made up of stepping stones representing small patches of habitats that enable species to move.

1.5. African elephant and its vulnerability to climate change

The African elephant (*Loxodonta africana* Blemenbach, 1797) and the Asian elephant (*Elephas maximus* Linnaeus, 1758) are the only elephant species remaining from a formerly diverse evolutionary radiation. They are from the family of Elephantidae and the order of Proboscidea. The African elephant is believed to be the more primitive of the two surviving elephant species. African elephant is divided into two subspecies: *Loxodonta africana cyclotis* Matschie, 1900 (forest elephant) and *Loxodonta africana africana* (savanna elephant). Recent study by **Rohland *et al.* (2010)** found that the African savanna elephant (*Loxodonta africana* Blemenbach, 1797) and the African forest elephant (*Loxodonta cyclotis*, Matschie 1900) should be classified as two distinct species. However, the African Elephant Specialist Group believes that more extensive research is required to support the proposed re-classification **(Blanc, 2008)**. Therefore, individuals of elephant in Africa are considered to be from the same species. The African savanna elephant is the largest living terrestrial mammal. An individual elephant weighs 3 to 7 t and measures 2 to 4 m in height **(Ouattara, 2010)**.

The threat of climate change has become an overwhelming concern in the field of wildlife conservation **(Heinz-Center, 2012)**. However, very little has been done to understand the extent of the impacts of climate change on the African large mammal species. Detailed computer modeling studies of climate change impacts on the African elephant are lacking but an initial vulnerability assessment for this species as proposed by The Heinz Center **(Heinz-Center, 2012)** is presented here. This vulnerability assessment combined basic information about the biology of the species with information about projected climate impacts in sub-Saharan Africa. Vulnerability is defined as “the propensity or predisposition to be adversely affected” by climatic change **(IPCC, 2012)**. There are three factors that contribute to the overall vulnerability of a species to climate change: sensitivity, exposure and adaptive capacity **(Glick *et al.*, 2011)**. Sensitivity generally refers to innate characteristics of a species or system and considers tolerance to changes in such things as temperature, precipitation, fire regimes, or other key processes. Exposure, in contrast, refers to extrinsic factors, focusing on the character, magnitude, and rate of change the species or system is likely to experience. Adaptive capacity addresses the ability of a species or system to accommodate or cope with climate change impacts with minimal disruption.

1.5.1. Elements of African elephant vulnerability to climate change

- ❖ Water requirements

The African elephant is a water-dependent species, with requirements of 150 to 300 liters of water per animal per day for drinking, with additional amounts required for bathing **(Du Toit, 2002a**, **c; Garai, 2005)**. As might be expected, acquisition of water forms a significant part of the daily activity for the species, although elephants in wet areas may go for three days without drinking **(Spinage, 1994)**. Water also plays an important role in many aspects of elephant behavior, including communal watering, group or individual play, and communal traveling between water sources. Herds of elephants will walk considerable distances (30 to 50 km or more) in search of water **(Spinage, 1994; Garai, 2005)**. Elephants readily dig for water in dry riverbeds if surface water is not available **(Garai, 2005)**.

- ❖ Sensitivity to heat

Elephants are heat-sensitive animals and individual elephants are susceptible to heat stress as well as sunburn **(Garai, 2005)**. An increase in body temperature of 1° to 2°C is considered a significant fever **(Du Toit, 2002a)**. Elephants manage their body temperature through a variety of means, including physiological (heat dissipation through their ears) as well as behavioural (mud baths, water baths, spraying of water through the trunk onto the body, and seeking shade) **(Spinage, 1994; Garai, 2005)**.

- ❖ Sensitivity to drought

Drought has caused significant mortality in elephant populations in historic times, including well-studied incidents in Kenya’s Tsavo National Park from 1960 to 1961 and from 1970 to 1975 **(Spinage, 1994)**. Drought also inhibits conception in female elephants **(Spinage, 1994)**.

- ❖ Reproductive biology

Reproduction in African elephants is closely associated with seasonal climate conditions, with birth peaks coinciding with rainfall peaks **(Du Toit, 2002a)**. Drought conditions inhibit conception in female elephants **(Spinage, 1994)**. Changes to seasonal rainfall cycles could have effects on the reproductive biology of African elephants.

- Intraspecific interactions

Under drought conditions, elephants will crowd the remaining water sources, leading to intraspecific fighting which may result in injuries such as tusk breakage **(Spinage, 1994)**.

- Disease

Elephants are sensitive to a wide range of diseases, including: anthrax, trypanosomiasis, encephalo-myocarditis, salmonellosis, endotheliotropic herpes, foot-and-mouth disease and floppy trunk disease **(Du Toit, 2002a; Garai, 2005)**, many of which are exacerbated by drought or heat stress.

- Human interactions

Human-wildlife conflict poses a significant threat to conservation efforts **(Muruthi, 2005)**. Poaching, crop-raiding, water use and other conflicts with humans will increase as food and water resources are reduced due to climate change **(Heinz-Center, 2012)**.

1.5.2. Elements of African elephant resiliency to climate change

- Broad current distribution

Although the current range of the species has been substantially reduced from its maximum historic extent, the African elephant remains widely distributed throughout sub-Saharan Africa **(Kingdon, 1997)**. Across the range of the species, populations of African elephants have been exposed to considerable variation in temperature and precipitation regimes as well as elevational gradients and vegetation communities.

- High population growth rate

Populations of African elephants in southern and eastern Africa are currently growing at an annual rate of approximately 4% per year **(Blanc, 2008)**. Elephant populations in the WAP ecosystem have also grown in recent year. This is the only savanna elephant population in western or central Africa with over 2000 elephants. However, there is currently a continent wide decrease in elephant population by 4% per year from 2005-2014 and 8% per year from 2010-2014 with population growth rates slightly above zero **(Chase *et al.*, 2016)**.

- Food

Elephants will feed on a wide range of plant materials, including: grasses, forbs, aquatic plans, leaves and twigs of trees, fruit, bark, roots and pith **(Sukumar, 2003; Garai, 2005)**. Individual populations will often show preferences for particular plant species during particular seasons, but as many as 173 plant species may be consumed by a single population of elephants over the course of a year **(Sukumar, 2003)**.

- Translocation and game ranching methods developed

Southern African wildlife biologists have developed methods for the translocation and long-term maintenance of individuals and herds of African elephants in game ranch conditions **(Du Toit, 2002a)**. Herds of animals have been successfully maintained in captivity and under game ranch conditions for many years **(Du Toit, 2002a; Garai, 2005)**.

- Potential exposure

The broad distribution of the African elephant across much of sub-Saharan Africa means that the species will inevitably be exposed to a variety of changes in future climate. In general, the species will experience warmer and drier conditions than at present, except for populations in central and eastern Africa which are expected to experience wetter conditions (precipitation changes by up to +7%) **(IPCC, 2007)**.

Populations in the central plateau of South Africa are likewise expected to experience greater precipitation from convective weather systems in summer **(IPCC, 2007)**.

1.5.3. Adaptation strategies

- Provide Water

Given the importance of water to African elephant biology and behavior, ensuring the continued presence of surface water is an important climate adaptation strategy for this species. Artificial water sources (boreholes and tanks) may need to be provided in areas where surface water is no longer readily available. According to **Du Toit (2002c)**, artificial watering sources are preferred by African elephants. However, some problem elephants may damage windmills and waterholes **(Du Toit, 2002b)**. In addition, it should be noted that water provision can create artificially high densities and concentrations of elephants and this can change the ecosystem in ways that disadvantage other species **(Gaylard *et al.*, 2003)**.

- Managing other stressors

At the present time, populations of African elephants continue to decline outside southern and eastern

Africa **(Blanc, 2008)** and particularly in West Africa, largely due to poaching, habitat loss, and habitat fragmentation. Reducing the effects of these stressors will help ensure that these populations have the capacity and opportunity to adapt to the effects of climate change.

- Habitat Protection and Landscape Heterogeneity

Maintaining the opportunity for elephants to move across large landscapes offers them a better chance of adapting to a changing environment.

1.6. Elephant conservation and distribution in West Africa

West Africa region encompasses a variety of ecosystems such as Sahara Desert and associated habitats, Sudano-Sahelian grasslands and transitional woodlands, humid lowland and montane forests of the Guinea-Congolian biogeographical region, and coastal mangroves along the Gulf of Guinea. The vegetation in West Africa can be classified into four vegetation zones with two centres of endemism and two transitional zones **(Hahn-Hadjali *et al.*, 2010)**. These are from South to North the Guineo-Congolian zone (centre of endemism), the Guineo-Congolian/Sudanian zone (transition zone), the Sudanian zone (centre of endemism) and the Sahel zone (transition zone). The Upper Guinean Forest in the South is one of the eight hotspots identified in Africa from the 35 currently identified hotspots worldwide **(Conservation-International, 2014)**.

Until 1950s, African elephants were widely distributed across the Sudano Sahelian range **(Roth and Douglas-Hamilton, 1991)**. Currently, West Africa host fragmented population of both forest and savanna elephants (*Loxodonta africana cyclotis* and *Loxodonta africana africana*) **(Blanc *et al.*, 2007)**. Only 5% of the elephant continental range remains in West Africa involving thirteen (13) range states **(UNEP/CMS, 2015)**. But nearly three-quarters of the total range area is distributed among five countries, namely, Côte d'Ivoire, Mali, Ghana, Nigeria and Burkina Faso. However, cross-border movements of elephants between many countries have been reported by several studies **(Okoumassou *et al.*, 1998; Sam *et al.*, 1998; Blake *et al.*, 2003; Parren and Sam, 2003; Sebogo and Barnes, 2003; Blanc *et al.*, 2007; Bouché, 2007; UNEP/CMS, 2015)**. The largest population is that of the "WAPOK" ("W"-Arly-Pendjari-Oti-Mandori-Keran) complex, which straddles the borders between Benin, Burkina Faso, Niger and Togo **(Blanc *et al.*, 2007)**. Though higher proportion of the West African elephant range (60%) is found inside protected areas, one of the main issues affecting elephant conservation in this region as well as elsewhere in Africa is habitat loss and fragmentation **(Sebogo and Barnes, 2003; Blanc *et al.*, 2007; Slater, 2015; UNEP/CMS, 2015)**. Therefore, a regional strategy and action plans for the conservation and the management of transboundary elephant and migration corridors were developed **(Sebogo and Barnes, 2003; UNEP/CMS, 2015)**. Moreover, many countries developed their own national strategy for elephant conservation within this same framework.

According to **Blanc *et al.* (2003)**, the population of elephant with transboundary range account for more than half of the forest elephants and more than two-thirds of the savanna elephants in West Africa. Thus, the successful management of transboundary ranges would make a significant contribution to the conservation of West African elephants. Therefore, conservation corridors, spanning international boundary, were promoted. There are eighteen (18) transboundary ranges in West Africa, and the five most important ones (Figure 1) according to **Sebogo and Barnes (2003)** are:

1. the complex of protected areas in eastern Burkina Faso, including W National Park in Niger and Benin, and the protected areas of northern Togo;
2. the sahelian elephants of the Gourma which move between Mali and northern Burkina Faso, Africa's northernmost elephant population;
3. the network of protected areas in southern Burkina Faso (Nazinga Game Ranch, Parc National Kabore Tambi) that connects via riverine forest to the Sissili valley and Mole NP in northern Ghana, and also to the Red Volta ecosystem of north-eastern Ghana which extends into northwest Togo;
4. the forests of the Bia-Goaso complex in western Ghana that connect to Djimbarakrou forest reserves in eastern Cote d'Ivoire;
5. the Tai National Park and associated forests in western Côte d'Ivoire and the Grebo Forest in Liberia.

A recent study by **Bouché *et al.* (2011)** on the size and the distribution of elephant populations across West and Central Africa identified three migration corridors currently agreed both by authorities and communities. The same study proposed six top priority corridors to maintain critical links between blocks of elephant populations. Moreover, this study advocated that corridors conservation and establishment between the largest blocks of protected areas should be a primary management objective in West Africa though the feasibility of such corridors will depend on the willingness of local people to pursue consistent land use changes.

The framework of elephant conservation in West Africa presents one of the best option to adapt the network of protected areas to climate change impacts. But its effective implementation is still hampered by many problems including the lack of technical capacity, the weakness of political willingness, the lack of funds among others, and the weakness of the implication of local people.

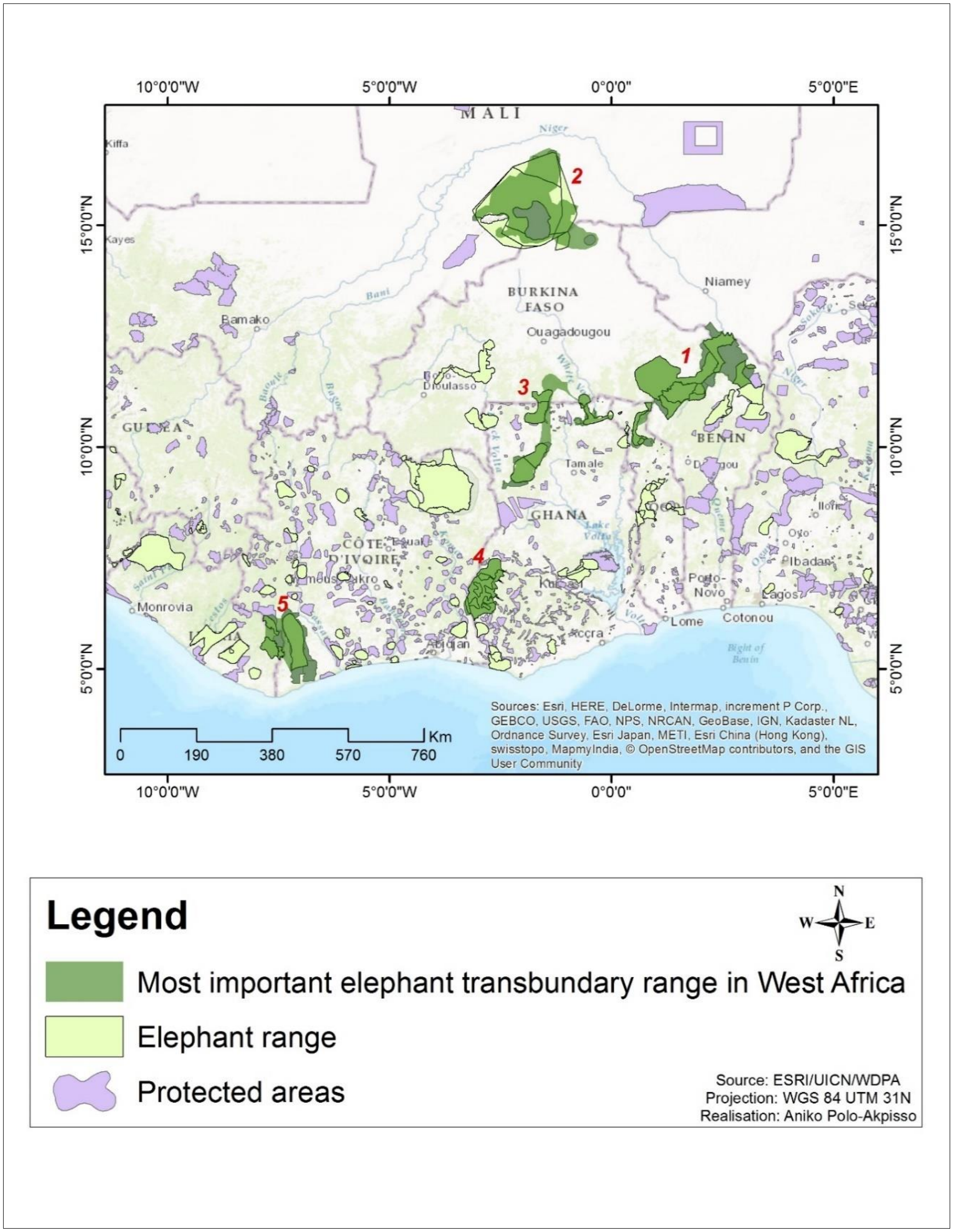

Figure 1: Five most important transfrontier elephant conservation corridor (1= WAPOK; 2= Gourma elephants; 3= Nazinga Game Ranch - Parc National Kabore Tambi - Sissili valley - Mole National Park - Red Volta ecosystem – Doung Forest; 4= Bia-Goaso complex - Djimbarakrou forest reserves; and 5= Tai National Park - Grebo Forest)

II. MATERIAL AND METHODS

2.1. Study area

2.1.1. General environmental context

Oti-Keran-Mandouri (OKM) is a complex of protected areas covering about 179 000 ha **(Adjonou, 2012)** and located in the northern flat plains of Oti River basin in northern Togo (Figure 2). This zone belongs to the eco-floristic zone I of Togo **(Ern, 1979)**. It is characterized by a tropical dry climate with a rainy season during June to October and a dry season between November and May. The total rainfall is between 800 and 1000 mm and the temperature vary between 17° and 39°C during the dry season and between 22° and 34°C during the rainy season (Figure 3).

The predominant vegetation is Sudanian savanna, with some dry forest patches and gallery forests along rivers. The large wetlands of Oti River and its tributaries present important biotopes for migrating birds and is internationally recognized as Important Bird Area **(Cheke, 2001)**. Oti-Keran National Park and Oti-Mandouri Game Reserve, which together form the complex of OKM, are representative of several key terrestrial ecosystems found in Togo (savannas, forests, wetlands…). Therefore, they were listed as Ramsar sites (Oti-Keran in 1997 and Oti-Mandouri in 2007). They are part of the most important protected areas in Togo **(IUCN, 2008)** and considered as a key component of the range of the savanna elephant in West Africa. They are designated as one of the most important conservation corridor **(Sebogo and Barnes, 2003)** and one of the first priority migration corridor to be managed for elephant population conservation in West Africa **(Bouché *et al.*, 2011)**. Unfortunately, these protected areas are under continuous anthropogenic pressure that significantly transformed their biotopes into degraded habitats.

2.1.2. Relief and geology

The study area is mainly characterized by the flood plain of Oti River. This is a basin where the many rivers individualized a series of cuirassed uplands. The city of Mango is located on top of one of these uplands.

Considering the tectonic of the region, the study area is constituted by two zones:

- the first one (south-eastern area) is part of the ‘’mobile zone’’ of the African orthogenesis. This is the Buem;
- the second zone is part of the the cratonic stable zone of West Africa. This is the socle.

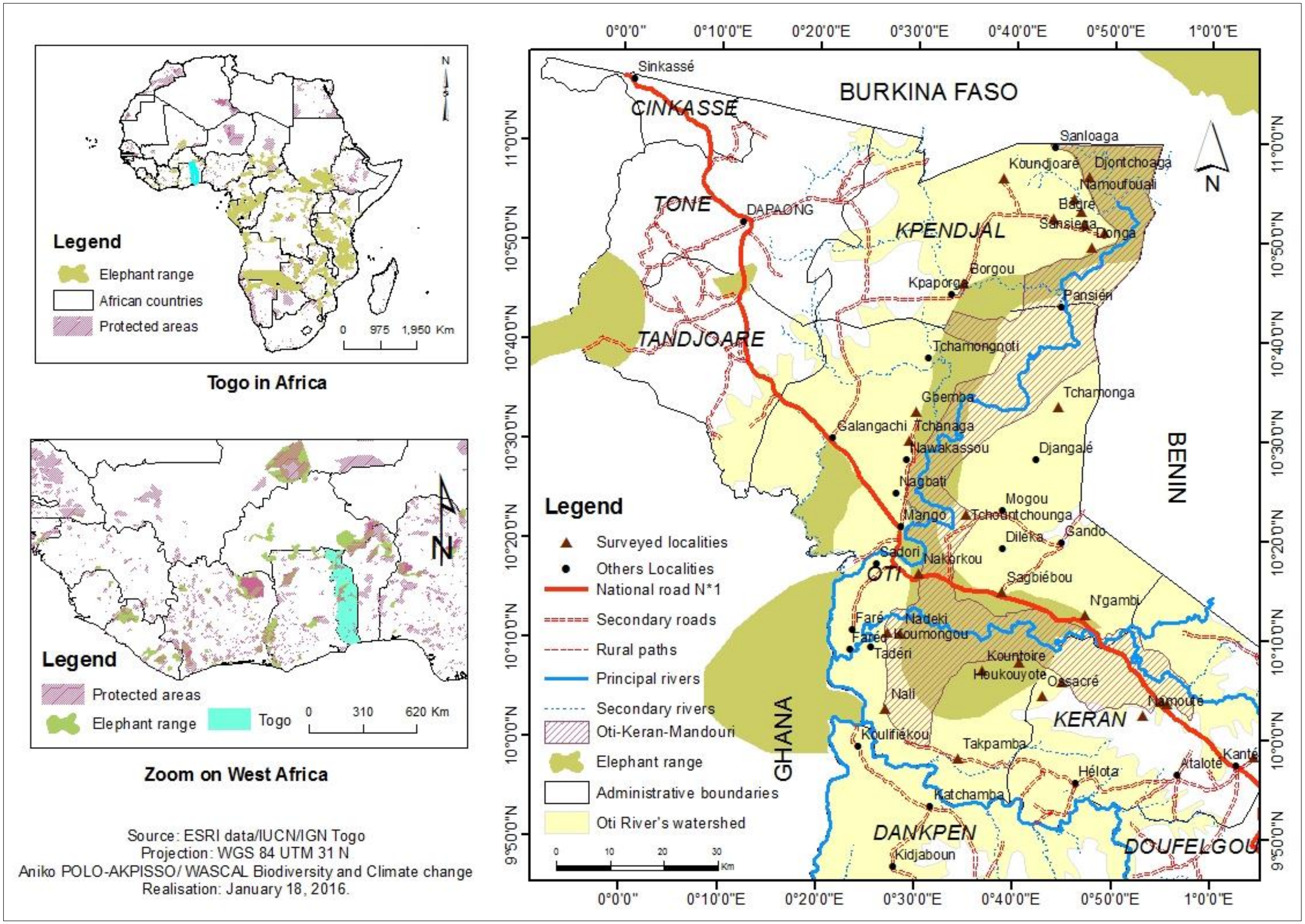

Figure 2: Map of the study area

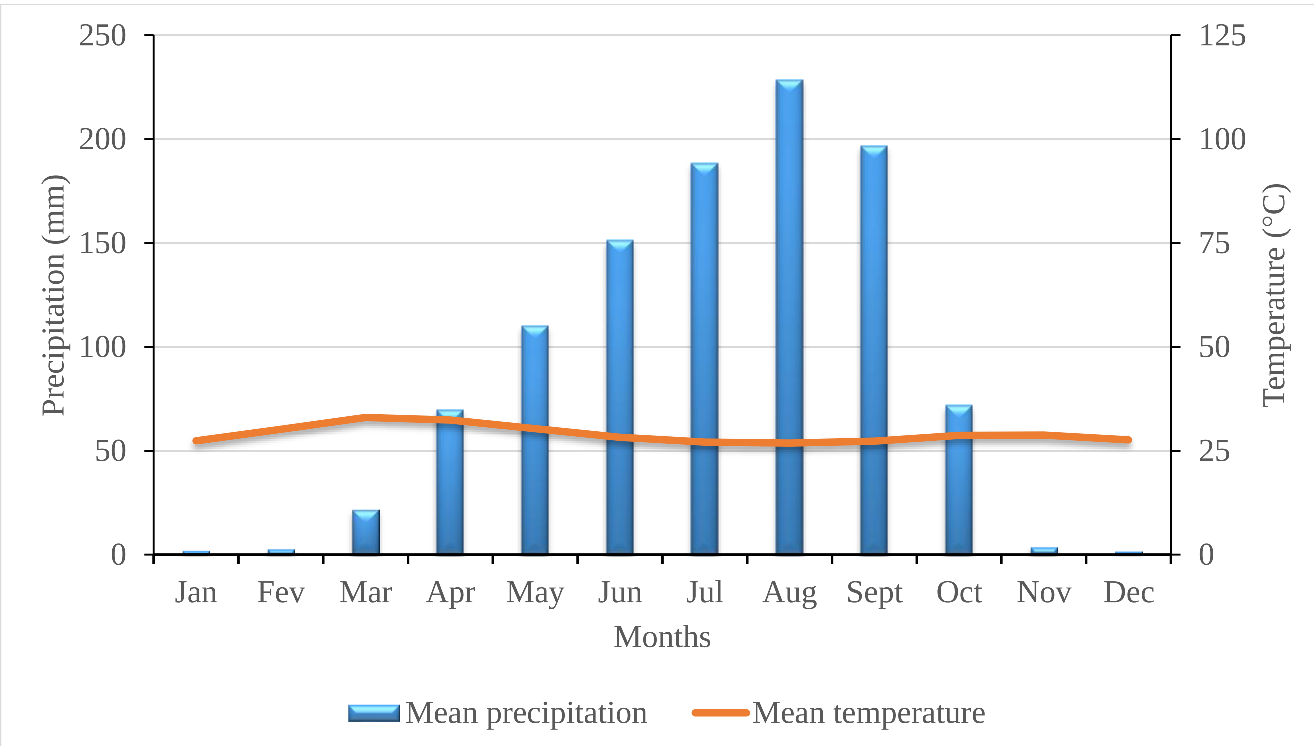

Figure 3: Mean precipitation and temperature at the meteorological station of Mango from 1981to 2013 (Data source: National Direction of Meteorology)

There are mainly three geologic formations: the superficial formations, the upper Proterozoic and the inferior Proterozoic. The superficial formations are alluvium with layered deposits more or less cuirassed for the ancient ones and beads of fine sand on the banks of important rivers. There are oxide iron endured formations composed of pisoliths locally sandy with debris of quartz. For instance, the group of Mango distributed in the plain usually at the latitude of 100 m to 200 m.

The upper Proterozoic is constituted by sedimentary formations. There are essentially the schistes of Kante and the series of Oti. The schistes of Kante cover the south-eastern area and is part of the chain of Dahomeyids. Meanwhile, the series of Oti are constituted by the sandstone of Gando and the silexite of the Triade. This series is also called the group of Pendjari. This is in discordance and directly on top of the socle.

The lower Proterozoic is the crystalline socle that is a peneplain constituted of dark granit. For instance, granit with biotite at Koundjoare.

2.1.3. Climate

The study area is under a contrasted tropical climate with an important dry season (October to may) that is hampering the development of agriculture and water supply to local population. This climate is under the influence of two wind types: a continental Alize and the equatorial maritime wind.

- The continental Alize is commonly called Harmattan blowing from November to March. This is a Saharian anticyclone, dry and cold, that carries dust from the desert. Blowing from North-East, its velocity is from 3 m/s to 7 m/s.
- The second wind blows from April to October from the Ocean to the interior of the African continent. This is the Monsoon. Its mean velocity is between 2 m/s to 6 m/s. This is an instable wind that is hot and humid.

The maximum temperatures are between 38°C and 41°C. They are recorded in March-April and the minimum ones between 18°C and 19°C are recorded between November and January. The insolation is high (7 h 30 min) and the diurnal temperature range is higher than the annual temperature range. The difference in temperature is between 10°8’ in September and 20°6’ in November at the station of Mango whereas it is very low during the rainy season and high during the dry season for the whole of the region.

The relative humidity is very variable from one station to another, from one season to another one and even during the same day. It is very low during the dry season (15%) and very high during the raining season (86%). It is lower during the hottest period of the day and higher in the night. The evaporation and the evapotranspiration are 2400 mm and 2000 mm respectively.

The precipitations start usually in April and long for five months. The highest rains are recorded in August but they diminish gradually from October toward the South. The precipitations range between 1000 mm and 1100 mm and are irregular and insufficient making water supply difficult in this area.

2.1.4. Hydrology

Oti river is the main river draining this area. It has many tributaries but the main one is Koumongou river. Oti river and Koumongou river are the only permanent rivers in this area whereas the others are dry up during the dry season.

In general, the recorded flows are null from February to May and the annual mean are less than 5 m3/s. Oti river constitute the exception with the flow higher than 100 m3/s. It can reach more than 500 m3/s. However, at lower water the minimum annual flow could reach 0.350 m3. The importance of the flows during the rainy season and their weakness during the dry season make the hydrologic regime very contrasted in this area.

2.1.5. Vegetation

The vegetation within Oti-Keran is dominated by degraded savanna on cuirassed plateau. The presence of savanna composed of *Mitragyna inermis* (Willd.) Kuntze and *Andropogon gayanus* Kunth var. *bisquamulatus* (Hochst.) Hack. indicates the influence of Keran River during raining season. There are also woodland savannas dominated by *Pterocarpus erinaceus* Poir.. Gallery forest, relatively dense and well conserved are dominated by big trees such as *Celtis integrifolia* (Lam.), *Cola laurifolia* Mast., *Diospyros mespiliformis* Hochtst. ex A.DC., *Parinari congensis* F.Didr., *Pterocarpus santalinoides* L'Hér. Ex DC., *Tamarindus indica* L.. Dry forests associated with gallery forests are among the best of the country **(IUCN, 2008)**.

The vegetation in Oti-Mandouri Game reserve is a soudanian savanna with large grasslands that are flood plains of Oti River and zones of Acacia that were very suitable to wildlife. There are tree savanna, woodland savanna and diversified gallery forest with numerous important and useful speices such as *Afzelia africana* Sm.*, Diospyros mespiliformis, Khaya senegalensis* (Desr.) A.Juss.*, Vitellaria paradoxa* C.F.Gaertn.*, Parkia biglobosa* (Jacq.) R.Br. ex Benth., *Combretum sp.* The herbaceous vegetation is composed mostly with *Andropogon gayanus* Kunth, *Hyparrhenia rufa* (Nees) Stapf, *Imperata clindrica* (L.) P.Beauv.

2.1.6. Wildlife

In 1971, with the enlargement of the game reserve of Oti and Keran National Park offered habitat to diversified mammals and birds. The main mammals encountered in this area were *Phacochoerus africanus* Cuvier 1826, *Kobus kob* Erxleben 1777, *Syncerus cafer* Sparrman 1779, *Sylvicapra grimmia* Linnaeus 1758, *Hippotragus equinus* É. Geoffroy Saint-Hilaire 1803, *Alcelaphus buselaphus major* Pallas 1766, *Kobus ellipsiprymnus defassa* Ogilbyi 1833 and *Loxodonta aficana* **(Addra *et al.*, 1990)**. Birds are well represented in this area with 214 species justifying the designation as RAMSAR site and as Important Bird Area (IBA) **(IUCN, 2008)**.

2.1.7. Historic and socio-economic context

From Keran classified forest in 1950 of 67 sq. km (Order N° 779 du 09/28/1950) enlarged in 1971 to a National Park (862 sq. km) with an integral protection (fortress management). Another enlargement (1975-1976) brought its area to 1636 sq. km. This area reached 1700 sq. km in 1982. At this same period, the game reserve of Oti was gazetted along Oti river with an area of 1878.40 sq. km. The Game reserve of Oti and Keran National Park together covered about 3578.40 sq km. These protected areas were marked by three important periods as described by **Folega *et al.* (2014c)**. The first period from colonial to 1990 is marked by strict biodiversity protection; the second period from 1990 to 2000 is marked by anarchic exploitation; and the third period from 2000 characterized by a process of consensual rehabilitation. The area of both protected areas were reduced with this process of rehabilitation. The area of Oti-Keran was reduced to 69 000 ha while the area of Oti-mandouri was set to 110 000 ha. These two protected areas are currently considered as a complex of protected area because of a possible connexion with the nearby WAP complex of protected areas composed with Parks W, Arly and Pendjari located between Niger, Benin and Burkina Faso **(Adjonou, 2012)**.

Oti-Keran-Mandouri covers 179 000 ha and lies within two administrative regions: “Savanes” and “Kara” and straddles three prefectures (Keran, Oti and Kpendjal). The prefectures it straddles are among the poorest in the regions. Keran belongs to “Kara” region whereas Oti and Kpendjal belong to “Savannes”. Keran is the 3rd poorest in “Kara” with a rate of poverty of 80.5%; Oti is also the 3rd poorest in “Savanes” with a rate of poverty of 89.3% whereas Kpendjal is the poorest prefecture in Savanes and in the whole of Togo with a rate of poverty of 96.5% **(DSRP-C, 2009)**. The main towns in the area of OKM are also the administrative centers of each Prefecture: Kante (Keran Prefecture), Mango (Oti Prefecture) and Mandouri (Kpendjal Prefecture). The population of Keran is 94 061, in Oti and Kpendjal, it is 190 543 people and 155 091 people respectively **(RGPH, 2011)**. The highest per annum population growth in Togo is found in “Savannes” region with 3.18% growth rate whereas it is 2.04% in “Kara” region. The communities living in and around Keran prefecture are mainly from the following ethnic groups: Lamba, Temberma, Ngamgam, Gnande and Mossi. In Oti prefecture there are mainly Tchokossi, Moba, Bissa, Berma and Gangan whereas Gourmantche and Moba are those living in Kpendjal prefecture.

Agriculture is the principal activity in the surrounding area and occupies around 70 to 80% of the active population in these districts **(UICN, 2009)**. The most cultivated crops are sorghum (*Sorghum bicolor* (L.) Moench.), maize (*Zea mays* L.), rice (*Oryza sativa* L.), yams (*Dioscorea* sp), and cassava (*Manihot esculenta* Crantz.). There is currently increasing interest in cash crop production that is cotton (*Gossypium hirsutum* L.). Consequently, there is a great pressure to access fertile lands. This leads to over-exploitation and degradation of soils and natural habitats even within protected areas. Land use by residents in this region is based on a traditional system of ownership by local community groups who inherit land through common ancestry.

Other rural activities in this area include collection of timber and firewood **(Adjonou *et al.*, 2009; Folega *et al.*, 2011a)**, collection of non-timber products (fruits, medicinal plants, straw), charcoal production **(Kokou *et al.*, 2009; Atato *et al.*, 2011; Folega *et al.*, 2012a)**, and also hunting and fishing **(Dimobe *et al.*, 2012)**. Transnational livestock transhumance constitutes also an important threat to biodiversity in this area. The majority of the people evicted, when the reserve was gazetted, have resettled, creating large cleared areas in the natural landscape. Efforts are on-going to create village management associations but encroachments in the protected areas has not completely stopped. New management approaches involving the local communities and new partners, important institutional, policy, legal and financial reforms and capacity building, are needed to enhance the effectiveness of the management of these protected areas.

Nonetheless, there are many important cultural sites of references within or close to the OKM complex, where nature is strongly associated with the rituals and beliefs of communities and that could form the basis for cultural and natural ecotourism development. For instance, the Koutammakou landscape which extends into neighbouring Benin, is home to the Batammariba whose remarkable mud tower-houses (Takienta) have come to be seen as a symbol of Togo. This site located in the canton of Nadoba (Keran pefecture) was listed as a UNESCO World Cultural Heritage site in 2004 due to their exceptional traditional architecture **(UNESCO, 2004)**.

2.2. Materials

2.2.1. Biological materials

This study concerns the habitat of the elephant and the socio-ecological aspects of its conservation within a complex of protected areas, Oti-Keran-Mandouri. Therefore, the biological materials to study are the vegetation as a surrogate of habitat, the African savanna elephant and resident human populations of the complex of protected areas.

The resident human populations were composed of peoples of different tribes with different dialects and cultural background.

The vegetation in the study area is mainly composed of sudanian savannas with riparian forest along rivers and patches of dry forests. This area is part of the historical range of the African savanna elephant.

The African savanna elephant also called African bush elephant was the focal species considered for this study. Direct sightings (Figure 4) and indirects ones such as dungs (Figure 5) and footprints were considered in the assessment of the distribution of the elephant. The systematic of the animal is as follows:

Kingdom	Animalia
Phylum	Chordata
Clade	Synapsida
Classe	Mammalia
Order	Probosidea
Superfamily	Elephantoidea
Family	Elephantidae
Genus	Loxodonta
Species	*Loxodonta africana* (Blumenbach, 1797)

2.2.2. Technical materials

A GPS (GPSMAP 62STC) was used to record geographic coordinates. A compass (MC2/360/D DM/IN NH) was used to look for orientation. A binocular (PERMA FOCUS.10X50MM) was needed for distant vision. A camera (Nikon D3200 Kit Reflex 24,2 Mpix Noir + Objectif AF-S DX 18-55 mm VR) was used to take pictures. In vegetation study, a decameter and a topofil were used when setting vegetation sampling plots. A hand pruner (Model BP6250 Corona) was needed for plant specimen collection. Sheets of newspapers were used to conserve and bring collected specimen that were not determined on the field to the Laboratory of Botany and Plant Ecology of the University of Lome. A tape meter was used to measure the circumference of woody plant species with dbh equal or higher than 10 cm that were recorded in sampling plots.

2.3. Data collection

The data needed for this study were collected using a multidisciplinary approach involving social science, remote sensing, botany and Geographic Information System (GIS). Different data collection methods were used. A social survey based on questionnaire was conducted to assess the socio-ecological system among residents of OKM. The magnitude and directions in land cover change and habitats change processes from 1987 to 2013 were assessed by satellite image classification and landscape change process analysis. Vegetation sampling was conducted to assess plant species richness, major ecological gradients driven plant species' distribution and plant communities in the habitats. GIS modelling specifically a multicriteria evaluation was used to assess the suitable habitat by considering the elephant as the focal species.

Figure 4: Loxodonta africana near Koumongou River within Oti-Keran-Mandouri (Photography by Koumantiga, November 2014)

Figure 5: Elephant's dung pile (Photography by Polo-Akpisso, October 2014)

2.3.1. Assessment of the occurrence of elephant from 2010 to 2013

The movement patterns of elephant from 2010 to 2013 in the three districts or prefectures straddled by OKM were assessed through a social survey. The social survey was conducted using a questionnaire in the surrounding villages. The respondents were selected following a stratified random sampling method. After a preliminary discussion with administrative authorities and park rangers, eighteen villages were selected with respect to their distance from the park borders (Figure 6).

Three categories of villages falling into the following ranges 0 – 2 km, 2 – 5 km, and 5 – 10 km were considered in each of the three prefectures straddled by the park. It was fixed to survey 100 persons in each of the three ranges. The sampling size was apportioned to the area occupied by the park in a given prefecture (15% for Keran, 64% for Oti and 21% for Kpendjal). In each selected village, the sample size was calculated according to the following formula:

$$ni = n(Ni/N)$$

Where:

- ni is the sample size in the selected village;
- n is the proportion of the sample size for a given range;
- Ni is the reported population size of the selected village from the national census data;
- N is the population size of all the selected villages within the same range.

Before starting the investigation, the aim of the study was first explained to local authorities in order to obtain their permission to release inquiries. Then, semi-structured interviews using questionnaires were done in focus groups and by randomly selecting individuals informants **(Atakpama *et al.*, 2012)**. Questions were related to the knowledge of elephant movement, the frequency of elephant migration from 2010 to 2013, the occurrence period and their preferred feeding resources. Human-elephant conflict events were also explored. Discussions with rangers provided also useful data and relevant direct observations were recorded. Geographic coordinates of prospected villages and for any direct observation were recorded using a handheld Global Positioning System receiver.

2.3.2. Assessment of the elephant habitat

Therefore, the assessment of elephant habitat was conducted by analyzing the vegetation structure according to the habitat suitability of the elephant within OKM. Field campaigns were conducted from March to December 2014. The characteristics of vegetation were recorded in sampling plot installed at some ground verification points generated for the accuracy assessment of a land cover map derived from the supervised classification of Landsat 8 image (October 2013).

2.3.2.1. Landsat image acquisition, training sites and ground verification points determination

Landsat 8 image (Path/Row: 193/53) of 30 m spatial resolution was downloaded from the United States Geological Survey via Global Visualization platform (USGS/GloVis). The image was acquired on October 29, 2013. It has 0.43 % of cloud coverage which, however, does not affect the study area.

Training sites were defined on the basis of colour infrared composition **(Lowry *et al.*, 2005)** for six land categories (Table I). These land categories were distinguished during field campaigns from 11th to 30th November 2013. This classification scheme was based on the one recommended by the Intergovernmental Panel on Climate Change (IPCC) for national greenhouse gases emission inventories in Land Use, Land use change and Forestry sector **(IPCC, 2003)**.

The binomial distribution was used to determine the appropriate sample size to obtain unbiased ground reference for a valid statistical testing of the land cover map accuracy. This is recognized as an appropriate mathematical model to use in determining an adequate sample size for accuracy assessment **(Hord and Brooner, 1976; Hay, 1979; Rosenfield and Melley, 1980; Fitzpatrick-Lins, 1981; Rosenfield, 1982)**. The formula used for the binomial distribution is:

$$N = \frac{z^2 pq}{E^2}$$

where,

N = Number of samples

p = Expected or calculated accuracy (in percentage)

q = 100-p

E = Allowable error

Z = Standard normal deviate for the 95% two-tail confidence level (1.96).

The confidence level is set in a realistic way taking into account field effort and time. Therefore, an allowable error of 5% and an overall map accuracy of between 60% and 95% are usually set **(Maingi *et al.*, 2002; McCoy, 2005)**. Here the allowable error E was set to 5% for an overall expected accuracy of 80%. The minimum sample size was then calculated and apportioned to the area of the different land cover categories (Table II). A minimum threshold of 20 sample points has been set for each land category **(van Genderen and Lock, 1977)**. However, this minimum threshold was not reached for the category water bodies because of field condition.

Ground verification points were generated in ERDAS IMAGINE by applying a stratified random sampling scheme with a window kernel of 3 X 3 pixels and on the basis of a majority rule. This results in selection of a sample point only if a clear majority threshold of six pixels out of nine in the window belonged to the same class **(Maingi *et al.*, 2002)**. The generation of sample points in this manner ensured that points were extracted from areas of relatively homogenous land cover class.

2.3.2.2.Elephant habitat suitability within OKM

A multicriteria evaluation was performed based on defined criteria considered necessary for elephant habitat. These criteria and corresponding source layers used to rate suitable habitat are listed in Table III. The source layers represent site characteristics that are factors know to determine locations that are suitable for the elephant **(Boettiger *et al.*, 2011)**.

The normalized difference vegetation index (NDVI) is the ratio of the difference between the near-infrared band (NIR) and the red band (R) and the sum of these two bands **(Rouse *et al.*, 1974)**. This parameter is given by the formula below:

$$NDVI = NIR - R/NIR + R$$

NDVI is an index related to plant photosynthetic capacity but it is used here as a proxy of the Net Primary Production of the habitat. Potential for the use of NDVI as a proxy for land productivity (one of the indicators of the state of land degradation) is based on numerous and rigorous studies that have identified a strong relationship between NDVI and NPP **(Field *et al.*, 1995; Prince and Goward, 1995; Vlek *et al.*, 2010)**. The distance to stream, road and encroachments layers were derived from Euclidean distance analysis. The slope was derived from a Digital Elevation Model SRTM 30 m distributed by the United State Geological Survey (USGS) whereas the thickness of water pounds was calculated for the water pounds located within OKM. The land cover/ land use map was derived from the supervised classification of the recent Landsat image (Landsat 8 image for October 2013).

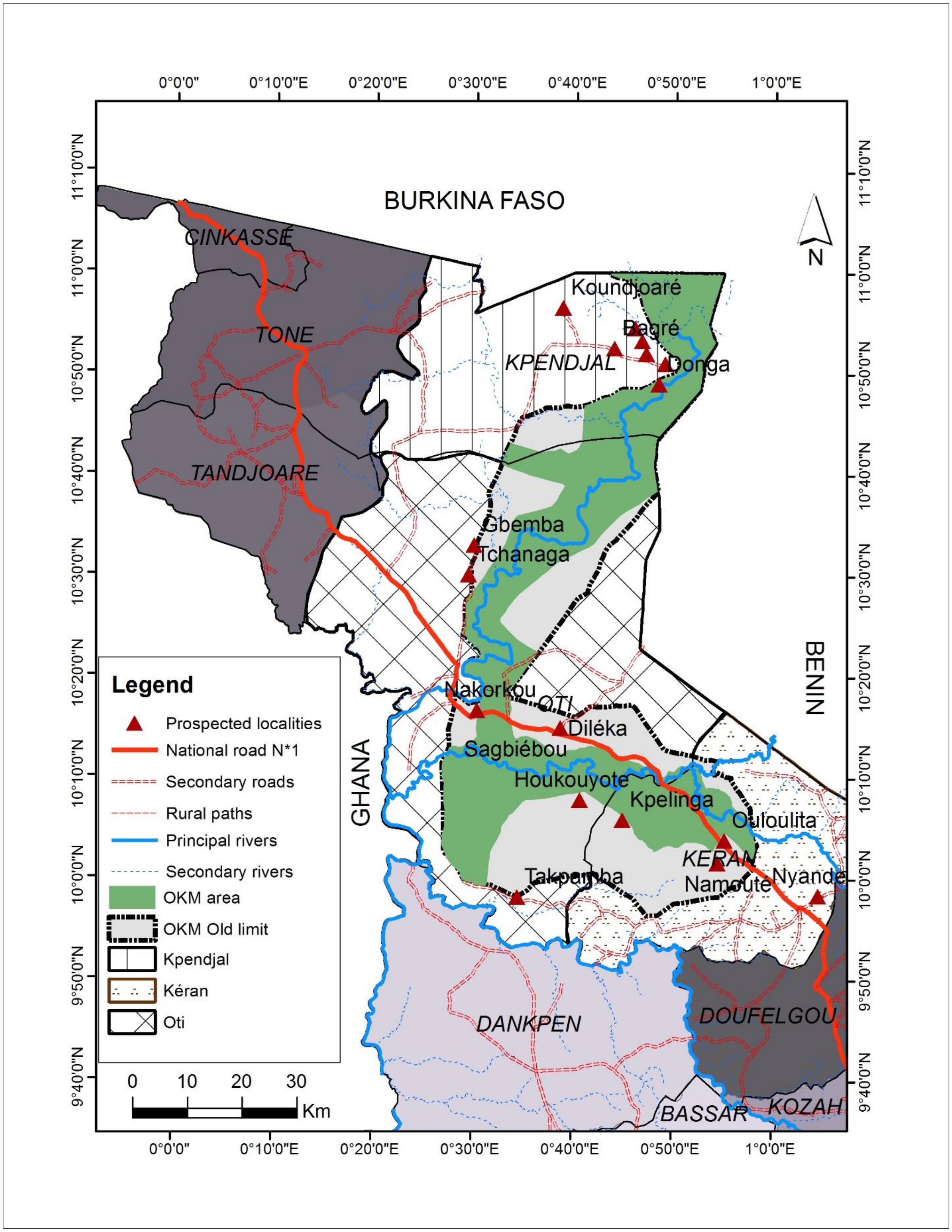

Figure 6: Localization of prospected localities

Table I: Land categories' definition

N°	Land category	Definition
1	Forest	This category includes vegetation dominated by trees above 7 m of height and with closed canopy. Shrubs or herbaceous may be present.
2	Savannah	This category includes vegetation with a continuous grass cover. Trees and shrubs may be present but scattered.
3	Wetland	Marchland or areas covered permanently or temporary by water
4	Cropland	This includes all open lands and pastures exploited to grow crops and livestock including traditional agroforestry systems and parklands
5	Settlements	This category includes transportation infrastructure, human settlements of any size, and bare soils
6	Water bodies	This category is reserved to any stretch of water including rivers and water pounds

Table II: Minimum sample size per land category for image 5 (October 2013)

Class	**Categories**	**Area (ha)**	**%Area**	**Estimated sample**	**Final sample size**
1	Forests	4038.21	2.236061	5.50071	20
2	Savannahs	33255.18	18.41425	45.29906	46
3	Wetlands	57267	31.71022	78.00713	80
4	Croplands	62858.07	34.80614	85.62309	90
5	Settlements	18454.86	10.21893	25.13857	27
6	Water bodies	4721.49	2.614411	6.431451	7
	Total	180594.8	100	246	270

2.3.2.3. Vegetation sampling

2.3.2.3.1. Floristic data

Floristic data were collected in plots of 50 m X 20 m. Herbaceous species were recorded in subplot of 10 m X 10 m at the center of the big plot **(Jürgens *et al.*, 2012)**. In a given plot, all the plant species were recorded. Each species was given a coefficient of abundance/dominance according to the phytosociological scale of Braun-Blanquet **(Braun-Blanquet, 1932)**. This coefficient goes from 1 to 5 and represent less than 5%, 5-25%, 25-50%, 50-75% and more than 75% of cover respectively.

2.3.2.3.2. Dendrometric measurements

Dendrometric measurements concerned total height and diameter of woody species with diameter at breast height equal or greater than 10 cm (DBH ≥10 cm) **(Tehou *et al.*, 2012; Dimobe *et al.*, 2014)**. Woody species with DBH<10 cm were counted in three subplots of 5 m X 5 m installed diagonally to assess plant regrowth (two at the angles and one at the center of the 50 m X 20 m plot).

2.3.2.3.3. Environmental variables

Environmental variables described canopy cover, topographic position, slope, soil type, water availability and anthropogenic footprints such as cropping, wood cutting, fire, charcoal production etc. These variables are described in Table IV.

The geographic coordinates of each sample and any relevant environmental or ecological feature were recorded using a handheld Global Positioning System receiver (GPS GARMIN GPS Map 62stc). For instance, all the sighting points of elephants or their footprints in the vegetation sampling plots were recorded. Figure 7 shows the distribution of sampling plots.

2.3.3. Assessment of habitat dynamics from 1987 to 2013

Landsat images of 30 m spatial resolution. In addition to the 2013 image, others images acquired in 1987 and 2000 were downloaded from the United States Geological Survey via Global Visualization platform

Table III: Criteria and source layers for elephant suitable habitat within Oti-Keran-Mandouri

Criteria	***Source layer***
Areas that provide food (vegetation)	NDVI
Areas near streams	Distance to streams (rivers)
Areas with low elevation	Slope
Areas with large water pounds	Thickness of water pounds
Areas far from roads	Distance to road
Areas far from encroachments	Distance to encroachments
Areas well conserved	Land use / land cover map

Table IV: Description of the recorded environmental variables

N°	**Label**	**Description**
1	VegeOpen	Vegetation openness
2	TreeC20m	Tree cover of individual with height higher than 20 m
3	TreeC720	Tree cover of individual with height between 7-20 m
4	TreeC.7m	Tree cover of individual with height less than 7 m
5	HerbC	Herbaceous cover
6	HTree	Tree height
7	Hshrub	Shrub tree height
8	Hherb	Estimated overall herbaceous plant height
9	Topograp	Topography
10	EdaphSub	Edaphic substratum
11	Submers	Submersion (presence of water)
12	Fire	Fire occurrence
13	Grazing	Pastureland or grazing activity
14	Cropping	Existence of cropland
15	Wood-cut	Wood cutting activity
16	Swab	Bark or other plant organ harvesting
17	Charcoal	Charcoal production

(USGS/GloVis). All the images are 30 m spatial resolution. These time frames were selected because they characterized three important periods in the dynamic of protected areas in Togo as described by **Folega *et al.* (2014c)**. The first period from colonial to 1990 is marked by strict biodiversity protection; the second period from 1990 to 2000 is marked by anarchic exploitation; and the third period from 2000 up-to-date, characterized by a process of consensual rehabilitation. All the dates of the downloaded images were within the beginning of the dry season to avoid cloud cover and also account for green vegetation. The images were already orthorectified and terrain corrected and have not been subjected to further radiometric corrections. Their characteristics are presented below in Table V. Even though the second image (1987) has 10% of clouds, the study area was not affected.

2.3.4. Assessment of the vulnerability of habitat patches to climate induced anthropogenic pressure

A second stage of social survey was conducted to evaluate the perceptions of climate change, the adaptive strategies elaborated by the residents of OKM. The vegetation condition and the way people value conservation and the existence of the complex of protected areas OKM were also assessed. At this stage the interviewees were restricted to stakeholders, elders and traditional dignitaries who usually take part to the decision making process at the local level. This restriction was observed because of the current litigious context between residents and administrative authorities. Participants were selected on a voluntary basis. The interviews were held using a semi-structured questionnaire in seventeen villages surrounding the protected areas.

The questions were related to how people perceive the change in precipitations, temperature, flood events and violent wind events in their locality. The adaptive strategies elaborate to cope with any noticed change were also recorded. Furthermore, the social value ascribed to OKM using a twelve points values index was assessed to have an idea on the relationship between local population and the management of natural resources in their area. The social value index used was updated from the social value types proposed by **Sherrouse and Semmens (2014)** representing the relative perceived social values of ecosystem services for stakeholders. For this purpose, the participants were asked to make a choice of values they found important to them. Each of these values is described in Table VI.

Table V: Landsat image characteristics

Image	Path	Row	Sensor	Date of acquisition	Cloud cover (%)
1	193	053	Landsat 4 Thematic Mapper	1987-10-30	0.00
2	193	052	Landsat 4 Thematic Mapper	1987-10-30	10.00
3	193	053	Landsat 7 Enhanced Thematic Mapper	2000-12-04	0.00
4	193	052	Landsat 7 Enhanced Thematic Mapper	2000-12-30	0.00
5	193	53	Landsat 8 Operational Land Imager	2013-10-29	0.43

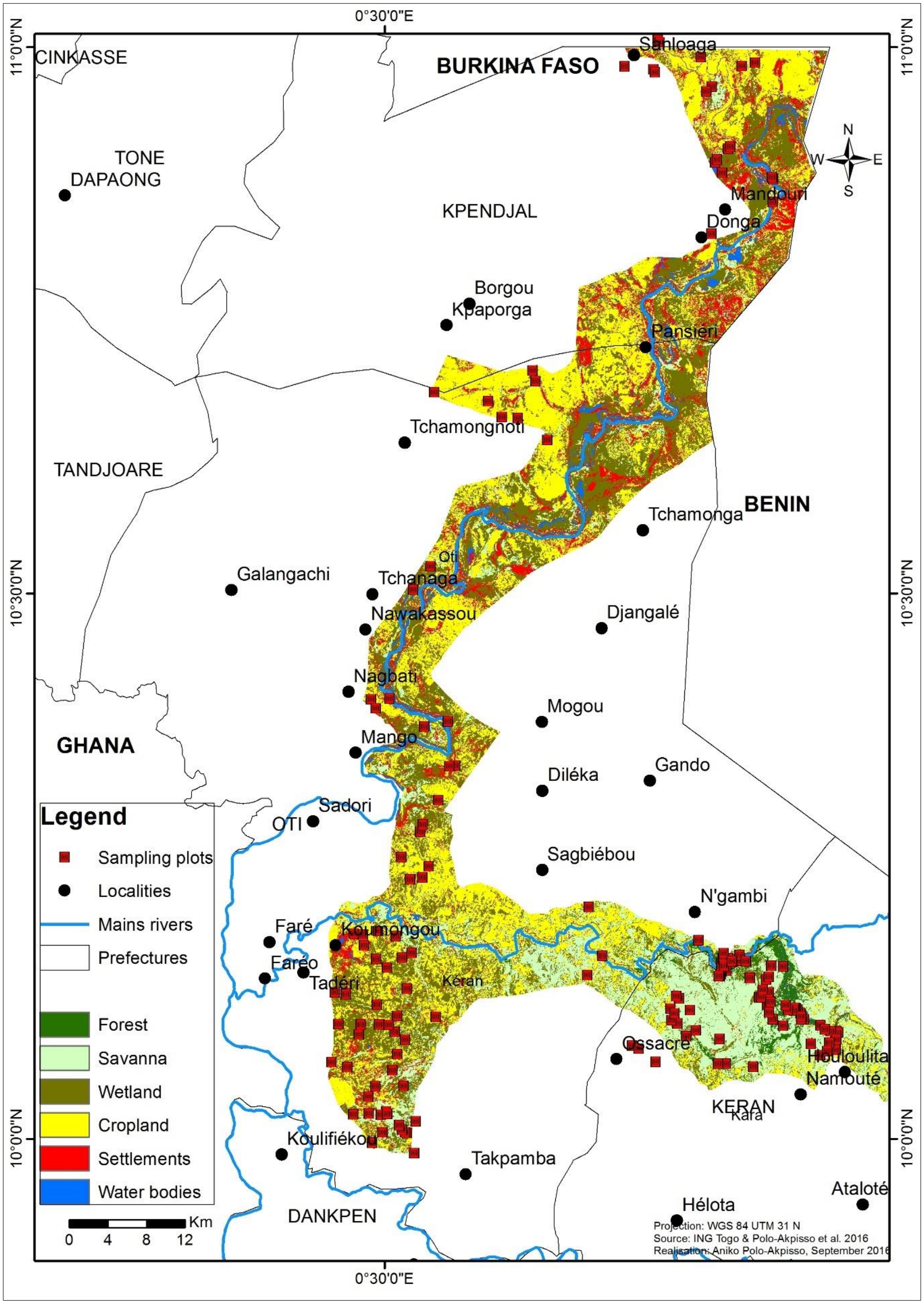

Figure 7: Distribution of the 182 vegetation sampling plots

Table VI: Description of each of the 12 point value indices used to assessed the social values ascribed to biodiversity conservation within OKM

Value	Description
A- Aesthetic	I value OKM because I enjoy the scenery, sights, sounds, smells, etc.
B- Biological diversity	I value OKM because it provides a variety of fish, wildlife, plant life, etc.
C- Cultural	I value OKM because it is a place where ancestral or traditional ceremonies are held.
D- Economic	I value OKM because they provide timber, fisheries, minerals, and/or tourism opportunities such as outfitting and guiding.
E- Future	I value OKM because it allows future generations to know and experience the wilderness as it is now.
F- Historic	I value OKM because there are places and things inside that are linked to the establishment of our ancestors.
G- Intrinsic	I value these protected areas in and of themselves, whether people are present or not.
H- Learning	I value these protected areas because we can learn about the environment through scientific observation or experimentation.
I- Life sustaining	I value these protected areas because they help produce, preserve, clean, and renew air, soil, and water.
J- Spiritual	I value this area because there are sacred, religious, or spiritually special places or because I feel reverence and respect for nature there.
K- Therapeutic	I value these protected areas because they contain relevant plants used for traditional therapy.
L- No value	There is no benefit conserving this area

2.4. Data analysis

2.4.1. Assessment of the occurrence of elephant from 2010 to 2013

Collected data for the overall period of 2010 to 2013 during the social survey on the movement patterns of elephants were processed using the Statistical Package for the Social Sciences (SPSS 20). The error margin at 95% confidence level of the proportion of people knowing something about elephants in each of the prefecture was computed using the normal approximation of binomial distribution **(Dagnelie, 1998)**.

$$n = U_{1-\alpha/2}^2 \frac{p(1-p)}{d^2}$$

Then

$$d = U_{1-\propto/2}\sqrt{\frac{p(1-P)}{n}}$$

Where:

d is the error margin

n is the sample size

$U_{1-\alpha/2}$ = 1.96 : value of the Normal random distribution at probability of 1-α/2

with α = 0.05.

p = proportion of the surveyed population who know something about elephant migration

Descriptive statistics were computed for elephant group size and migration frequency data. The agreement (A) among interviewee concerning elephant migration was computed for each response using a formula adapted from **Monteiro *et al.* (2006)**

$$A = Fx/Ft$$

Where

- Fx is the number of times any value or answer is reported within a given prefecture or range
- Ft is the total number of citations within a given prefecture or range

The statistical significance of the answers from each prefecture was tested by Chi square goodness of fit for the elephant occurrence frequency and Poisson regression model for the reported elephant group size.

2.4.2. Assessment of the elephant habitat

This assessment was conducted by analyzing the characteristics of the vegetation in different habitats according to their level of suitability.

2.4.2.1. Land cover mapping for the year 2013

The classification scheme was based on the one recommended by the Intergovernmental Panel on Climate Change (IPCC) for national greenhouse gases emission inventories in Land Use, Land use change and Forestry sector **(IPCC, 2003)**. Based on defined training sites, a supervised classification using maximum likelihood algorithm was performed. The maximum likelihood was used because it is the most commonly used algorithm in remote sensing image classification **(Richards, 2013)**. The classifications were run with all bands except Bands 1, 6, 8, 9, 10 and 11. It was performed using IDRISI GIS and Image Processing software. The accuracy assessment was based on Cohen's Kappa **(Cohen, 1960; Congalton *et al.*, 1983)** as well as on user's, producer's and overall accuracies **(Liu *et al.*, 2007)**.

2.4.2.2. Assessment of the elephant habitat suitability within OKM

An elephant habitat suitability model was developed using overlay technics. The source layers were assigned fuzzy membership values and then the resultant layers were combined using raster calculator and fuzzy overlay to create an overall suitability layer. For each source layer, the likelihood that each observed value is a member of the defined set of suitable locations is based on the relationship between observed values and fuzzy membership values that captures the best that criterion. The entire process was schemed and run in ArcGIS ModelBuilder.

Elephant habitat and degraded habitat were finally determined based on the outputs of the analysis of vegetation data. Furthermore, the least cost past between patches of the suitable habitat was determined using an algorithm based on mathematical morphology available in the Graphical User Interface for the Description of image Objects and their Shapes (Guidos) Toulbox **(Vogt, 2016)**.

Finally, the pattern of elephant movement and occurrence was analysed in the light of an interpolation of the national census data and the spatial distribution of suitable habitat.

2.4.2.3. Assessment of the vegetation structure

First, an overview on the vegetation within OKM was given by the assessment of the overall species richness, plant chorology and species-environment relationship. Plant species were named and categorized into their respective genera and families according to those set by **Brunel *et al.* (1984); Akoègninou *et al.* (2006)**. EstimateS (version 9) was used to estimate the total species richness by constructing sample-based species accumulation curves using Chao 2 estimator with 100 randomization as recommended by the user's guide **(Colwell, 2013)**. Plant species were furthermore classified according to their phytogeographical types **(White, 1986)** and their life forms **(Raunkiaer, 1934)**. Major ecological gradients in species distribution and species-environment relationship were assessed by a direct gradient analysis using CANOCO software (Canonical Correspondence Analysis (CCA)) **(Leps and Smilauer, 2003)**. After the first run, outlier samples were deleted and this analysis was finally performed on a matrix of 161 samples X 312 species with 17 environmental variables. The analysis was performed using a log transformed plant species abundance data recorded according to the scale of Braun-Blanquet with inter-species scaling, Hill's distance and downweighting of rare species.

Based on woody species, plant communities were assessed using a hierarchical clustering with presence-absence data following Ward's method and Euclidian distance measure by using the Community Analysis Package (CAP 2.15) software **(Pisces-Conservation, 2002)**. The data was a matrix of 123 plots x 94 woody plant species. Furthermore, the diversity of plants species was assessed by alpha diversity indices. These are species richness (S), Shannon-Wiener diversity index (H') and Pielou evenness index (E). The Pielou's evenness measures the similarity in the abundance of the different woody species sampled. Its value varies between zero and one. The value tends to zero when one or few species have higher abundance than others and one in the situation where all species have equal abundance. Shannon-Wiener diversity index could varie generally between 0 and 6. High values of H' would be representative of more diverse communities **(Magurran, 2004)**.

The formulas of these indexes are:

$$H' = -\sum_{i=1}^{s} p_i \, log_2 p_i \text{ with } p_i = \frac{r_i}{r}$$

Where r_i is the number of individuals belonging to the species i, r the total number of all individuals in the considered plot and s is the species richness in the plot.

$$E = \frac{H'}{H'_{max}} \text{ with } H'_{max} = log_2 s$$

Where H' represents the Shannon-Wiener's diversity index, H' max is the maximum value of the diversity index and S is the number of species recorded in the considered plant community.

Furthermore, a thorough characterization of each plant community was performed by computing the Indicator value index (IndVal) and the species Importance Value Index (IVI).

The indicator species analysis was computed using R package ''Indicspecies'' **(De Cáceres and Legendre, 2009)**. This package provides a set of functions to assess the strength and statistical significance of the relationship between the species occurrence or abundance and site groups, which may represent habitat types, community types, disturbance states, etc. The indicator value index is the product of two components, referred to as 'A' and 'B' **(Dufrene and Legendre, 1997)**. Component 'A' is the probability that the surveyed site belongs to the target site group given the fact that the species has been found. This conditional probability is called the specificity or the positive predictive value of the species as indicator of the site group. Component 'B' is the probability of finding the species in sites belonging to the site group. This second conditional probability is called the fidelity or sensitivity of the species as indicator of the target site group **(De Cáceres, 2013)**.

The Importance Value Index (IVI) **(Cottam and Curtis, 1956)** characterizes the place occupied by each species within vegetation, compared with the other species. Its formula is:

$$IVI = FREQesp + DENSesp + DOMesp$$

The relative frequency of a species (FREQesp) is the ratio of its specific frequency (a number of plots in which it is present) over the sum of the specific frequencies of all species. The relative density of a species (DENSesp) is the ratio of its absolute density over the sum of the absolute densities of all species. Relative dominance of a species (DOMesp) is the quotient of its basal area with the sum of basal areas of all species.

The basal area of a species (G) is the sum of the cross-sectional area at 1.3 m above the ground level of all individual trees of this species expressed in m² per ha:

$$G = \frac{\pi}{4s} \sum_{i=1}^{n} 0.0001 d_i^2$$

Where n is the number of trees found on the plot, and d_i the diameter (in cm) of the *i*-th tree.

Species regeneration rate was estimated for each woody plant species in each plant community.

Second, different habitats were distinguished according to their level of suitability. Alpha diversity as well as dendrometric parameters were computed for these habitats. For instance, the tree density for one habitat (N) which is the average number of trees per plot for a given habitat expressed in trees/ha:

$$N = \frac{n}{s}$$

n is the overall number of trees in the plot, and *s* the area.

The mean diameter (D) in cm of the trees in a given habitat:

$$D = \left(\frac{1}{n}\sum_{i=1}^{n} d_i^2\right)^{1/2}$$

Where n is the number of trees found on plots

Furthermore, the combinations of indicator species for each habitat were described using R package ‘’Indicspecies’’ **(De Cáceres and Legendre, 2009)** with the same motrix of woody plant species of 123 plots x 94 species. This matrix was rearranged according the habitat suitability level. The beta diversity was described by computing Jaccard index of similariy **(Chao *et al.*, 2005)** by using the R package “Fossil” **(Vavrek, 2011)**. The Jaccard index depend on three simple incidence counts: the number of species shared by two assemblages and the number of species unique to each of them. These counts are refered as A, B and C, respectively:

$$J = \frac{A}{A + B + C}$$

The basal area of trees in each habitat (G_1) was also computed. This is the sum of the cross-sectional area at 1.3 m above the ground level of all trees on a plot of a given, expressed in m^2/ha:

$$G_1 = \frac{\pi}{4s}\sum_{i=1}^{n} 0.0001 d_i^2$$

Where d*i* is the diameter (in cm) of the *i*-th tree of the plot, *s* is the plot area.

The Lorey’s mean height (H_L in meters) was also computed. This is the average height of all the trees found in a plot weighted by their basal area:

$$H_L = \frac{\sum_{i=1}^{n} g_i h_i}{\sum_{i=1}^{n} g_i} \qquad \text{with } g_i = \frac{\pi}{4} d_i^2$$

Where gi and hi are the basal area (in m^2/ha) and the total height of tree i.

The habitats were compared to each other for these parameters by a Kruskal-Wallis test. Furthermore, the diameter structure of tree stem of each habitat was assessed by the frequency of tree stems grouped in different diameter classes. The observed diameter structure was fitted to the 3-parameter Weibull distribution **(Johnson and Kotz, 1970)**. The density function of this distribution is very useful because its flexibility and has been used to describe vegetation structure in many studies **(Bonou *et al.*, 2009; Aleza *et al.*, 2015b)**. The density function f is expressed for a tree-diameter x by the following formula:

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} e^{-\left[x-\frac{a}{b}\right]^{c}}$$

Where x = tree diameter; a=10 cm, b= scale parameter linked to the central value of diameters and c = shape parameter of the structure.

Finally, according to the Jaccard indices, the four habitats distinguished earlier were merged two by two with respect to their similarity in species'richness. Therefore, the habiat of the elephant and the degraded habitat were mapped. A further analysis of the integrity of these habitats (their level of fragmentation) was assessed using morphological image processing with eight connectivity **(Vogt *et al.*, 2006)**. The fragmentation analysis was conducted following the hypsometric method by using Guidos Toolbox 2.5 **(Vogt, 2016)**. This method accounts for the dual nature of fragmentation (foreground is fragmented by background and vice versa). The degree of fragmentation for a given image is defined by the weighted sum of fragmentation (Frag) in the foreground and the background:

$$Frag\ (hypso) = \left(\frac{background_{area}}{100} \times backgroung_{frag}\right) + \left(\frac{forground_{area}}{100} \times forground_{frag}\right)$$

The so-defined fragmentation provides values in the range of [0, 100] %, accounting for and summarizing key fragmentation aspects such as duality, perforations, amount, division, and dispersion of image objects.

2.4.3. Assessment of elephant habitat dynamics from 1987 to 2013

The dynamics of the habitat were assessed considering land cover maps derived from landsat images classification. The analysis was conducted with a particular look at land cover categories that constitute natural ecosystems (forests, savannas, and wetlands).

Landsat 4 scenes (1 and 2) and Landsat 7 scenes (3 and 4) were mosaicked to create a larger image composite. This process was done by matching the images' grey level in the overlapping area using cover method and by calculating matching statistics based upon non-background values **(Eastman, 2012)**. The resulting composites were registered to the Landsat 8 scene with size of 185-km-cross-track-by-180-km-along-track **(Lira and Taborda, 2014)** that enable one scene to cover the entire study area.

The classifications were run with all bands except Band 6 and Band 8 for TM and ETM images and was performed using IDRISI GIS and Image Processing software.

Reference data have been generated differently for each image. They were based on ground verification data for the recent image while generated from the national topographic map established in 1980, the national vegetation map **(Afidégnon *et al.*, 2002)** and other available maps for the historical images (2000 and 1987).

Change analyses were performed on the basis of pixel by pixel comparison using Land Change Modeler fully integrated software in the IDRISI GIS and Image Processing system **(Eastman, 2012)**. The land cover maps were compared as following: 1987 and 2000, 2000 and 2013, and 1987 and 2013. Change maps were produced with the combination of Land Change Modeler and ArcGIS 10.2.2.

The Land cover maps of OKM were used to assess the change processes in the different land cover categories. The earlier and later land cover maps were compared and the nature of the change underway within each land cover class was measured. This analysis was performed by using a decision tree procedure **(Bogaert *et al.*, 2004)** that compares the number of land cover patches present within each class between the two time periods to changes in their areas and perimeters using the land change modeler **(Eastman, 2012)**. The output is a map where each land cover class is assigned the category of change that it is experiencing.

The decision tree procedure is proposed based on three spatial attributes that are easy to calculate and that are recognized as key elements of landscape pattern measures **(Giles and Trani, 1999)**: area, perimeter, and number of patches of the focal landscape class. The identification of the spatial process responsible for habitat pattern changes was implemented following the procedure outlined by **Bogaert *et al.* (2004)** and presented in Figure 8.

A cross-tabulation analysis **(Pontius *et al.*, 2004)** was performed afterwards to identify the particular change process in each land cover class. These analysis were done by using IDRISI GIS software **(Eastman, 2012)** while the number of patches was computed for each land cover by using LecoS **(Jung, 2013)** a plugin for the QGIS GIS software suite.

2.4.4. Assessment of the vulnerability of habitat patches to climate induced anthropogenic pressure

Collected data on the perceptions of climate change, the vegetation conditions and the value ascribed to conservation among resident communities were also processed using the Statistical Package for the Social Sciences (SPSS 20).

Descriptive statistics were computed. Further analyses were performed by grouping interviewees in their respective ethnic group and in three distance ranges from the limits of the protected areas (0 – 2 km, 2 – 5 km, and 5 – 10 km).

On another hand, the information collected during the social survey were analyzed in light of the annual variation in precitation and temperature from 1981 to 2013. The annual variation in precipitation and temperature were derived from the meteorological data for Mango collected at the National Direction of Meteorology. Data from Mango meteorological station were used because of the fact that the city of Mango is located almost at the center of our study area.

A hierarchical classification analysis was performed using the incidence data of the reported adaptation strategies to assess the link between the cultural background and the implemented adaptation strategies in a given community. The classification was performed following the Euclidean and Ward's method.

The correlations between the perceived changes in the climatic conditions and the access to formal education, the age as well as the cultural background were assessed using Chi-square test of independence. The same test was used to assess the correlation between the social values ascribed to the conservation of biodiversity within OKM and the distance to the park, the access to formal education and the cultural background of the residents.

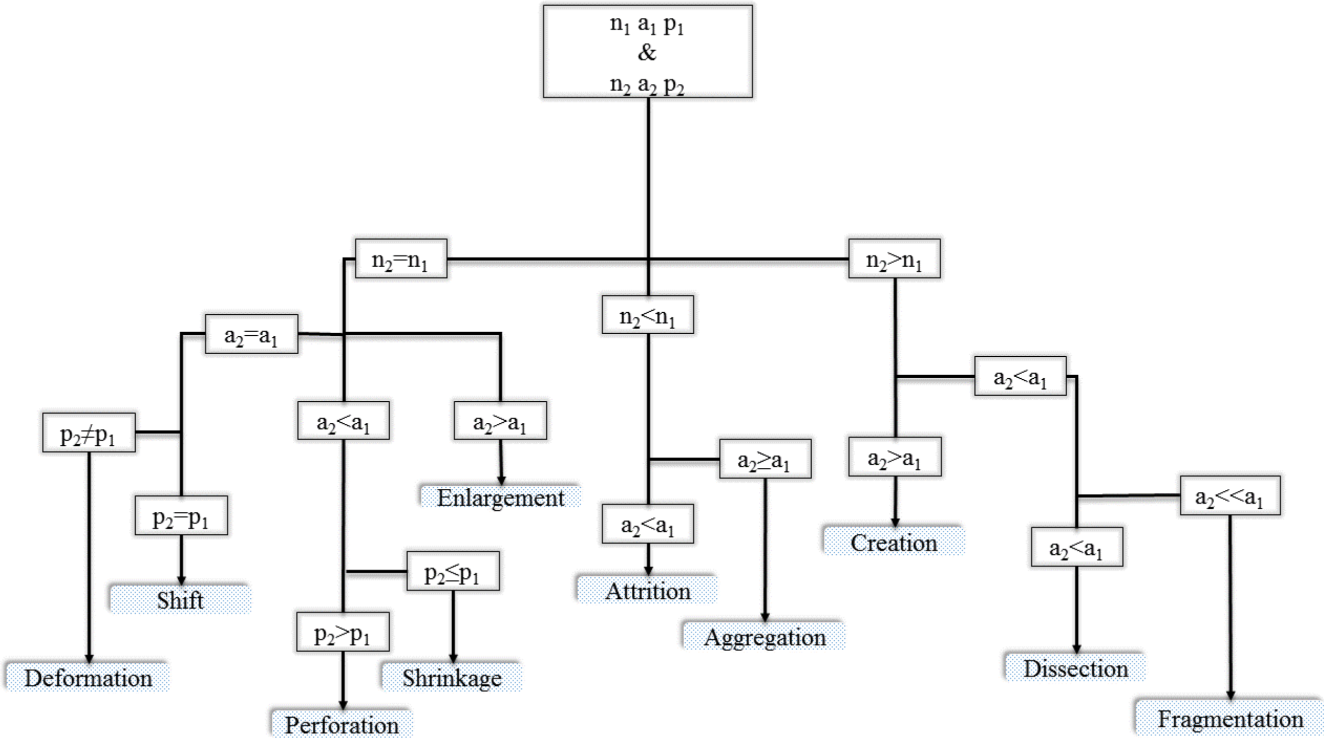

Figure 8: Decision tree procedure to identify transformation processes as outlined by Bogaert *et al.* (2004) (parameters a_1, p_1, and n_1 refer to the habitat area, perimeter, and number of patches before transformation, while a_2, p_2, and n_2 are the reciprocal values after pattern change)

III. RESULTS

3.1. Indigenous ecological knowledge on elephant occurrence within OKM from 2010 to 2013

The survey concerned 292 persons from 18 villages with a mean age of 34.83 years old. The proportion of the sampling size in each department and the error margin at 95% confidence level of the proportion of people knowing something about elephants in each of the prefecture is given in Table VII.

3.1.1. Knowledge on elephant occurrence in surveyed localities

The occurrence of elephants was reported in all the surveyed localities. On the total of eighteen surveyed villages, all the respondents reported the occurrence of elephants in their locality meanwhile the answers were balanced in eight villages (Figure 9). Negative responses were mostly reported in two villages that are Tchanaga and Donga. In Diléka, Nakorkou, Namoufouali, Namouté, Sagbiébou and Tindandéni, negative responses were reported but they were from less than 50% of the respondents. All the respondents interviewed in Bagré, Gbemba, Houkouyote, Koundjoaré, Kpelinga, Mandouri, Nyandé, Ouloulita, Sansiéga, and Takpamba only reported the effective occurrence of elephants in their localities.

3.1.2. Elephant occurence frequency

From 2010 to 2013, it was reported that elephant occurred within or around OKM from one to four times (Figure 10). One time is mostly reported within Keran and Oti whereas three times is widely reported in Kpendjal. Four times occurrence frequency is only reported in Oti. The presence of elephants within the park was signaled at least one time from 2010 to 2013 but they were mostly frequent in Kpendjal.

The box plot (Figure 11) shows that the mean elephant occurrence frequency reported is around one for Keran and Oti even if fluctuations in reported frequency value is noticed in Oti. Meanwhile, the mean frequency is around three in Kpendjal meaning that elephants occurred in that district at least one time each year. Therefore, Kpendjal can be considered as the most frequented by elephants. About 77.4% of all the respondents have seen elephant in their village but there is evidence of difference in elephant sighting between the three prefectures (X^2=13.801, df=2, p=0.001).

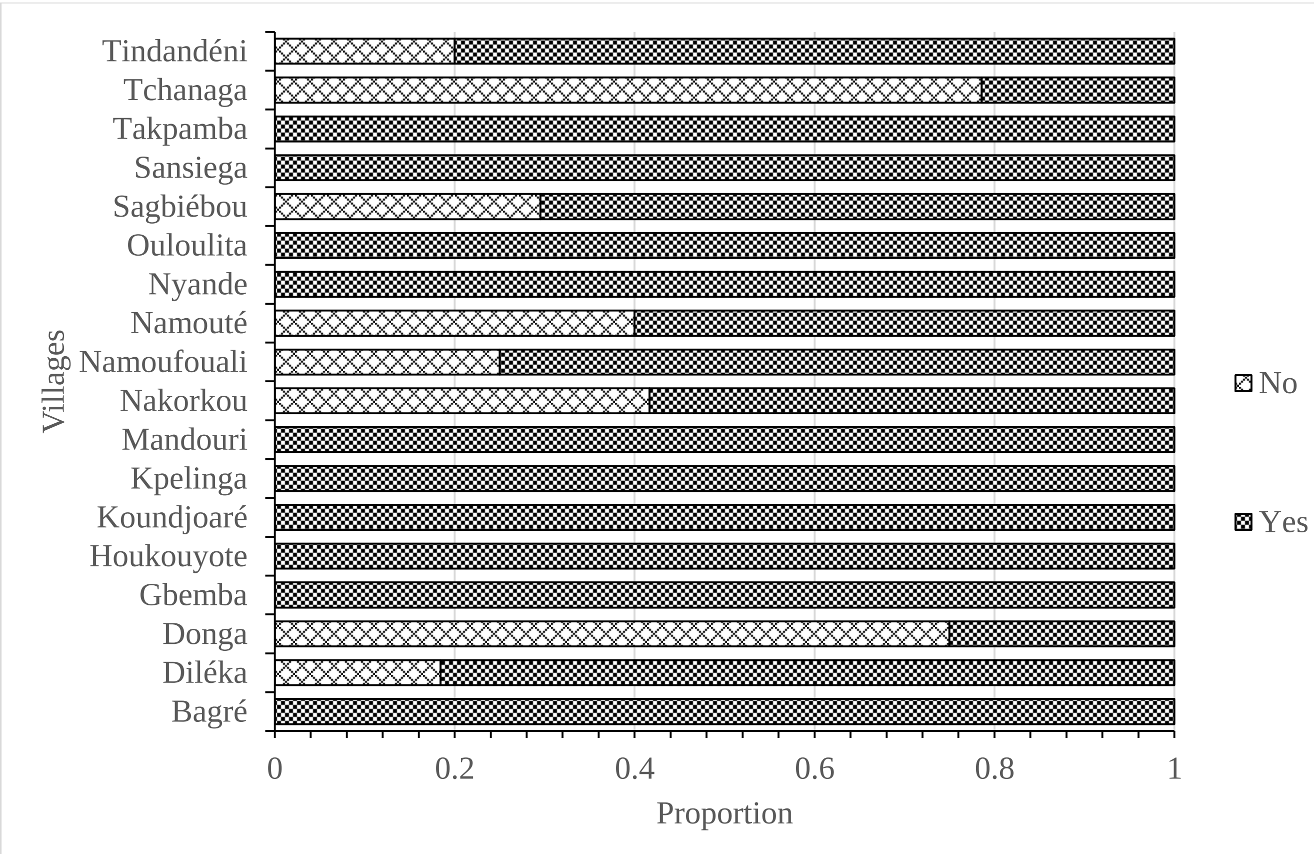

Figure 9: Knowledge on elephant occurrence in some localities surrounding OKM (Yes= Occurrence; No= Non occurrence)

Table VII: Sampling size in each prefecture

	Number of informants			Percentage			Error margin
	Women	Men	Total	Women	Men	Total for the prefecture	
Keran	21	27	48	43.75	56.25	16.438	0.057
Oti	77	87	164	46.95	53.05	56.164	0.066
Kpendjal	33	47	80	58.75	41.25	27.397	0.081

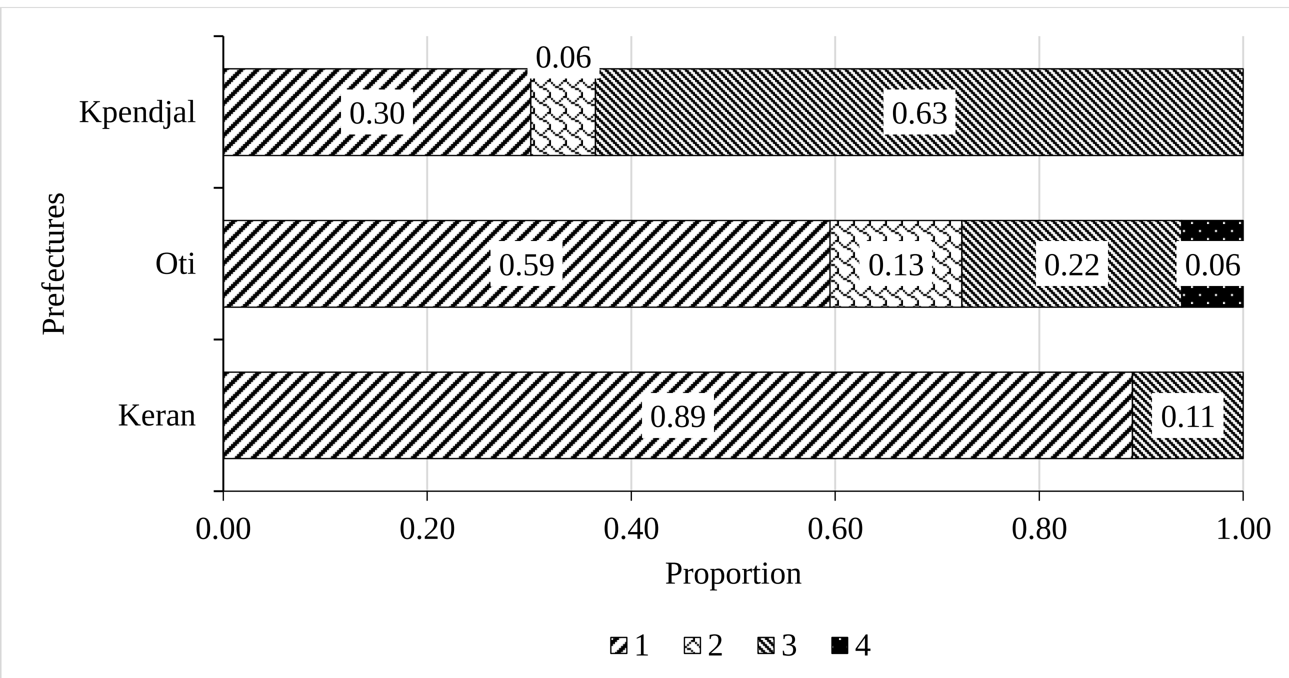

Figure 10: Agreement on elephant occurrence frequency from 2010 to 2013 within Oti, Keran and Kpendjal (1, 2, 3 and 4 are the number of time elephants are reported to be seen by local population in a given prefecture)

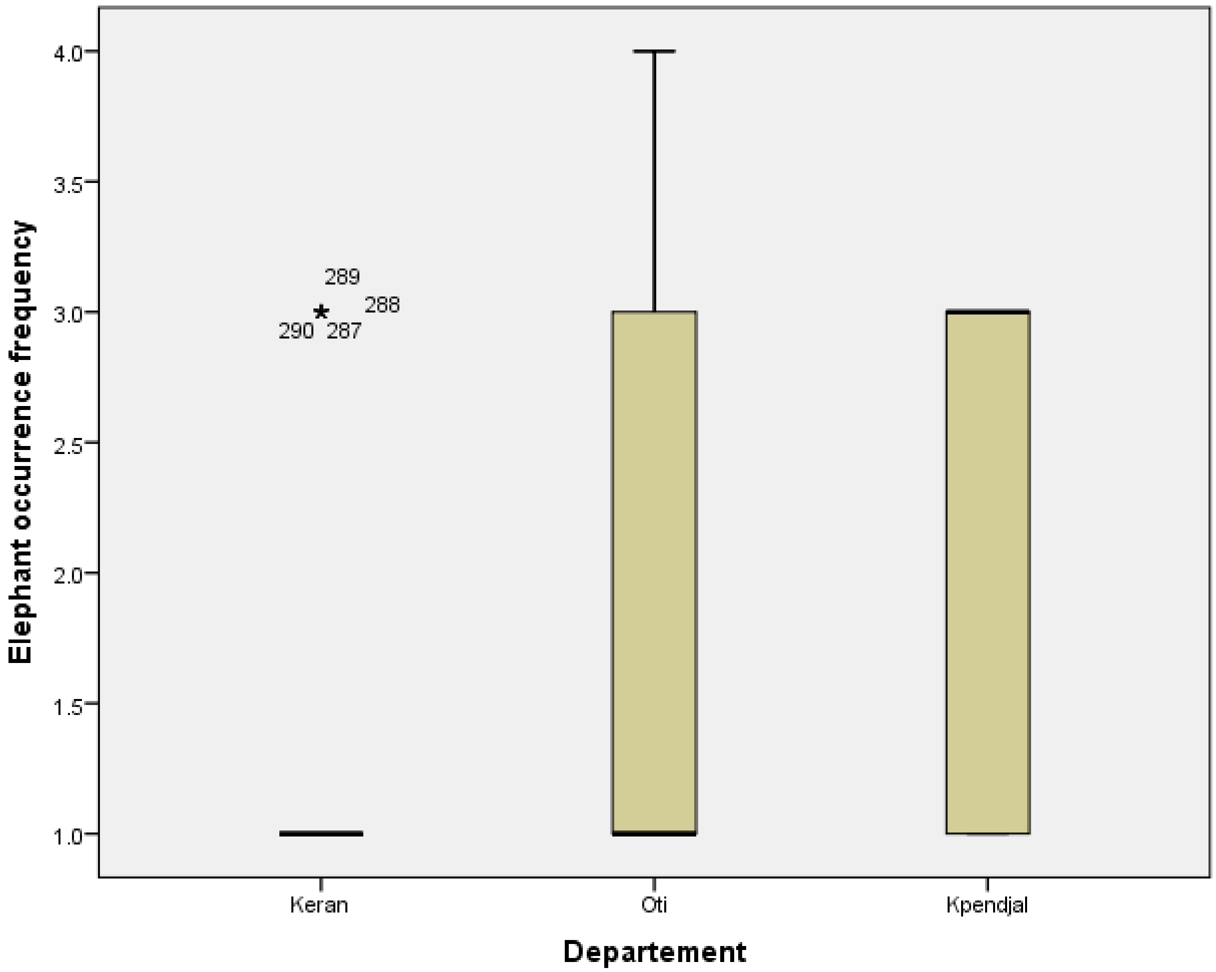

Figure 11: Elephant occurrence frequency within the three departments straddled by Oti-Keran-Mandouri according to local population

3.1.3. Estimated elephant group size

There is a high fluctuation in the reported occurring elephant group size. The reported values range from one to eleven (Figure 12). The most abundant group size reported is three, followed by four individuals. However, there are higher group sizes reported in Kpendjal (10 and 11).

There is significance relationship between the prefectures and the likelihood of count of elephants (Likelihood Ratio X^2 = 11.043, df=2 and p=0.004). The difference in the reported elephant group size from one prefecture to another is significant between Keran and Kpendjal but not significant between Keran and Oti (Table VIII) The box plot shows a mean group size of three for each department with more fluctuations in Oti (Figure 13).

3.1.4. Elephant occurrence period

Elephants are reported to occur mainly during two periods in Kpendjal: from May to September with emphasis on June and from January to February with emphasis on February. In Oti, they mostly occur in April and in November whereas in Keran the most reported occurrence months are October and December (Figure 14). Elephants occur only during dry season in Keran whereas they occur during rainy and dry seasons in Oti and Kpendjal.

3.1.5. Human-elephant conflict

Human-elephant conflicts (HEC) do not always occur however they are reported in some villages since elephant's occurrence periods sometimes coincides with shea nuts (*Vitellaria paradoxa* C. F. Gaertn.) harvest period (May-June) or sorghum (*Sorghum bicolor* (L.) Moench.) harvest period (November-December). Human-elephant conflict occurs almost everywhere with no regard to the distance from the park's boundaries (Figure 15).

Basically crop raiding has been reported as the main HEC and 60 % among the informants indicated that they fear elephant. The most destroyed crops are sorghum, maize (*Zea mays* L.), rice (*Oryza sativa* L.), yams (*Dioscorea* sp), and cassava (*Manihot esculenta* Crantz.). The most used deterrents used are noise, fire, and smoke made with the burning of elephant's dung.

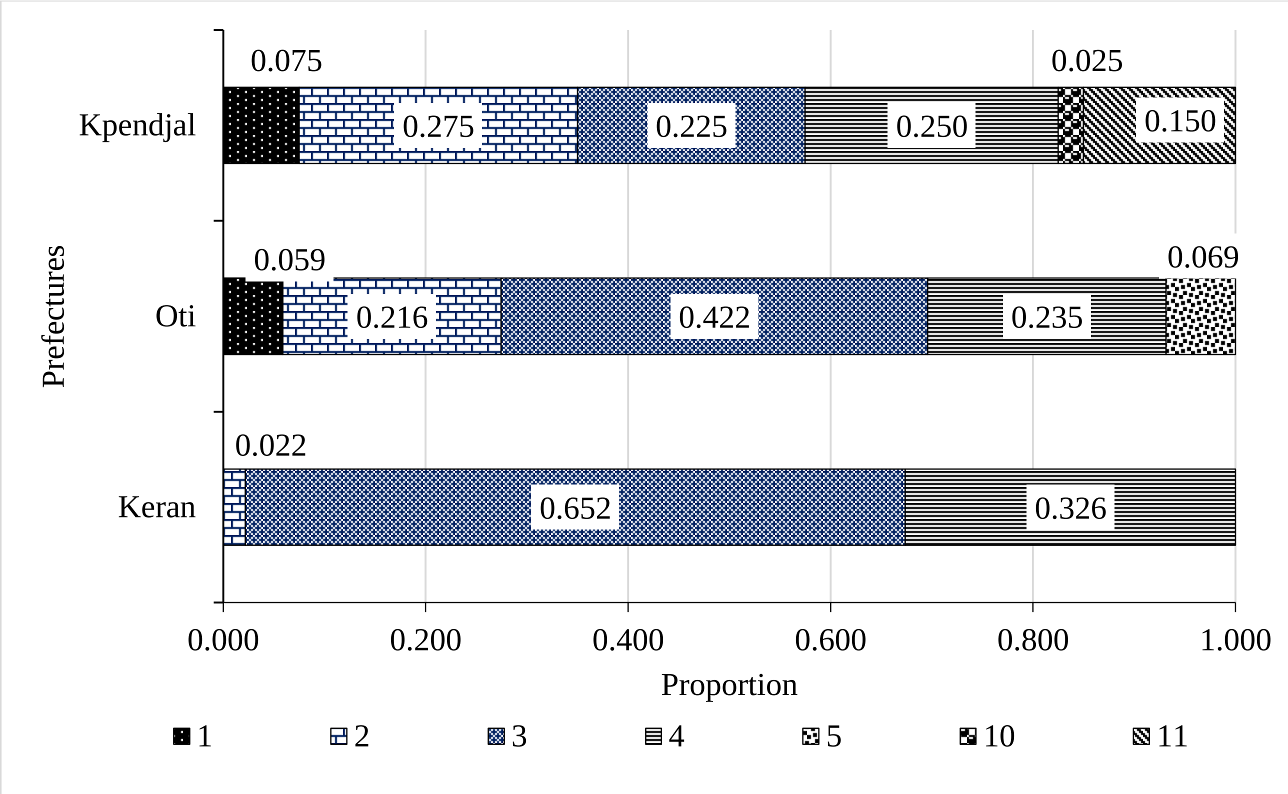

Figure 12: Agreement on estimation of occurring elephant group size according to local population (1, 2, 3, 4, 5, 10 and 11 are the reported number of elephants in a given prefecture)

Table VIII: Parameter estimates of Poisson regression model applied to reported elephant group size (95% Wald Confidence Interval)

Parameter (Rf= Keran)	**B**	**Std. Error**	**Hypothesis Test**			**Exp(B)**
			Wald Chi-Square	df	Sig.	
(Intercept)	1.195	0.0811	217.147	1	0	3.304
Kpendjal	0.24	0.1119	4.591	1	0.032	1.271
Oti	-0.084	0.099	0.713	1	0.398	0.92
(Scale)	1b					
Dependent Variable: Elephant group size						
Model: (Intercept), Prefectures						

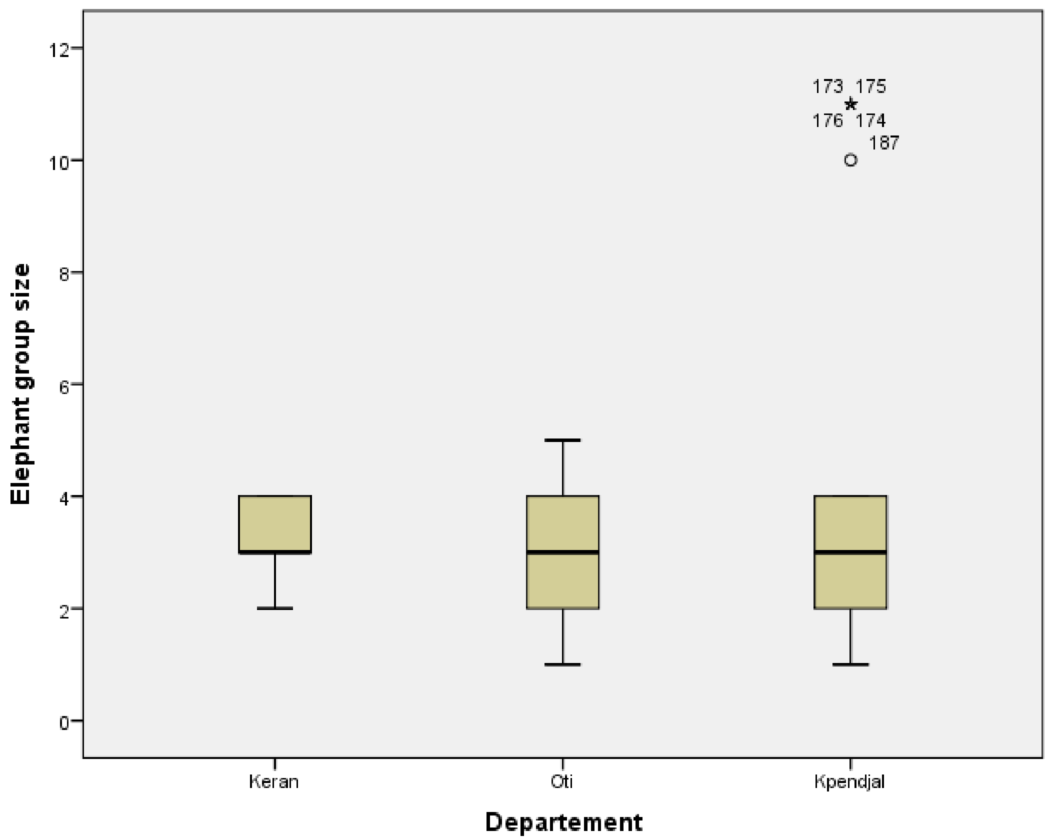

Figure 13: Estimated elephant group size in each department according to local population

There is no reported compensation mechanism. Authorities' response to crop raiding events is most of the time limited to a simple statement of the incident. Farmers are so deceived that they do not find it relevant to inform park managers or local administrative authorities when such event occurs. Almost all interviewees do not find any interest in elephant conservation because of all the problems they are having caused by them.

Farmers are really so fearful that they used to flee whenever they see elephants. Two elephants, one in 2010 and the other in 2011 were reported killed respectively in Défalé and near Katchamba because of the fact people were too afraid to see them near their settlements and very far from the park (more than 20 km). The animals were each time killed by administrative authorities to calm down threatened population. A third one was reported killed in 2014 near Kante for almost the same reason. But this time it was clearly shown that there is a disagreement between the local political leaders and park managers about the decision to kill problem elephant. The elephants were killed without the evaluation of other alternatives to resolve HEC.

3.2. Analysis of the elephant habitat within OKM

3.2.1. Elephant habitat suitability within OKM

The Figure 16 shows the elephant habitat suitability within OKM. Apart from a core area located in the south-east, the remnant good habitat patches are sparsely distributed in the protected area. They are mostly located along the rivers and around water pounds. The most important portion of suitable habitat and the largest suitable patche is located in Keran prefecture near the basement of park rangers that is called Naboulgou.

3.2.2. General characteristics of the vegetation within OKM

3.2.2.1. Floristic analysis

The floristic inventory in 182 plots (18.2 ha) revealed 320 plant species grouped in 209 genera and 66 families. The most frequent plant species are *Piliostigma thonningii* (Schumach.) Milne-Redhead (2.90%), *Pterocarpus erinaceus* Poir. (2.90%), *Combretum glutinosum* Perr. ex DC. (2.34%), *Anogeisus leiocarpus* (DC.) Guill. & Perr. (2.09%), and *Terminalia laxiflora* Engl. & Diels (2.09%) (Figure 17).

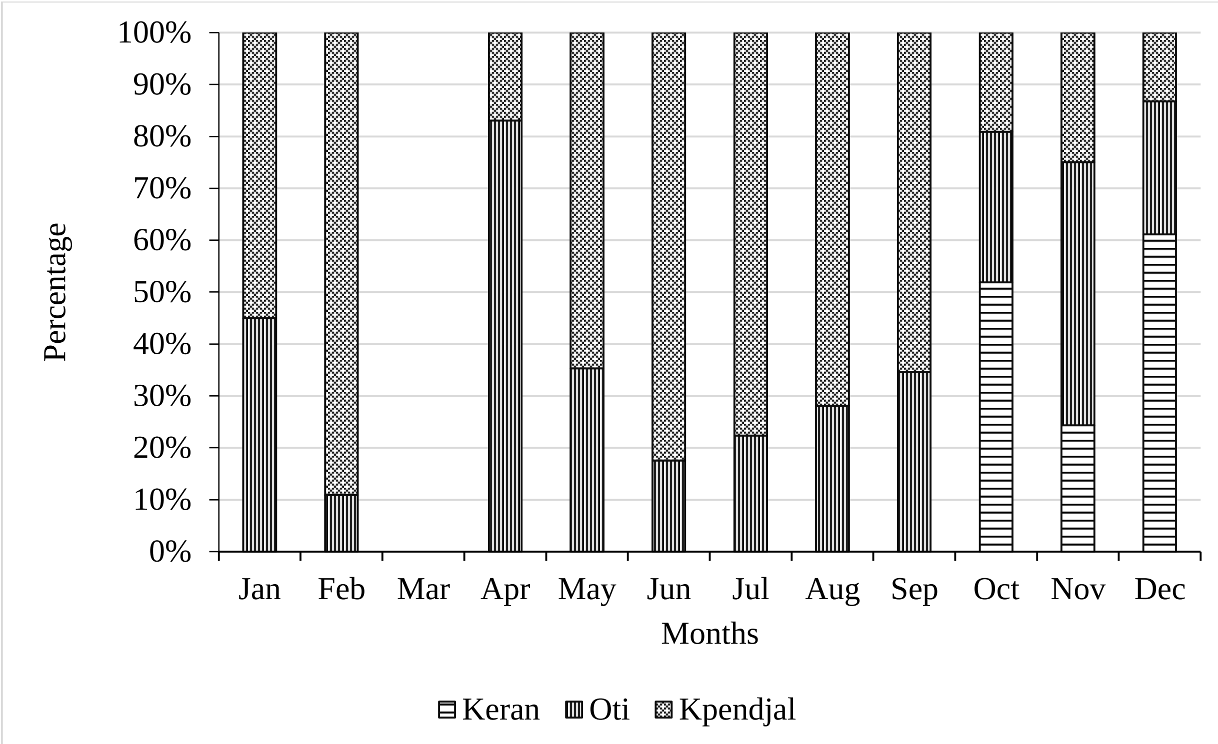

Figure 14: Elephants occurrence period in each department

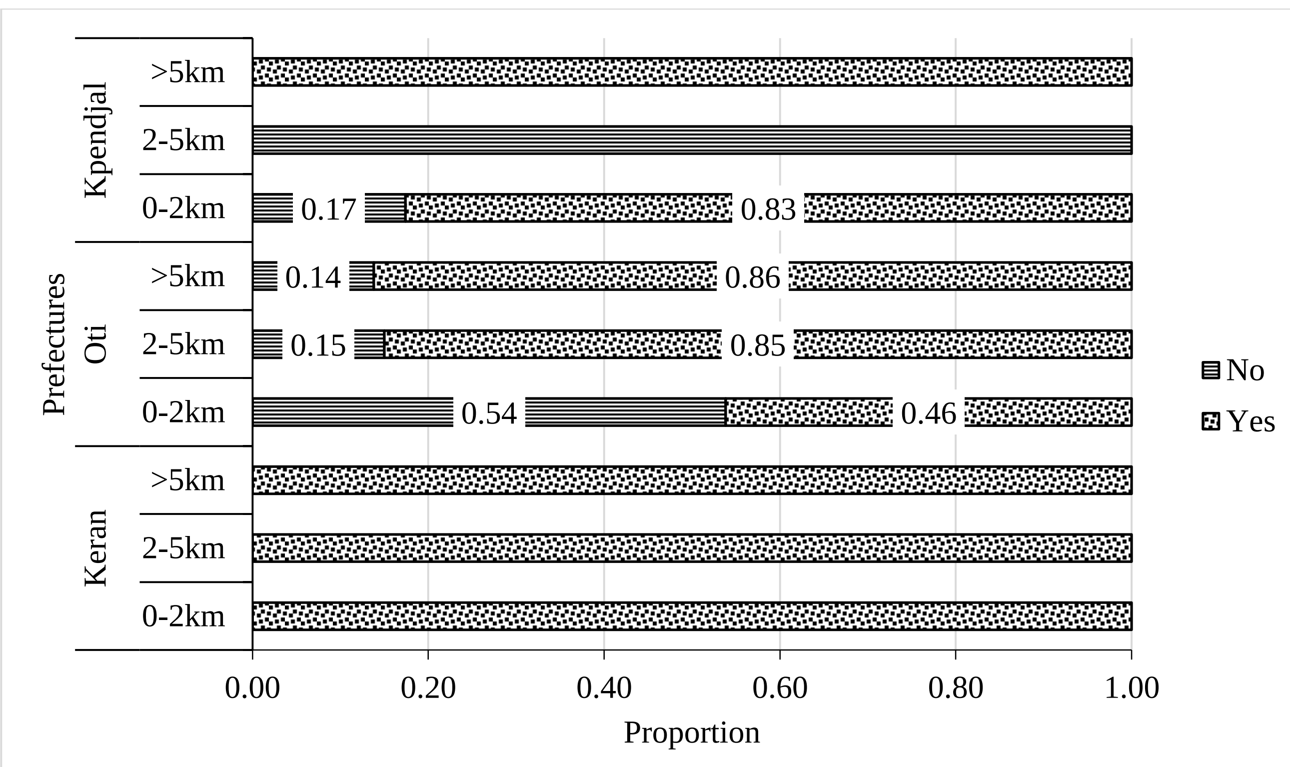

Figure 15: Human-elephant conflicts according to distance from the boundaries of Oti-Keran-Mandouri

The most important families in term of percentage of species richness are Poaceae (9.69%), Fabaceae (9.06%), Rubiaceae (6.25%), Euphorbiaceae (5.31%) and Combretaceae (5%). The most diversified genera in term of species richness are *Combretum* (2.81%) and *Acacia* (2.5%).

The estimation of the species richness based on Chao 2 estimator gives a total of 433±30 species for the study area (Figure 18). There is a high variation between the observed and the estimated species richness.

The most important plant species in the recorded data are phanerophytes (50.52%) followed by therophytes (26.30%) and geophytes (8.65%). The least represented plants are hydrophytes (0.34%) and epiphytes (0.69%) (Figure 19).

The phytogeographical spectrum is dominated by species from the Sudano-Zambesian (SZ) (21.94%) and the Sudanian endemism centre (S) (18.35%) types (Figure 20). There is a good representation of a large distribution scale species: Pan-tropical (12.23%), Paleotroprical (10.07), and Afro-American (1.44%). Species with a continental scale distribution are also well represented. These are, Afro-tropical (14.39%), African multi-regional (11.15%), Sudano-Guinean (4.32%), Guineo-Congolian (3.60%), Afro-Malgasy (1.08%), and Guinean (1.08).

3.2.2.2. Species-environment relation

There is a significant relationship between canonical axes, species, and ecological factors. The first four canonical axes of the Canonical Correspondence Analysis (CCA) express 9.4% of the variance in species distribution and 50.4% of the variance in species-environment relation. The total inertia is 19.66%. The most important variance in species data (3.5%) and in species-environment relation (37.7%) are only expressed by the first axe (Table IX).

The Monte Carlo permutation test on the first axis and on all axes (trace) is highly significant ($P = 0.002$). However, the F value is much higher for the test on the first axis ($F=5.263$) than for the test on the trace ($F=1.927$) meaning that the first axis explains more than the second, third, and fourth axes combined.

The CCA diagram revealed two major ecological gradients in species distribution (Figure 21). There is a gradient of habitat degradation along the second axis (vertical axis) showing an increasing

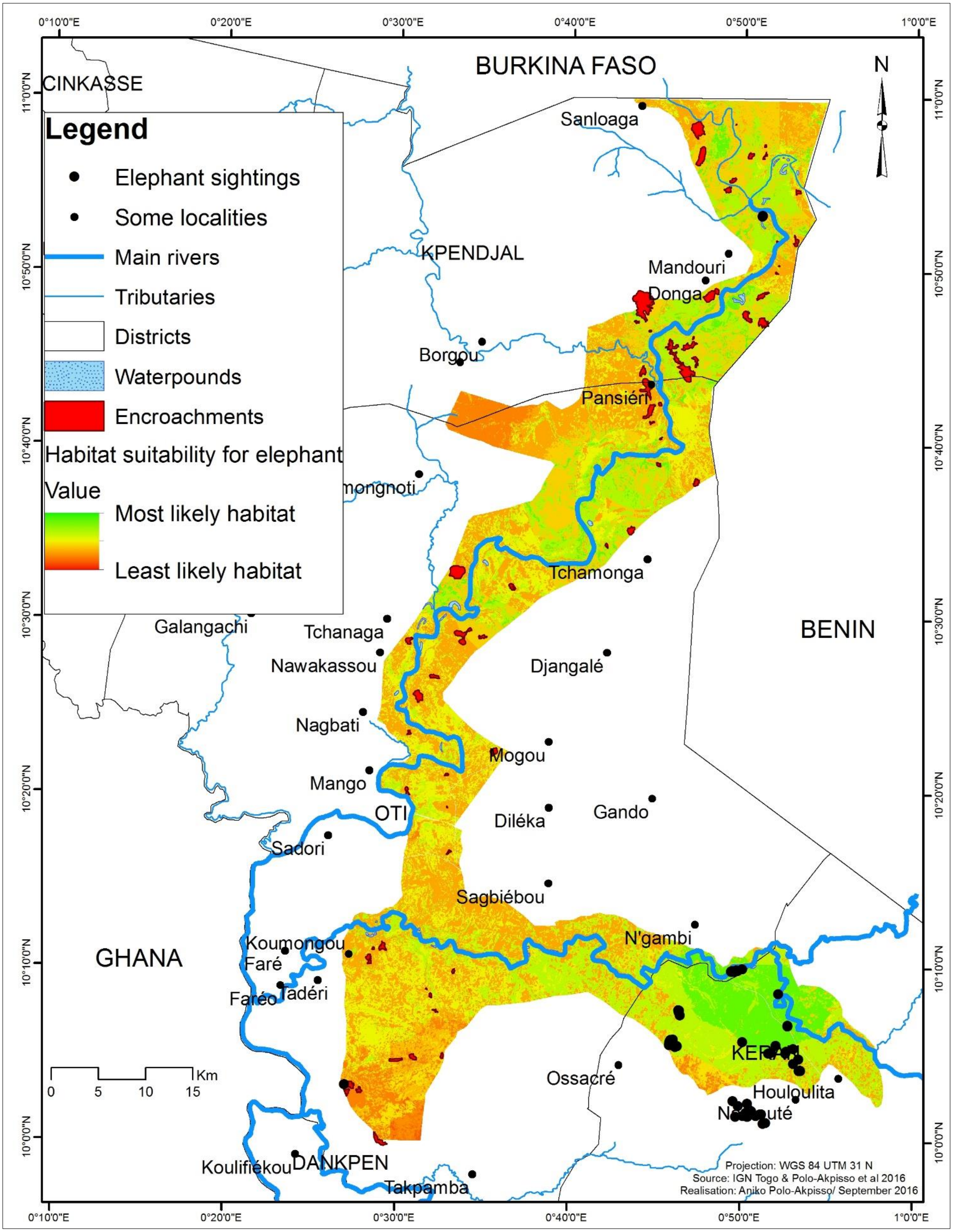

Figure 16: Elephant suitable habitat within OKM

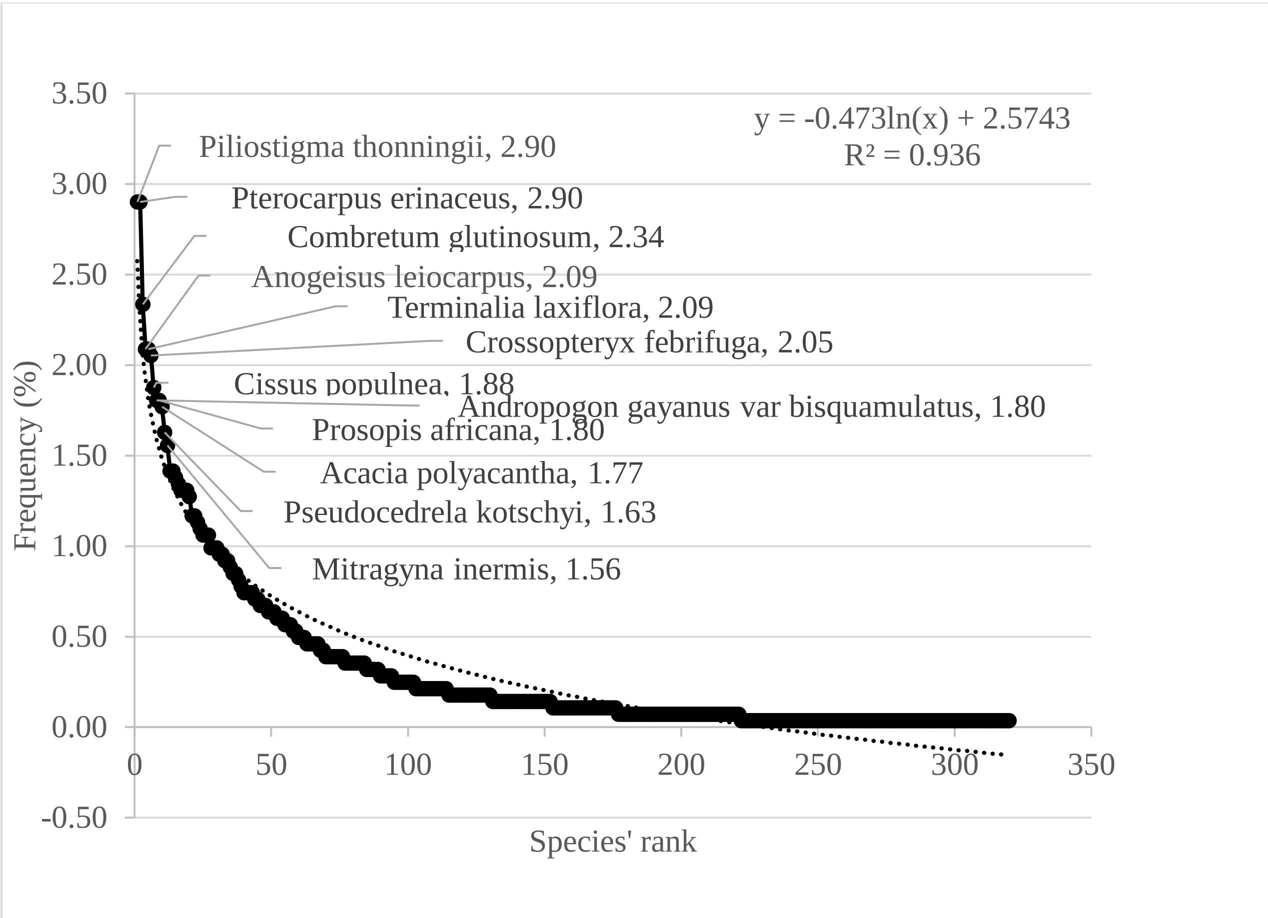

Figure 17: Species-rank curve of all species recorded in 182 plots within Oti-Keran-Mandouri

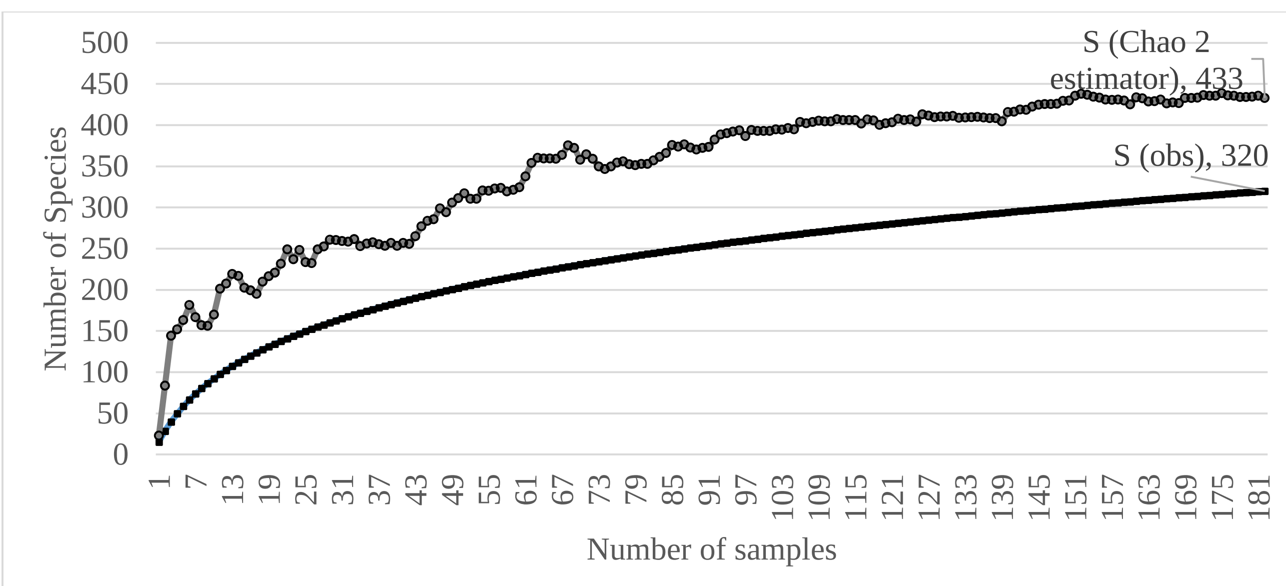

Figure 18: Species accumulation curve

degradation from the bottom to the top of the diagram. A gradient of humidity is also correlated to this axis but it is expressed the other way around. Humidity increases from the top to the bottom.

The canopy cover increases as well as woody species abundance from the left to the right of the diagram. This indicates a gradient of soil enabling the establishment of perennial plants. This second gradient is linked to the first axis (horizontal axis).

The analysis of Table X shows that the first axis is positively correlated with high tree cover and negatively with shrubs and small trees. It is also correlated with the edaphic substratum. Here the soil varies from clayed soil on the right to sandy soil on the left. The sandy soil is favourable to the establishment of woody vegetation type, usually a dry forest characterized by the abundance of *Anogeisus leiocarpus* (DC.) Guill. & Perr. The second axis is positively correlated to vegetation openness, topography and all the anthropogenic activities but it is negatively correlated with herbaceous cover and water availability (submersion).

3.2.2.3. Woody plant communities

The cluster analysis distinguished seven groups of woody plant communities (Figure 22). The first group (G1) is composed of samples from gallery forests distributed along the major rivers, the second one (G2) is composed of samples from dry forests and woodland savannas mostly on dry and sandy soil. The third group (G3) is composed of samples from shrub savannas mostly on wet and clayed soil, the fourth (G4) is composed of samples from tree savannas that is widely distributed, the fifth group (G5) is another group of gallery forests along minor rivers or tributaries. The sixth group (G6) is a mosaic group composed of samples from thorny woodland savannas, samples from gallery forests and some shea tree parklands that are mostly located in periodically flooded areas and well represented in the north-eastern part of OKM. The last group (G7) is composed of samples from *Borassus aethiopum* Mart. stands that are almost all the time in monospecific bands and usually transformed into parklands by residents.

The species diversity in each of these groups is reflected by the value of the species richness (S), Shannon-Wiener diversity index (H’) and Pielou evenness index (E) (Table XI). The species richness range from 9 woody plant species in *B. eathiopum* parklands (G7) to 54 woody plant species in tree savannahs (G4). Both Shannon-Wiener diversity index and Pielou’s evenness showed low species diversity and evenness within *B. eathiopum* parkland (G7) (H’=0.35 and E=0.37) whereas the species

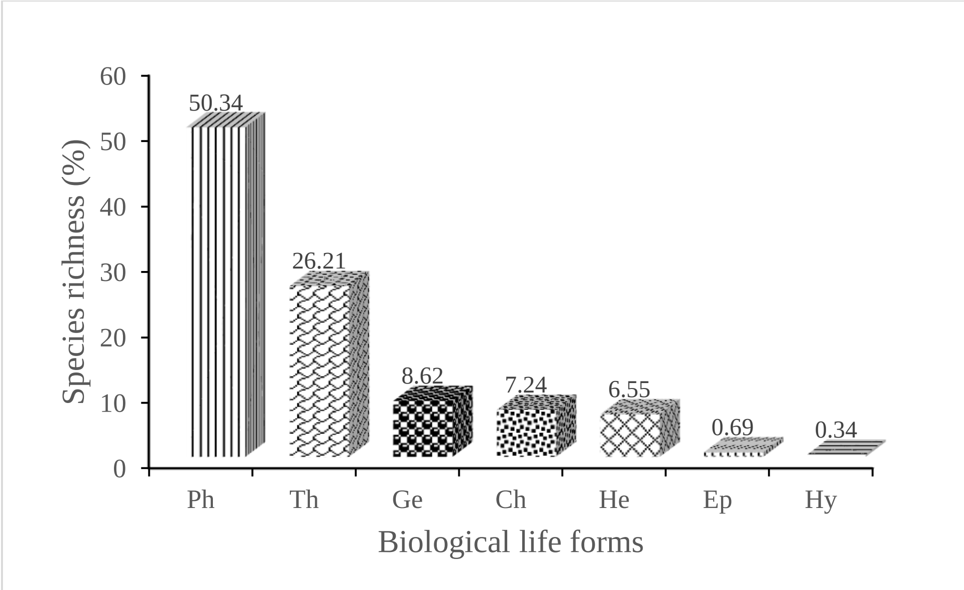

Figure 19: Life forms spectrum of recorded plant species in 182 plots within Oti-Keran-Mandouri (Ph: Phanerophytes, Th: Therophytes, Ge: Geophytes, Ch: Chamaephytes, He: Hemicryptophytes, Ep: Epiphytes and Hy: Hydrophytes)

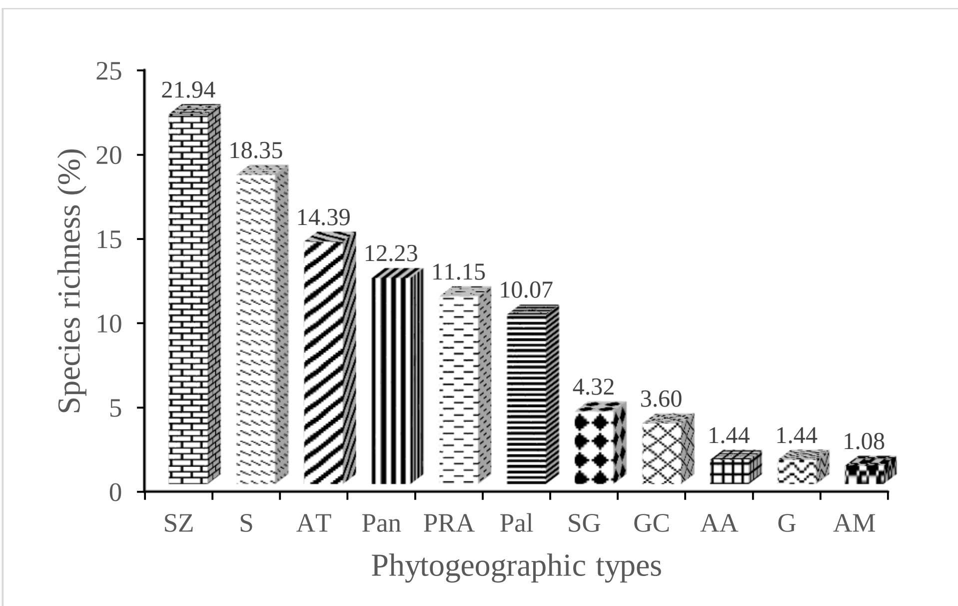

Figure 20: Phytogeographical types of recorded plant species (SZ: Sudano-Zambesian, S: Sudanian, AT: Afro-tropical, Pan: Pan-tropical, PRA: Pluri-regional in Africa, Pal: Paleo-tropical, SG: Sudano-Guinean, GC: Guineo-Congolian, AA: Afro-American, G: Guinean and AM: Afro-Malgash)

Table IX: Statistical synthesis of the Canonical Correspondence Analysis (CCA)

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues :	0.698	0.439	0.395	0.313	19.656
Species-environment correlations :	0.903	0.777	0.773	0.751	
Cumulative percentage variance					
of species data :	3.5	5.8	7.8	9.4	
of species-environment relation:	19	31	41.8	50.4	
Sum of all eigenvalues					19.656
Sum of all canonical eigenvalues					3.663

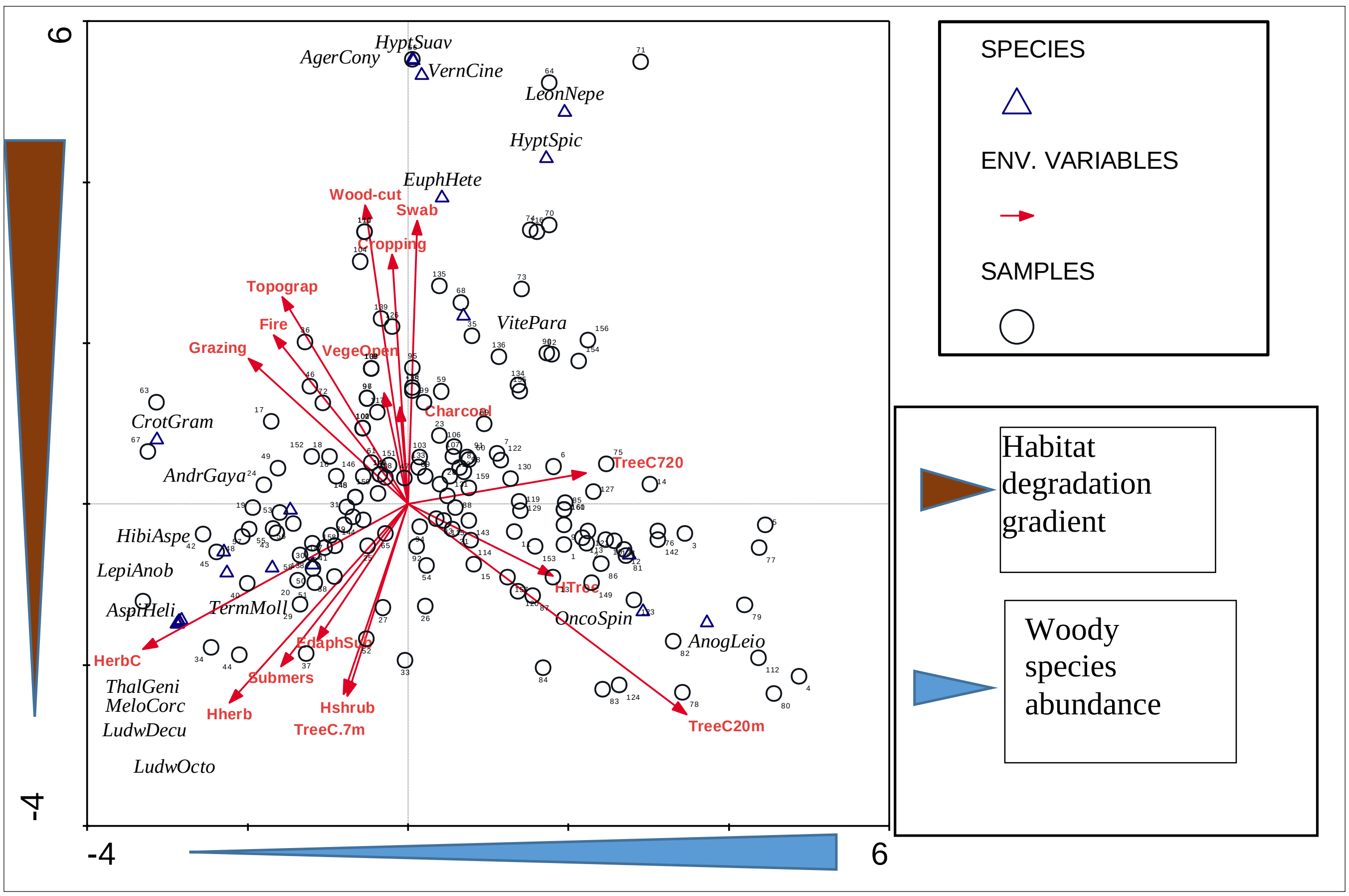

Figure 21: CCA diagram of species-environment relationship derived from a matrix of 161 samples x 312 species x 17 environmental variables

Table X: Weighted correlation between environmental variables and ordination axes of the CCA

Label	Significance	Axe 1 (species)	Axe 2 (species)	Canonical axe 1 (environmental variables)	Canonical axe 2 (environmental variables)
VegeOpen	Vegetation openness	-0.0566	0.1645	-0.0627	0.2119
TreeC20m	Tree cover of individual with height higher than 20 m	0.6557	-0.311	0.726	-0.4004
TreeC720	Tree cover of individual with height between 7-20 m	0.419	0.0459	0.464	0.0591
TreeC.7m	Tree cover of individual with height less than 7 m	-0.1509	-0.2809	-0.167	-0.3617
HerbC	Herbaceous cover	-0.6234	-0.2147	-0.6902	-0.2765
HTree	Tree height	0.3403	-0.106	0.3768	-0.1365
Hshrub	Shrub tree height	-0.1433	-0.2842	-0.1587	-0.366
Hherb	Herbaceous plant height	-0.4194	-0.2943	-0.4643	-0.379
Topograp	Topography	-0.2957	0.3063	-0.3274	0.3944
EdaphSub	Edaphic substratum	-0.2142	-0.2021	-0.2371	-0.2602
Submers	Submersion (presence of water)	-0.2983	-0.2406	-0.3303	-0.3098
Fire	Fire occurrence	-0.3154	0.2502	-0.3493	0.3222
Grazing	Pastureland of grazing activity	-0.3753	0.2154	-0.4156	0.2773
Cropping	Existence of cropland	-0.0368	0.3695	-0.0407	0.4758
Wood-cut	Wood cutting activity	-0.1007	0.4424	-0.1115	0.5697
Swab	Bark or other plant organ harvesting	0.0226	0.4193	0.025	0.5399
Charcoal	Charcoal production	-0.0191	0.1433	-0.0211	0.1846

diversity and distribution were more or less even in the other woody plant communities (1.06 ≤H'≤1.43 and 0.63≤E≤0.83). Species are more evenly distributed in gallery forest along tributaries of Oti River (mostly Koumongou River). The equitability was E = 0.82 agoinst E = 0.63 in gallery forest along Oti River. Since anthropogenic activities are the main factor influencing species composition in theses habitats, the gallery forests along Oti River are more pressured than those along Koumongou River. This could be explained by the well conserved area located around Naboulgou where are the offices of park rangers.

According to the indicator species analysis (multilevel pattern analysis using R) 22 species are significantly associated to just one group on a total of 94 species. Thus the discriminated habitats share many species. Among these 22 species, 4 species are associated to G1, 8 species to G2, 1 species to G3, 2 species to G4, 5 species to G5, and 1 species to both G6 and G7. The list of species associated to each group is presented below. The most important species in each of these groups are presented in Table XII with their relative values of density (Rde), dominance (Rdo) and frequency (RF) and their regrowth rate.

While the indicator species analysis shows the specific relationship between species and site groups, the importance value index (IVI) shows well the physiognomy of each group. The abundance of shared species is revealed and indicates that at a certain level the habitats within Oti-Keran-Mandouri are more or less fuzzy. Some species such as *Anogeisus leiocarpus* (DC.) Guill. & Perr. and *Pterocarpus erinaceus* Poir. are well distributed in this area. The former is well distributed with high regrowth rate in gallery forests while the latter is present in gallery forests as well as in dry forests.

3.2.3. Structure of habitat types according to the level of suitability for elephant

Four habitats were distinguished based on the elephant habitat suitability map. These are degraded habitat (Habitat 1), least suitable habitat (Habitat 2), secondary habitat (Habitat 3) and primary habitat (Habitat 4). The primary habitat is considered as a good and well conserved habitat. The secondary habitat is a moderately conserved habitat. The least suitable habitat undergone a certain level of degradation. The Figure 23 shows the spatial distribution of these habitats within OKM.

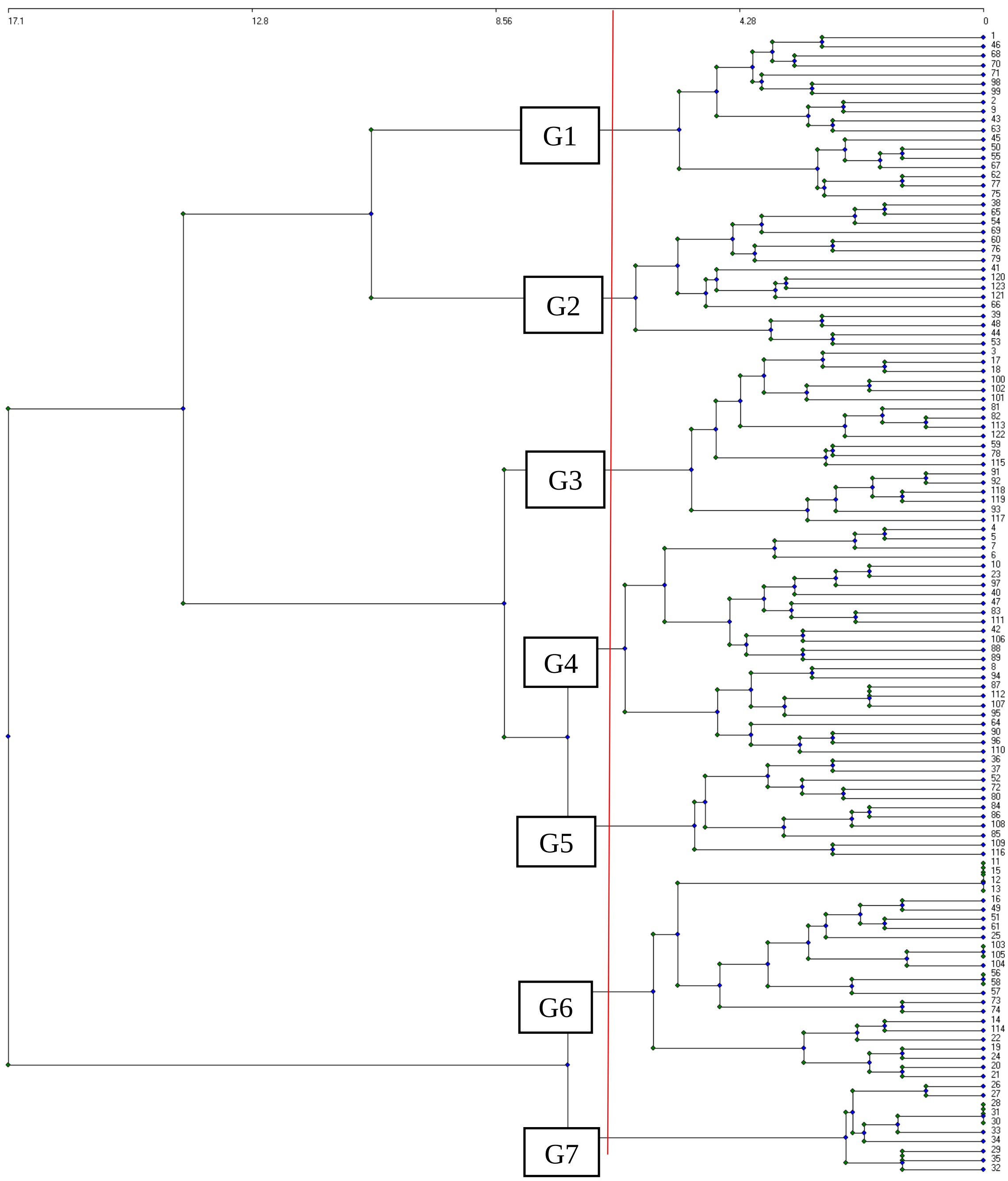

Figure 22: Dendrogram of the Hierarchical Cluster Analysis (HCA) performed on woody plant species from 123 samples within Oti-Keran-Mandouri (G1= Gallery forest; G2= Dry forest and woodland savanna; G3= Shrub savanna; G4= Tree savanna; G5= Gallery forest; G6= Mosaic composed of thorny woodland savanna, gallery forest and shea tree parkland and G7= *Borassus aethiopum* stand)

Table XI: Alpha diversity in the different woody plant communities discriminated within Oti-Keran-Mandouri

Vegetation groups	S	H' (bits)	E
G1	49	1.06	0.63
G2	49	1.27	0.75
G3	33	1.18	0.78
G4	54	1.43	0.83
G5	33	1.25	0.82
G6	29	1.14	0.78
G7	9	0.35	0.37

S=Number of species; H'=Shannon-Wiever Index; E=Pielou Equitability

Table XII: Most important woody plant species in each group and their estimated regrowth rate

Group	Species	Rde	Rdo	CVI	RF	IVI	Reg/ha
G1	*Anogeisus leiocarpus* (DC.) Guill. & Perr.	31.88	1.83	33.72	12.14	45.86	4156
	Diospyros mespiliformis Hochst. ex A. DC.	12.91	1.66	14.57	10.71	25.28	3100
	Tamarindus indica L.	14.93	1.14	16.07	7.14	23.21	544
	Mitragyna inermis (Willd.) O. Kuntze.	11.98	1.08	13.05	8.57	21.62	200
	Pterocarpus santalinoides DC.	0.31	13.76	14.07	0.71	14.79	0
G2	*Bombax costatum* Pellegr. & Vuill.	0.74	43.58	44.32	2.16	46.48	31
	Anogeisus leiocarpus (DC.) Guill. & Perr.	20.19	2.24	22.43	7.03	29.45	1005
	Crossopteryx febrifuga (G. Don) Benth.	18.15	0.70	18.85	7.03	25.88	431
	Pterocarpus erinaceus Poir.	7.59	2.32	9.92	5.95	15.86	595
	Vitellaria paradoxa C. F. Gaertn.	8.15	1.53	9.68	4.86	14.54	1477
G3	*Acacia gourmaensis* A. Chev.	29.29	4.66	33.95	6.59	40.55	1032
	Pseudocedrela kotschyi (Schweinf.) Harms	11.62	13.67	25.29	5.49	30.78	688
	Combretum glutinosum Perr. ex DC.	8.59	6.11	14.70	14.29	28.99	3039
	Lannea acida A. Rich.	5.56	7.62	13.17	7.69	20.87	84
	Balanites aegyptiaca (L.) Del.	7.07	6.28	13.36	3.30	16.65	196

Group	Species	Rde	Rdo	CVI	RF	IVI	Reg/ha
G4	*Pterocarpus erinaceus* Poir.	7.05	3.22	10.27	9.66	19.93	47
	Prosopis africana (Guill. & Perr.) Taub.	7.81	4.37	12.18	4.35	16.53	63
	Terminalia macroptera Guill. & Perr.	11.05	2.15	13.20	2.90	16.09	973
	Lannea microcarpa Engl. & K. Krause	6.48	2.55	9.03	4.83	13.86	55
	Pseudocedrela kotschyi (Schweinf.) Harms	6.48	2.02	8.49	5.31	13.81	361
G5	*Anogeisus leiocarpus* (DC.) Guill. & Perr.	23.28	4.43	27.71	4.76	32.47	1947
	Lannea barteri (Oliv.) Engl.	5.29	8.73	14.02	9.52	23.54	293
	Parkia biglobosa (Jacq.) R. Br. ex G Don f.	4.76	8.85	13.61	7.14	20.75	0
	Prosopis africana (Guill. & Perr.) Taub.	4.23	6.33	10.57	8.33	18.90	133
	Pterocarpus erinaceus Poir.	8.47	3.82	12.28	5.95	18.24	27
G6	*Adansonia digitata* L.	0.61	48.48	49.10	3.28	52.38	12
	Mitragyna inermis (Willd.) O. Kuntze.	12.68	1.00	13.68	11.48	25.16	909
	Anogeisus leiocarpus (DC.) Guill. & Perr.	13.50	5.33	18.83	4.92	23.75	0
	Acacia polyacantha Willd. ssp. *campylacantha* (Hochst. ex A. Rich.) Brenan	11.04	0.82	11.87	11.48	23.34	12
	Pterocarpus santalinoides DC.	13.91	1.44	15.34	3.28	18.62	0
G7	*Borassus aethiopum* Mart.	82.35	8.54	90.89	47.62	138.51	381
	Adansonia digitata L.	1.18	61.42	62.60	4.76	67.36	0
	Parkia biglobosa (Jacq.) R. Br. ex G Don f.	3.53	8.62	12.15	9.52	21.67	0
	Vitex doniana Sweet	4.71	4.51	9.21	9.52	18.74	19
	Lannea microcarpa Engl. & K. Krause	1.18	11.92	13.09	4.76	17.86	0

Rde=Relative density; Rdo=Relative dominance; CVI=Cover value index; IVI=Importance value index; Reg/ha= Regeneration rate per hectare

Multilevel pattern analysis

Association function: IndVal.g

 Significance level (alpha): 0.05

List of species associated to each combination:

Group 1 #sps. 4

Diospyros mespiliformis 0.789 0.001 ***

Tamarindus indica 0.721 0.001 ***

Khaya senegalensis 0.394 0.027 *

Feretia apodanthera 0.333 0.043 *

Group 2 #sps. 8

Crossopteryx febrifuga 0.748 0.001 ***

Combretum collinum 0.589 0.001 ***

Hymenocardia acida 0.569 0.003 **

Vitellaria paradoxa 0.548 0.002 **

Bridelia ferruginea 0.473 0.007 **

Tectona grandis 0.433 0.013 *

Gardenia aqualla 0.383 0.018 *

Grewia carpinifolia 0.368 0.046 *

Group 3 #sps. 1

Terminalia avicennioides 0.397 0.029 *

*Significance codes:0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Group 4 #sps. 2

*Grewia venusta 0.600 0.001 ****

*Lannea microcarpa 0.548 0.002 ***

Group 5 #sps. 5

*Oncoba spinosa 0.568 0.002 ***

*Acacia sieberiana 0.554 0.002 ***

*Parkia biglobosa 0.540 0.003 ***

*Ficus gnaphalocarpa 0.471 0.004 ***

*Securidacca longepedunculata 0.386 0.030 **

Group 6 #sps. 1

*Acacia amythetophyla 0.408 0.02 **

Group 7 #sps. 1

Borassus aethiopum 1 0.001 ***

3.2.3.1. Characteristic woody plant species for each habitat

The values of biodiversity indices for each habitat type are reported in Table XIII. The species richness is higher in Habitat 3 than in others type of habitats meanwhile Shannon index is higher for Habitat 4. The species diversity varies from eight species in degraded habitat (Habitat 1) to sixteen species in secondary habitat (Habitat 3). Shannon index shows a steady increase in habitat diversity from degraded habitat (Habitat 1) to primary habitat (Habitat 4) with the Shannon index increasing from 0.83 bit to 1.43 bit. In all the habitats, trees are more or less evenly distributed with an eveness higher than 0.7.

According to the indicator species analysis, many woody plant species and combination of species were identified as characteristics for each habitat. Nine species were associated with Habitat 1, seven species with Habitat 2, ten species with Habitat 3 and 81 with Habitat 4. The Table XIV reports the most important indicator species for each habitat according to their level of significance in the given habitat. According to Jaccard similarity index (Table XV), Habitat 1 and habitat 2 are quite similar (J<50%). The same pattern was noticed for Habitat 3 and Habitat 4.

3.2.3.2. Structural parameters of each habitat

The dendrometric parameters of the different habitats such as the density (N), the mean diameter (D), the basal area (G_1), the mean height (HM), the lorey's mean height (H_L) and the average regrowth rate are reported in Table XVI. Apart from the mean diameter and the average regrowgth rate, all the other dendrometric parameters are significantly different from one habitat to another according to the test of Kruskal –Wallis. Plant density (N), the mean height (HM) and the Lorey's mean height (HL) increase steadily from the degraded habitat (Habitat 1) to the well conserved habitat (Habitat 4). However, the basal area (G_1) is higher for the moderately conserved habitat (Habitat 3). The mean diameter (D) is almost the same in all the habitats. Meanwhile, the regrowth rate is higher in the least suitable habitat (Habitat 2) and more important in the degraded habitat (Habitat 1) compared to Habitat 3 and Habitat 4.

The Figure 24 shows the observed diameter structure for the distinguished habitats. Apart from Habitat 1 which shows a bell shape with the shape parameter c=2.07, the others habitat types which showed an inverse ''J'' shape with the c values of 1.11, 1.5 and 1.27 for Habitat 2, Habitat 3 and Habitat 4 respectively. The shape parameter c has its values ranged between 1 and 3.6 ($1<c<3.6$) characterizing the high frequency of plants with small diameter. The difference in shape from Habitat 1 (bell shape) to the others habitats (inverse "J" shape) is a sign of the gradual increase in density of trees with small diameter. Plants with a center diameter of 15 cm are almost absent in Habitat 1 while present in all the others habitats with the highest density in Habitat 4. Individuals of 25 cm of center diameter are well represented in every habitat and their density increases steadily from Habitat 1 to Habitat 4. Meanwhile, plants with diameter from 55 cm and higher are rare however individuals of such diameter could be found in Habitat 1 and mostly in Habitat 4.

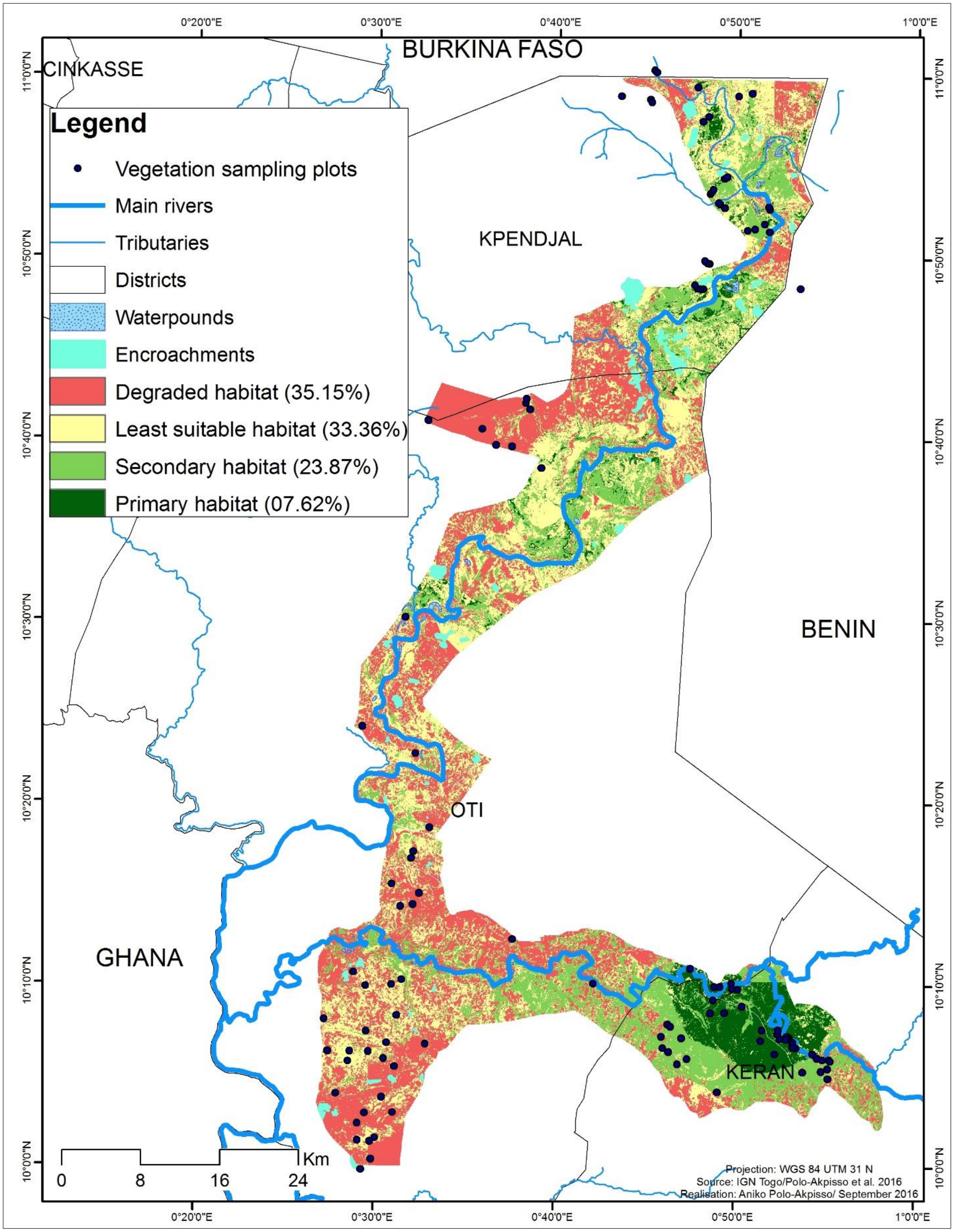

Figure 23: Distribution of habitat types according to their level of suitability within Oti-Keran-Mandouri

Table XIII: Alpha diversity for the distinguished habitats

Habitats	Sp Richness	Shannon	Eveness
Habitat 1 (n=27 plots)	8	0.83	0.75
Habitat 2 (n=19 plots)	14	1.04	0.79
Habitat 3 (n=28 plots)	16	1.07	0.74
Habitat 4 (n=24 plots)	13	1.43	0.74

Table XIV: Most important indicator species for each habitat according to their significance level

Indicator species	Habitat 1	Habitat 2	Habitat 3	Habitat 4
Individual species	*Vitellaria paradoxa**	*Combretum glutinosum**	*Burkia africana***	*Anogeissus leiocarpus****
	*Parkia biglobosa**	*Terminalia mollis**		*Diospyros mespiliformis****
		*Terminalia avicennioides**		*Oncoba spinosa***
				*Celtis integrifolia***
Combination of species	*Combretum glutinosum + Parkia biglobosa**	*Combretum glutinosum + Piliostigma thonningii***	*Crossopteryx febrifuga + Lannea acida***	*Anogeissus leiocarpus + Lannea barteri****
	*Combretum molle + Pteleopsis suberosa**	*Combretum glutinosum + Terminalia mollis***		*Anogeissus leiocarpus + Vitex doniana****
	*Lannea barteri + Parkia biglobosa**	*Combretum glutinosum + Terminalia macroptera***		*Anogeissus leiocarpus + Pterocarpus erinaceus***
	*Lannea barteri + Pseudocedrela kotschyi**			*Anogeissus leiocarpus + Oncoba spinosa***
	*Acacia gourmaensis + Combretum collinum**			*Anogeissus leiocarpus + Mitragyna inermis***
	*Parkia biglobosa + Vitex doniana**			*Anogeissus leiocarpus + Diospyros mespiliformis***

Indicator species	Habitat 1	Habitat 2	Habitat 3	Habitat 4
Combination of species	*Combretum collinum + Combretum glutinosum**			*Anogeissus leiocarpus + Piliostigma thonningii*** *Mitragyna inermis + Tamarindus indica*** *Diospyros mespiliformis + Mitragina inermis*** *Acacia Polyacantha + Mitragyna inermis*** *Anogeissus leiocarpus + Terminalia laxiflora*** *Oncoba spinosa + Pterocarpus erinaceus*** *Diospyros mespiliformis + Oncoba spinosa*** *Diospyros mespiliformis + Lannea barteri*** *Acacia polyacantha + Grewia carpinifolia*** *Celtis integrifolia + Diospyros mespiliformis*** *Diospyros mespiliformis + Pouteria alnifolia***

Significance codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.'**

3.2.3.3. Fragmentation of habitats within OKM

According to the value of Jaccard indices Habitat 1 and Habitat 2 were aggregated into degraded habitat (background) meanwhile Habitat 3 and Habitat 4 were aggregated into suitable habitat of elephant (foreground). The hypsometric analysis revealed that the suitable habitat of elephant constitutes 31.5% of the area of OKM while 68.5% is degraded habitat. The overall habitat fragmentation (for the whole of OKM) is 84.74%. Meanwhile the suitable habitat is 81.81% fragmented and the degraded habitat fragmented by 86.08% (Figure 25).

3.3. Changes in land cover categories within OKM between 1987 and 2013

3.3.1. Classification accuracy

The overall accuracy of the land cover map is 79.28%, 73.33%, and 79.06% for 1987, 2000, and 2013 respectively. There is a good agreement of the classification results and reference data with values of Kappa statistics of 0.69, 0.65 and 0.72 as respective overall classification accuracy. However, there were low producer's accuracies for earlier land covers (1987 and 2000): settlements and water bodies for ETM 2000 (14.29% and 16.67%) and settlements for TM 1987 (26.32%). On the other side, user's accuracy was low for cropland and water bodies for TM 1987 (Table XVII).

3.3.2. Land cover dynamics

Wetland was the most represented land cover type. Wetlands, forests and savannas regressed to the profit of anthropogenic land cover types that are cropland and settlements from 1987 to 2013 (Figure 26). Figure 27 shows the change in percentage of the overall area of OKM in each land cover type from 1987 to 2013. Wetlands decreased in percentage of the overall area from 43.05% in 1987 to 36.30% in 2000 and to 31.71% in 2013. Savanna decreased from 37.72% in 1987 to 26.34% in 2000 and to 18.41% in 2013. Forests increased from 8.84% in 1987 9.03% in 2000 but decreased to 2.24% in 2013. Meanwhile, croplands increased from 0.91% in 1987 to 13.75% in 2000 and to 34.81% in 2013. Settlements decreased from 7.74% in 1987 to 13.22% in 2000 and to 10.22% in 2013. Water bodies decreased from 1.74% in 1987 to 1.36% in 2000 but increased to 2.61% in 2013.

Table XV: Similarity between distinguished habitat according to Jaccard similarity index

Jaccard similarity index	Habitat1	Habitat2	Habitat3	Habitat4
Habitat1	1			
Habitat2	0.60	1		
Habitat3	0.43	0.44	1	
Habitat4	0.39	0.38	0.54	1

Table XVI: Dendrometric parameters of the different habitat

	N	CvN	D	CvD	G	CvG	HM	CvHM	HL	CvHL	R	CvR
Habitat 1 (n=27 plots)	143	63.58	33.31	35.23	10.83	49.24	10.30	21.00	11.39	17.98	10922	97.65
Habitat 2 (n=19 plots)	156	58.30	32.42	34.75	12.81	84.31	10.41	22.57	11.47	23.04	12680	83.65
Habitat 3 (n=28 plots)	293	48.31	33.29	57.23	32.91	157.97	12.74	39.79	14.59	38.91	6444	68.37
Habitat 4 (n=24 plots)	305	33.08	27.63	27.78	18.32	49.97	14.12	35.17	17.21	30.99	4855	95.21
p-value*	<0.001	_	0.4538	_	0.003245	_	0.01778	_	<0.001	_	0.05584	_

* Kruskal-Wallis Test

N: Density (Nb of individual plants/ha)

Cv: Coefficient of variation

D: Mean diameter (cm)

G: Basal area (m2/ha)

HM: Mean height (m)

HL: Lorey's mean height (m)

R: Regrowth rate (Nb of Juveniles/ha)

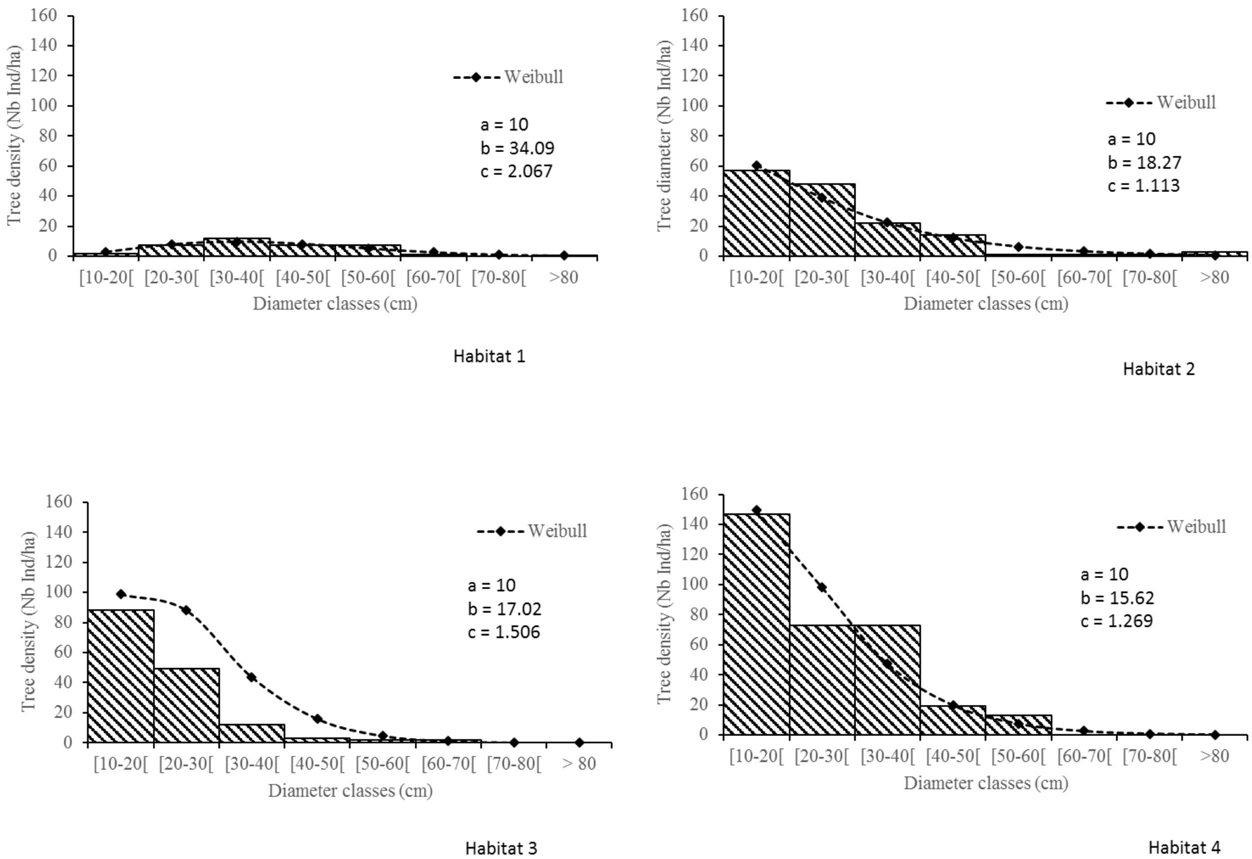

Figure 24: Tree stems diameter structure for distinguished habitats (a=fixed class with=10 cm, b= scale parameter linked to the central value of diameters and c = shape parameter of the structure)

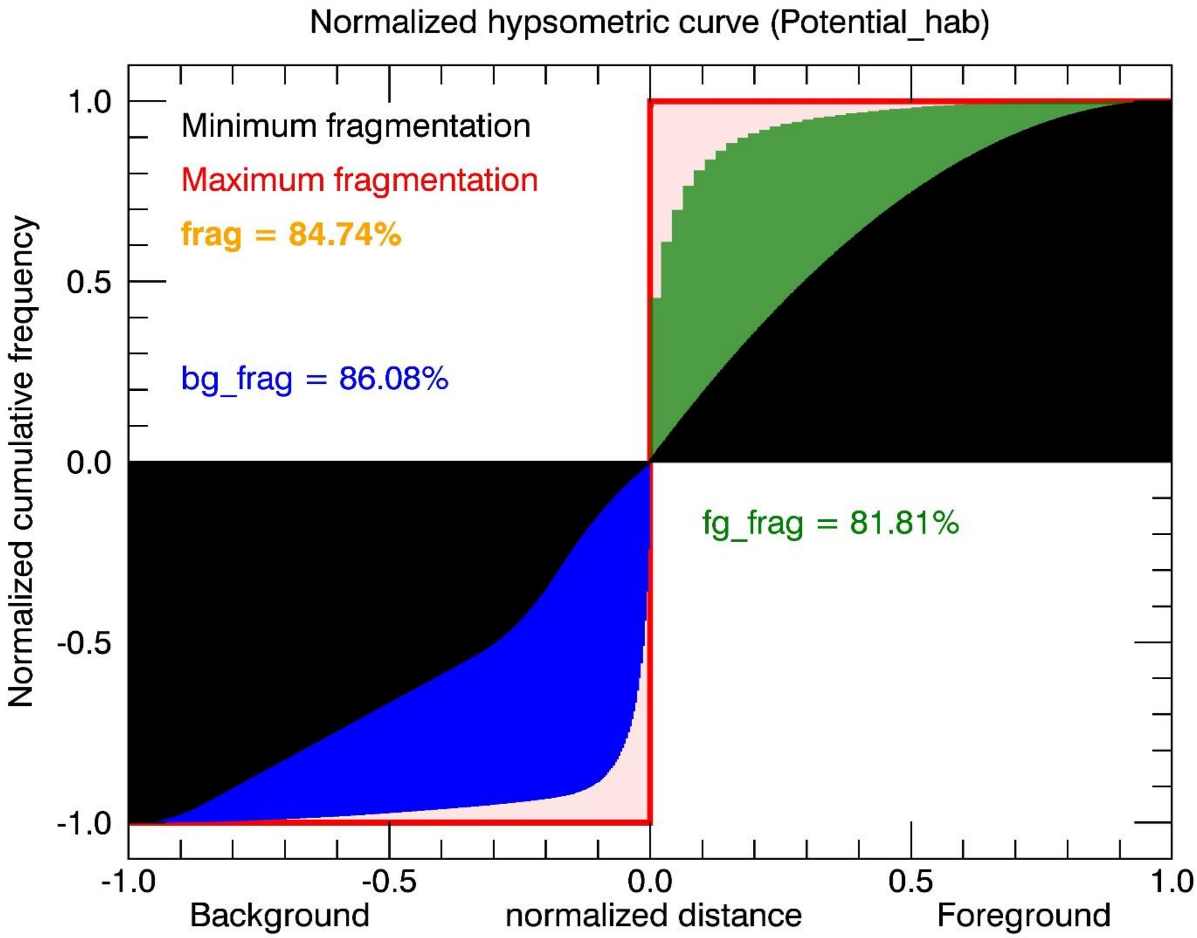

Figure 25: Normalized hypsometric curve of the fragmentation analysis of the habitat within OKM (frag= fragmentation; bg= background = degraded habitat; and fg= foreground = Elephant habitat)

3.3.3. Land cover change analysis

From 1987 to 2000, the most important changes in land cover were losses in wetland and gains in cropland. Table XVIII shows the transition in each land category in percentage of the overall area of OKM. Forests were mostly converted in savanna (3.28%) and in wetlands (2.68%) and less converted in cropland (0.30%) and settlements (0.18%). Savannas were mostly converted in wetlands (14.50%) and croplands (4.29%) whereas wetlands were mostly converted in settlements (8.53%) and in savannas (8.50%). Some portions of croplands were also converted in wetlands (0.30%) and in forests (0.17%). Settlements were mostly converted to wetlands (2.62%) and savannas (1.77%). There was less changes in water bodies but they were mostly converted to forests (0.53%) and wetlands (0.28%).

From 2000 to 2013, croplands and wetlands remained the land categories that changed most and wetlands remained the land category where changes have been more important. The transition in each land category in percentage of overall area of OKM is shown in Table XIX. Forests were mostly converted in wetlands (2.02%) and in croplands (1.95%). Savannas were mostly converted in wetlands (7.47%) and in croplands (7.40%) while (11.74%) and in (6.92%) of wetlands were respectively converted in croplands and in savannas. Part of croplands were also converted in others land categories: 3.70% were converted in wetlands, 1.51% in settlements and 0.81% in savannas. Water bodies were mostly converted in croplands (0.24%) and in wetlands (0.23%).

The overall change between 1987 and 2013 showed high variation in wetlands and croplands. Figure 28 shows land cover change maps from 1987 to 2013 and Table XX reports the transition in each land category. Wetlands were more converted in croplands (16.84%) and in settlements (6.19%) than in other land categories. There was also transition of savannas to wetlands (11.33%) and croplands (12.80%). Forests were more converted in savannas (4.02%) and croplands (1.71%) than in wetlands (0.83%) and water bodies (0.05%). Croplands were also converted in wetlands (0.28%), in settlements (0.14%), in water bodies (0.08%), in savannas (0.06%) and in (0.01%). Settlements were mostly converted in croplands (2.85%) and wetlands (2.81%). Water bodies were more converted in settlements (0.28%) and in croplands (0.27%) than in wetlands (0.18%), savannas (0.06%) and forests (0.01%).

Table XVII: Image classification accuracy

Land cover	1987		2000		2013	
	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)
Forests	100	61.11	82.22	78.72	83.87	89.66
Savannas	82.47	86.02	81.82	60	68	72.34
Wetlands	81.31	87	83.72	70.59	87.10	69.23
Croplands	50	33.33	62.96	85	84.62	91.67
Settlements	26.32	62.50	14.29	100	75	57.14
Water bodies	100	36.36	16.67	100	35.71	83.33
Overall accuracy	79.28%		73.33%		79.06%	
Kappa	0.69		0.65		0.72	
	PA=Producer's accuracy			UA=User's accuracy		

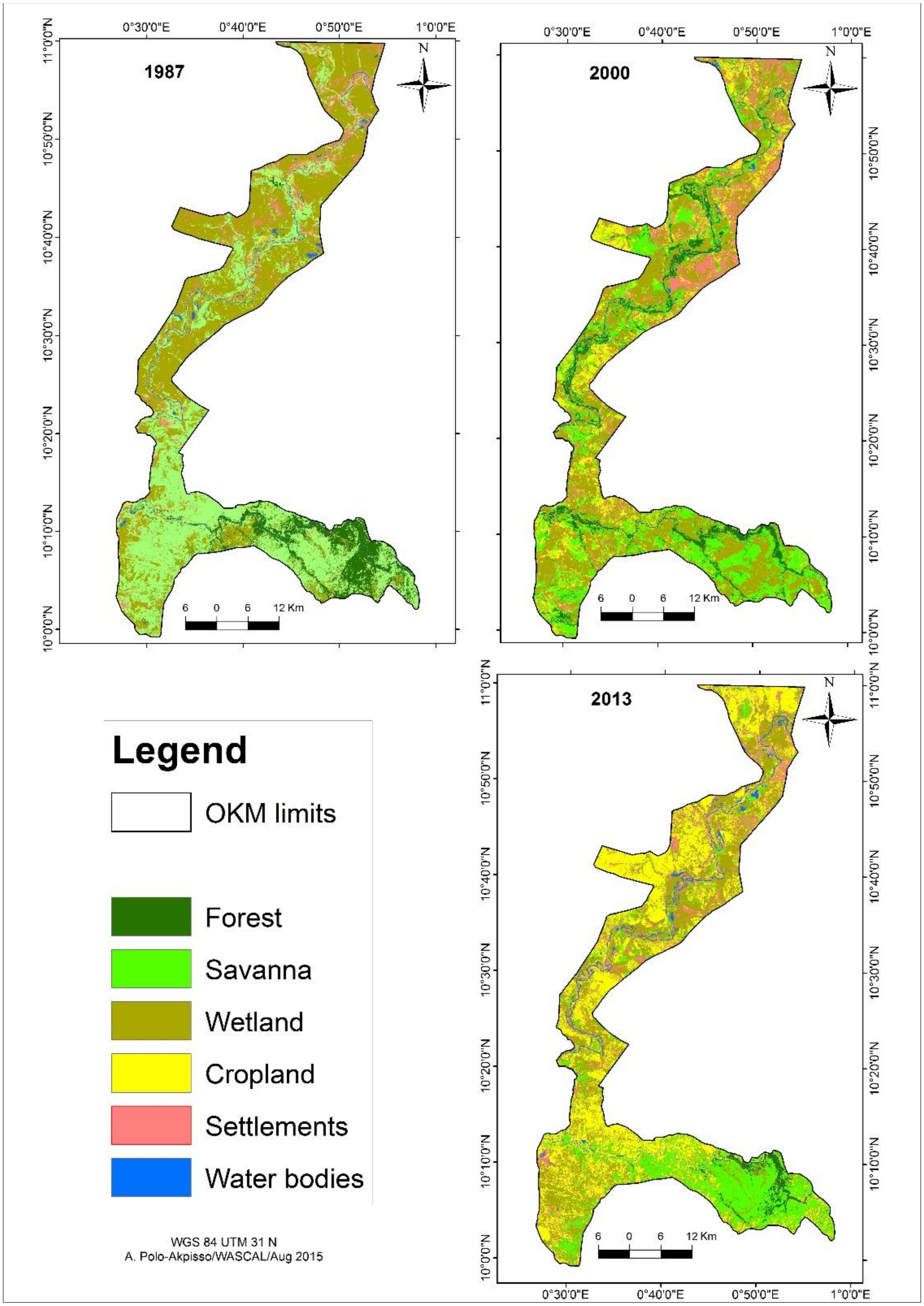

Figure 26: Land cover maps of Oti-Keran-Mandouri for 1987, 2000 and 2013

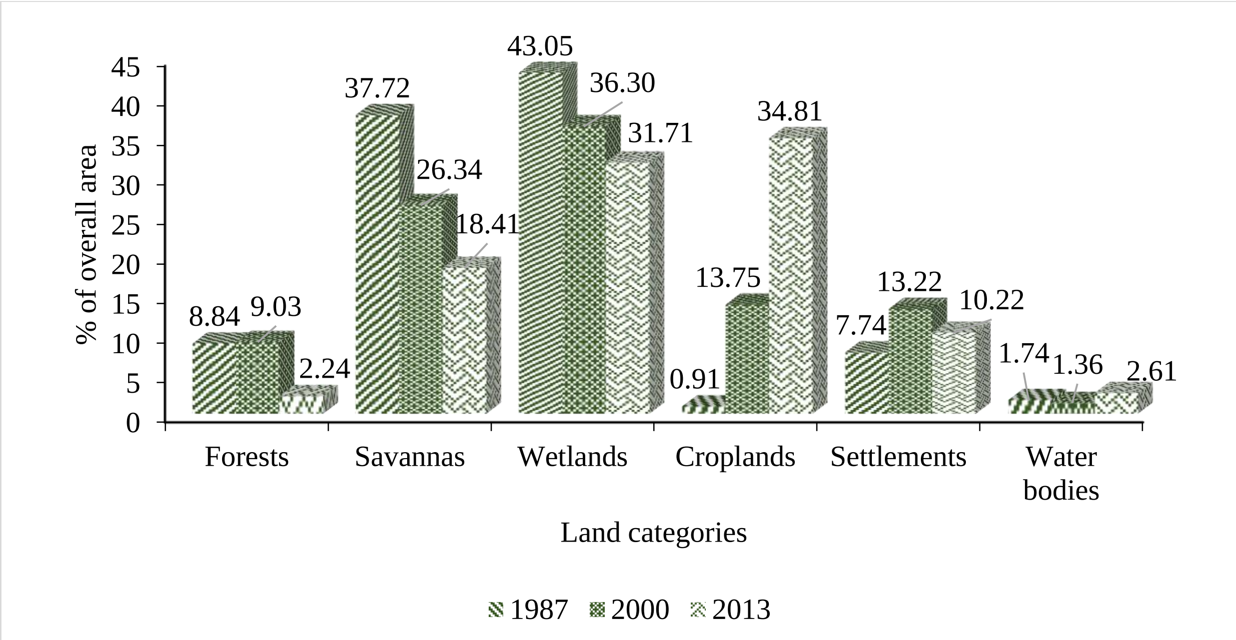

Figure 27: Changes in land categories within Oti-Keran-Mandouri complex in Togo from 1987 to 2013

Table XVIII: Transition matrix in percent (%) of overall area from 1987 to 2000 within Oti-Keran-Mandouri

		2000					
		Forests	Savannas	Wetlands	Croplands	Settlements	Water bodies
1987	Forests	2.31	3.28	2.68	0.30	0.18	0.10
	Savannas	3.29	12.39	14.50	4.29	2.85	0.40
	Wetlands	2.09	8.50	15.92	7.69	8.53	0.32
	Croplands	0.17	0.15	0.30	0.13	0.12	0.04
	Settlements	0.64	1.77	2.62	1.19	1.37	0.16
	Water bodies	0.53	0.27	0.28	0.14	0.18	0.34

Table XIX: Transition matrix in percent (%) of overall area from 2000 to 2013 within Oti-Keran-Mandouri

		2013					
		Forests	Savannas	Wetlands	Croplands	Settlements	Water bodies
2000	Forests	1.05	1.79	2.02	1.95	1.30	0.92
	Savannas	0.67	8.13	7.47	7.40	2.21	0.45
	Wetlands	0.46	6.92	13.78	11.74	3.04	0.37
	Croplands	0.02	0.81	3.70	7.57	1.51	0.15
	Settlements	0.02	0.69	4.50	5.91	1.96	0.14
	Water bodies	0.02	0.07	0.23	0.24	0.20	0.60

Table XX: Transition matrix in percent (%) of overall area from 1987 to 2013 within Oti-Keran-Mandouri

		2013					
		Forests	Savannas	Wetlands	Croplands	Settlements	Water bodies
1987	Forests	2.00	4.02	0.83	1.71	0.24	0.05
	Savannas	0.16	10.67	11.33	12.80	2.23	0.54
	Wetlands	0.04	3.03	16.29	16.84	6.19	0.66
	Croplands	0.01	0.06	0.28	0.34	0.14	0.08
	Settlements	0.02	0.57	2.81	2.85	1.15	0.35
	Water bodies	0.01	0.06	0.18	0.27	0.28	0.93

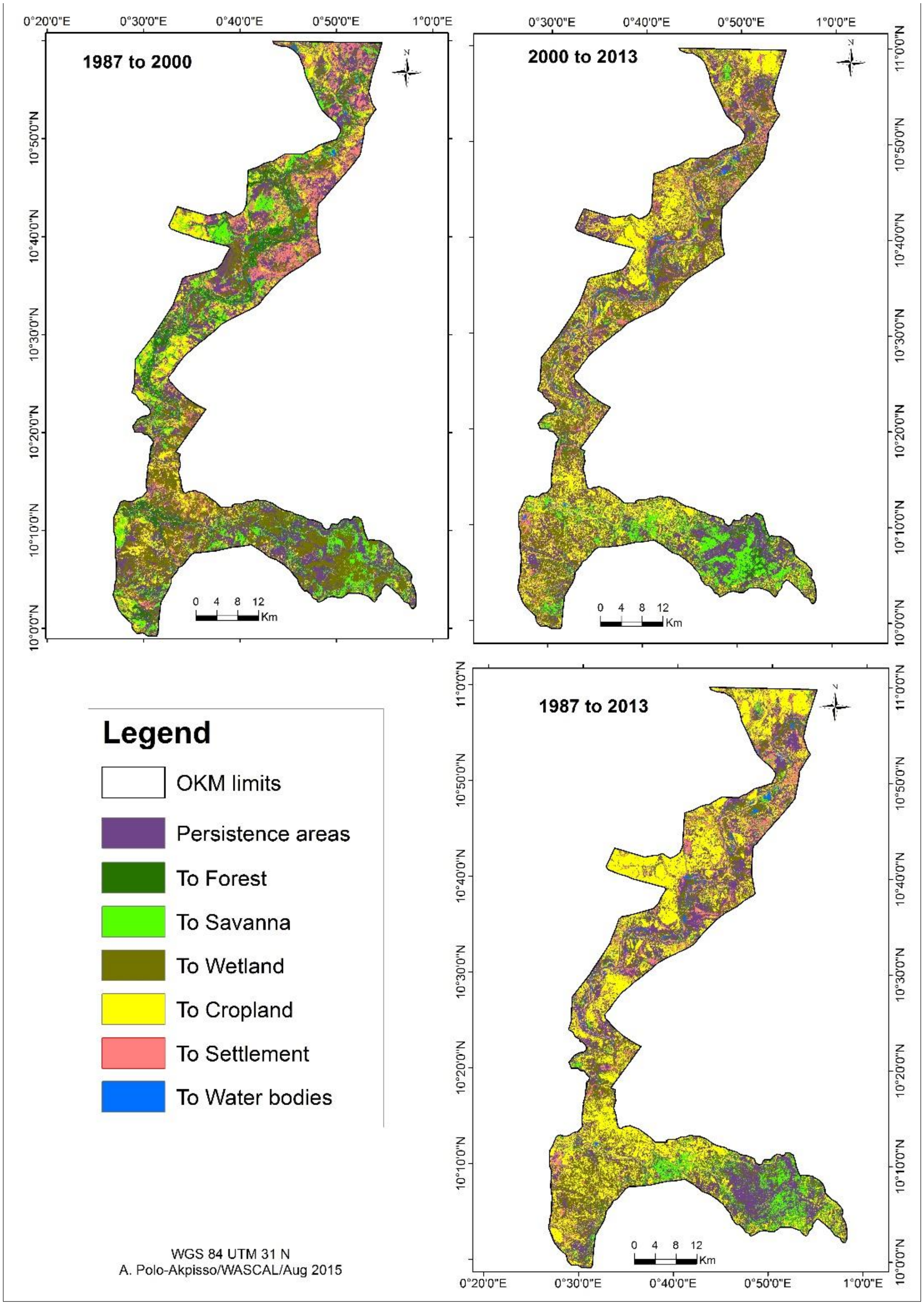

Figure 28: Land cover change maps within Oti-Keran-Mandouri from 1987 to 2013

The net change in each land category i.e. the result of taking the earlier land cover areas, adding the gains and then subtracting the losses is reported in Table XXI. Croplands and settlements respectively increased at an average of 108.13% and 5.45% each of the proportion of their own area from 1987 to 2000. From 2000 to 2013, croplands gained from all other land categories and continue then to increase but at a rate of 11.77% per year of their own area. Whereas forests and savannas respectively decreased at an annual average rate by 5.79% and 2.32% of their own area. Globally from 1987 to 2013, forests, savannas and wetlands have decreased at an average annual percentage of their own area by respectively 5.74%, 3.94% and 2.02% whereas croplands increased at an average annual rate of 285.39% of its own area.

3.3.4. Habitat change processes from 1987 to 2013

Different habitat transformation processes dominated the time periods considered for this analysis (1987 to 2000; 2000 to 2013; and the overall period from 1987 to 2013). These processes were aggregation, attrition, dissection and creation. Table XXII summarizes the different change processes occurring in each land cover category from 1987 to 2013. Meanwhile, Figure 29 and Figure 30 represent for each land category for the same period the number of patches and their area respectively. The change process was different from one land category to another. Forests experienced creation from 1987 to 2000 and attrition from 2000 to 2013. But, the dominant change process from 1987 to 2013 is attrition. Concurrently, the number of forest patches increased and an expansion of the area was observed from 1987 to 2000. But, forest patches as well as their area decreased from 2000 to 2013. The number of savanna patches increased from 1987 to 2000 and decreased from 2000 to 2013 whereas their area decreased during both of the two periods. These conversion processes are denoted as dissection from 1987 to 2000 and as attrition from 2000 to 2013. Meanwhile, the wetlands were dominated by attrition from 1987 to 2000 and dissection from 2000 to 2013. The number of wetland patches decreased from 1987 to 2000 and increased from 2000 to 2013. The area of wetlands decreased consistently from 1987 to 2000 and from 2000 to 2013. Croplands experienced a continuous increase in area from 1987 to 2013 while the number of cropland patches increased only from 1987 to 2000 but decreased from 2000 to 2013. The underlining land conversion processes were creation from 1987 to 2000 and aggregation from 2000 to 2013. The dominant habitat change processes from 1987 to 2013 are attrition in forests and savannas, dissection in wetlands and creation in croplands.

Table XXI: Net change in each land category within Oti-Keran-Mandouri

	1987 to 2000			2000 to 2013			1987 to 2013		
	Total net change (ha)	Average net change per year (ha)	Annual net change in % of earlier area	Total net change (ha)	Average net change per year (ha)	Annual net change in % of earlier area	Total net change (ha)	Average net change per year (ha)	Annual net change in % of earlier area
Forests	336	25.85	0.16	-12269	-943.77	-5.79	-11923	-917.15	-5.74
Savannas	-20548	-1580.62	-2.32	-14321	-1101.62	-2.32	-34869	-2682.23	-3.94
Wetlands	-12186	-937.38	-1.21	-8285	-637.31	-0.97	-20472	-1574.77	-2.03
Croplands	23190	1783.85	108.13	38019	2924.54	11.77	61209	4708.38	285.39
Settlements	9894	761.08	5.45	-5415	-416.54	-1.75	4479	344.54	2.47
Water bodies	-685	-52.69	-1.68	2272	174.77	7.14	1586	122.00	3.89

Table XXII: Change process for different land categories within Oti-Keran-Mandouri from 1987 to 2013

	Change process		
	1987 to 2000	2000 to 2013	1987 to 2013
Forest	Creation	Attrition	Attrition
Savanna	Dissection	Attrition	Attrition
Wetland	Attrition	Dissection	Dissection
Cropland	Creation	Aggregation	Creation

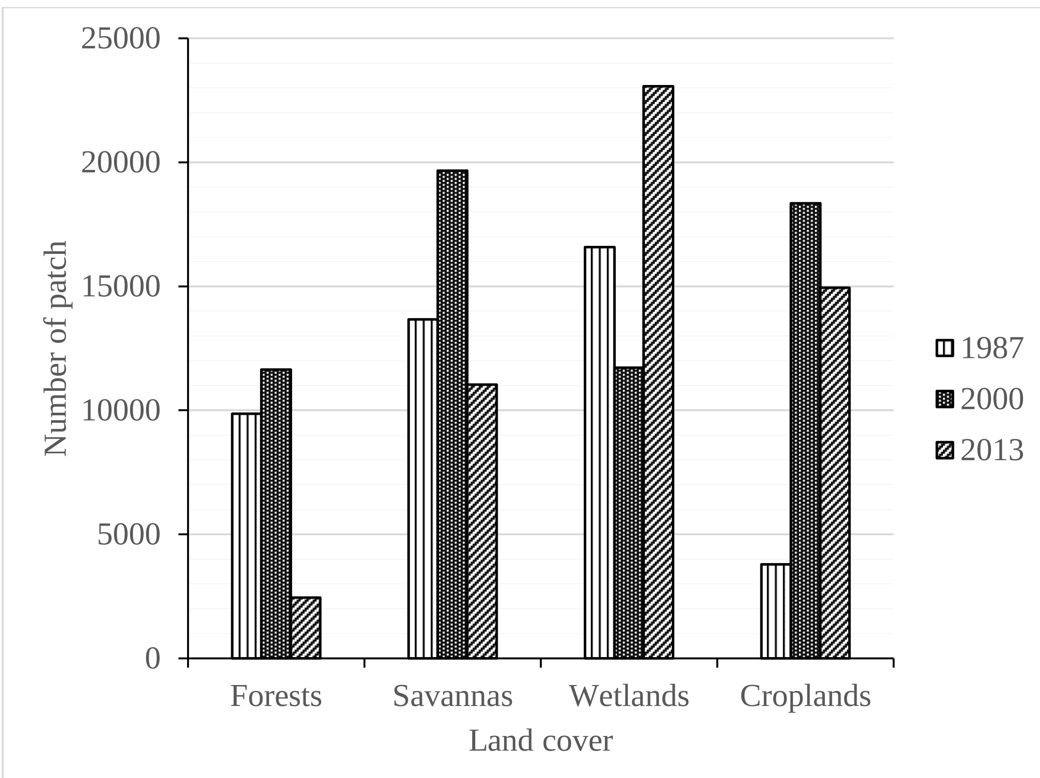

Figure 29: Number of patches for different land cover category within Oti-Keran-Mandouri from 1987 to 2013

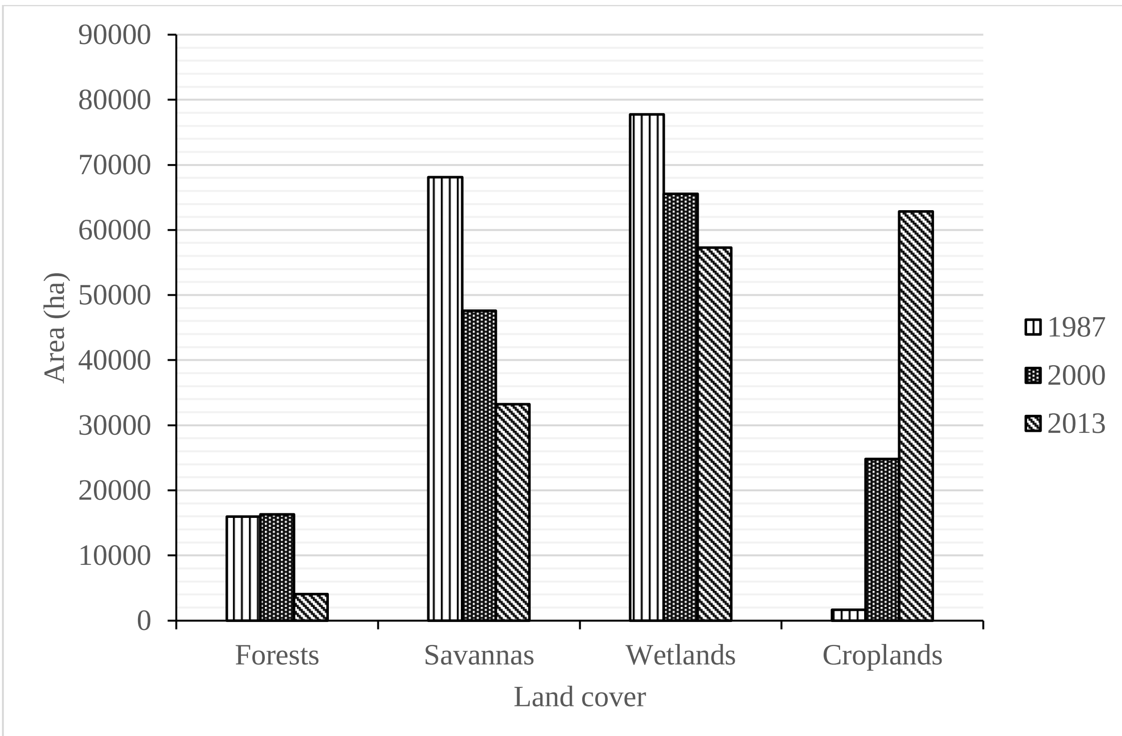

Figure 30: Area of different land cover categories within Oti-Keran-Mandouri from 1987 to 2013

3.4. Vulnerability of habitat patches to climate induced anthropogenic pressure

3.4.1. Description of socioeconomic conditions of the sampled respondents

A total of 53 stakeholders, head of their household, was surveyed in seventeen villages surrounding OKM. The sample was composed of three women (5.66%) and 50 men (94.34%). All the age categories were represented. There were young people of age between 20 to 40 years old (16.98%), adults of age between 41 to 60 years old (32.08%) and old persons of age higher than 61 years old (50.94%). Essentially, five ethnic communities were surveyed. These are Gourma (28.30%), Gangam (26.42%), Tchokossi (20.75%), Lamba (15.09%) and Konkomba (9.43%). The Gourma communities are located in the northern part of the protected areas in Kpendjal district. Konkomba are in the south-western part whereas Lamba are in the south-eastern part. Meanwhile Gangam and Tchokossi are in between and mostly located in the Oti district. About 41.51% of the respondents attended the formal education with 5.66% reaching the Senior high school and 18.87% the Junior high school. More than half of them (58.49%), mostly the old persons, did not have any formal education. The mean size of the household was 18.57 ±18.89 individuals.

3.4.2. Perceptions of climate change

The quantity of rainfall has decreased these last decades for 94.30% of the respondents. It has increased for 3.80% and 1.90% of the respondents found it not stable. Compared to the last decades the rainy season is delayed for 71.70% and not stable for 24.5% of the respondents. Meanwhile it has increased for 3.8%. The rainy season is currently shortened for 90.60% and not stable for 3.80% of the respondents. However, 5.70% found it longer.

All the respondents found drought period to be increasing steadily along the years. The temperature has increased for 81.10% and decreased for 15.10% of the surveyed residents. Meanwhile, 3.8 % of them found no change in the condition of temperature. Natural disaster such as violent wind events has increased for 81.10% but decreased for 13.20% of the respondents. The violent winds are not stable for 1.90% and have not changed for 3.80% of the respondents. The frequency of flood events has not changed for 37.70% but increased for 35.80%. About, 13.20% found that flood events have decreased in their locality meanwhile another 13.20% reported no flood in their area.

There are three main interpretations for all these changes (Figure 31). The first one is that God is responsible for these changes and this idea is supported by 35.80% of the residents. The second one is that there is more and more disrespect to the local traditions and this is supported by 32.10%. Finally, 30.20% of the residents reported that the degradation of the vegetation constitutes the cause of all these changes.

No correlation was found between the perceived change and the cultural background, the age of the respondents and their access or not to formal education. The Chi-square test was not significant in none of these cases.

3.4.3. Vegetation condition

All the surveyed residents found that the vegetation cover has decreased in the region. The expansion of agricultural land (41%), charcoal production (28%), illegal logging (25%) and the expansion of settlements (6%) were reported as the main causes of vegetation degradation (Figure 32). These causes are mainly triggered by demographic factors (51%), poverty (43%) and transhumance (6%) (Figure 33).

3.4.4. Climatic condition from 1981 to 2013

The climatic normality indices calculated based on data from 1981 to 2013 of the meteorological station in Mango showed a high variability in rainfall and an increase tendency of temperature from the year 2002 (Figure 34 et Figure 35).

3.4.5. Adaptation strategies to the perceived changes in the climatic conditions

The surveyed resident communities have elaborated different strategies to cope with the perceived change in climatic variables. Their agricultural activities are the main impacted by these changes. Therefore, some strategies were elaborated to adapt their cultivation system (Figure 36). The main reported strategies are crop diversification (37.11%), recessional agriculture (34.02%) (Figure 37), introduction of new varieties (17.53%) (Figure 38) and the increase of farmland (5.15%). However, some stakeholders (5.15%) asserted that they were not implementing any strategies.

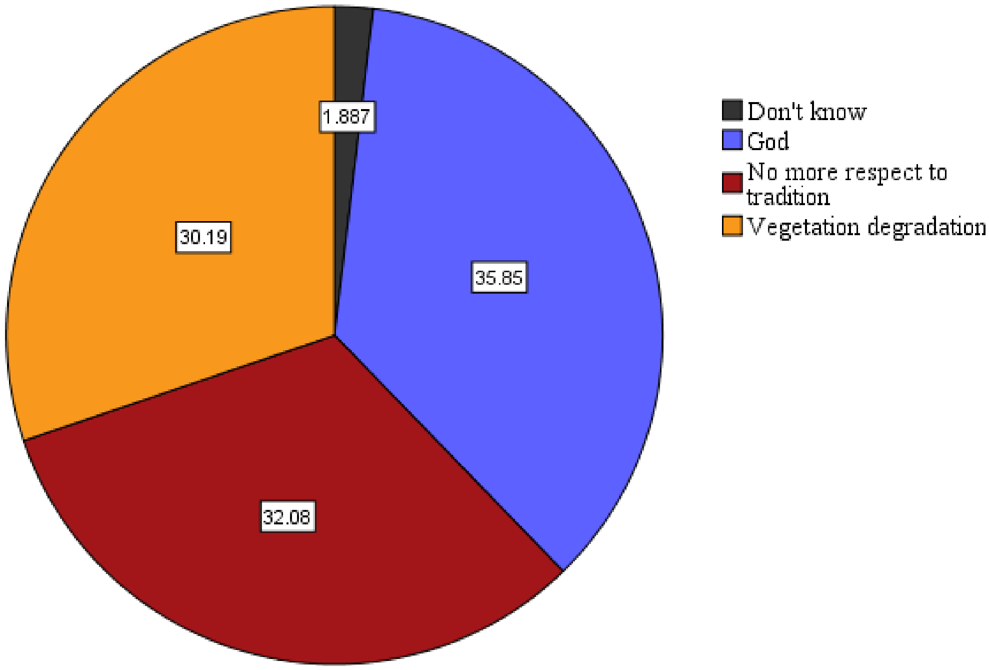

Figure 31: Interpretation of the changes in climatic variables by stakeholders around Oti-Keran-Mandouri (Proportion in percentage)

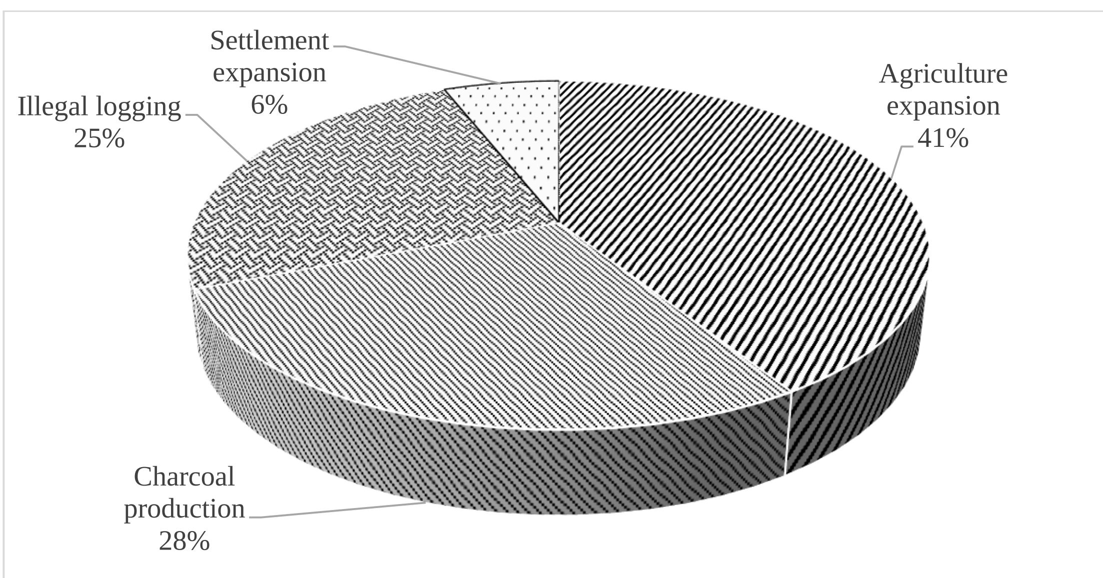

Figure 32: Reported causes of vegetation degradation in the Oti-Keran-Mandouri region

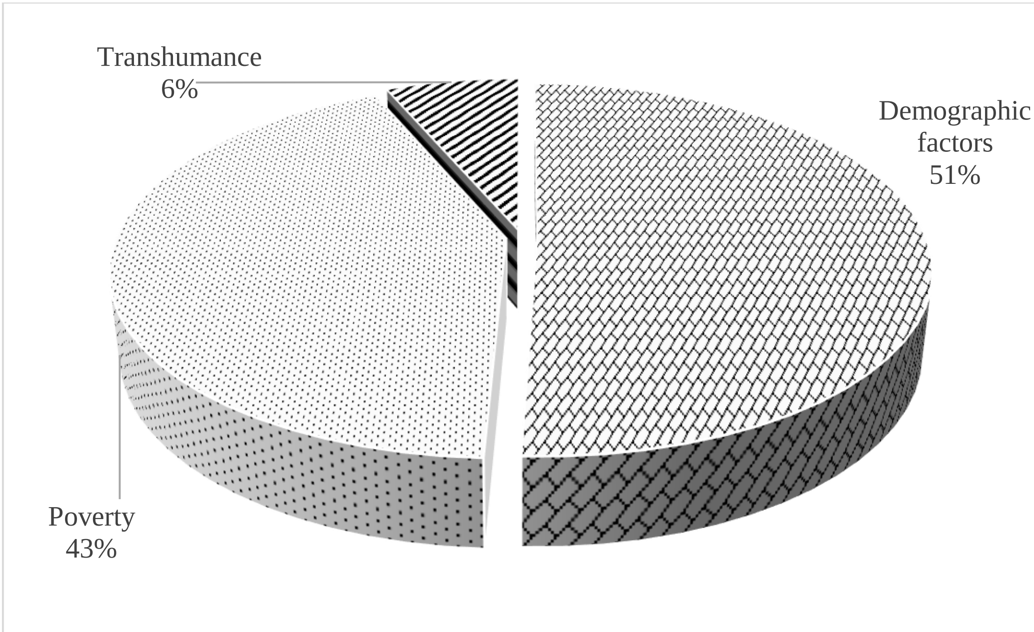

Figure 33: Underpinning factors of vegetation degradation in the Oti-Keran-Mandouri region

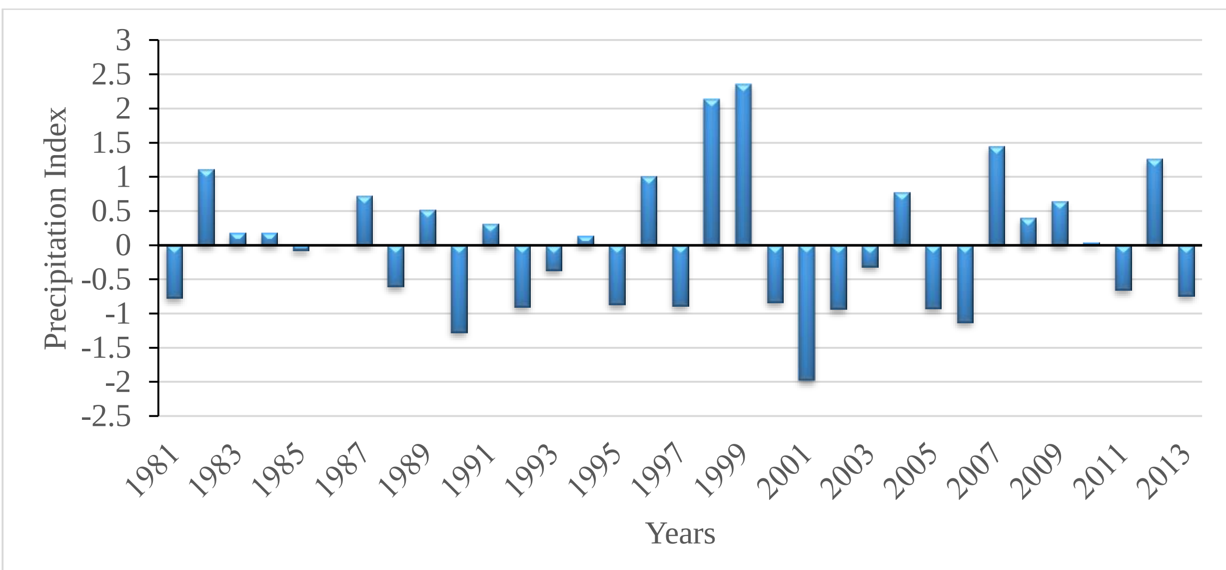

Figure 34: Annual variability in precipitation at Mango meteorological station from 1981 to 2013 (Data source: National Direction of Meteorology)

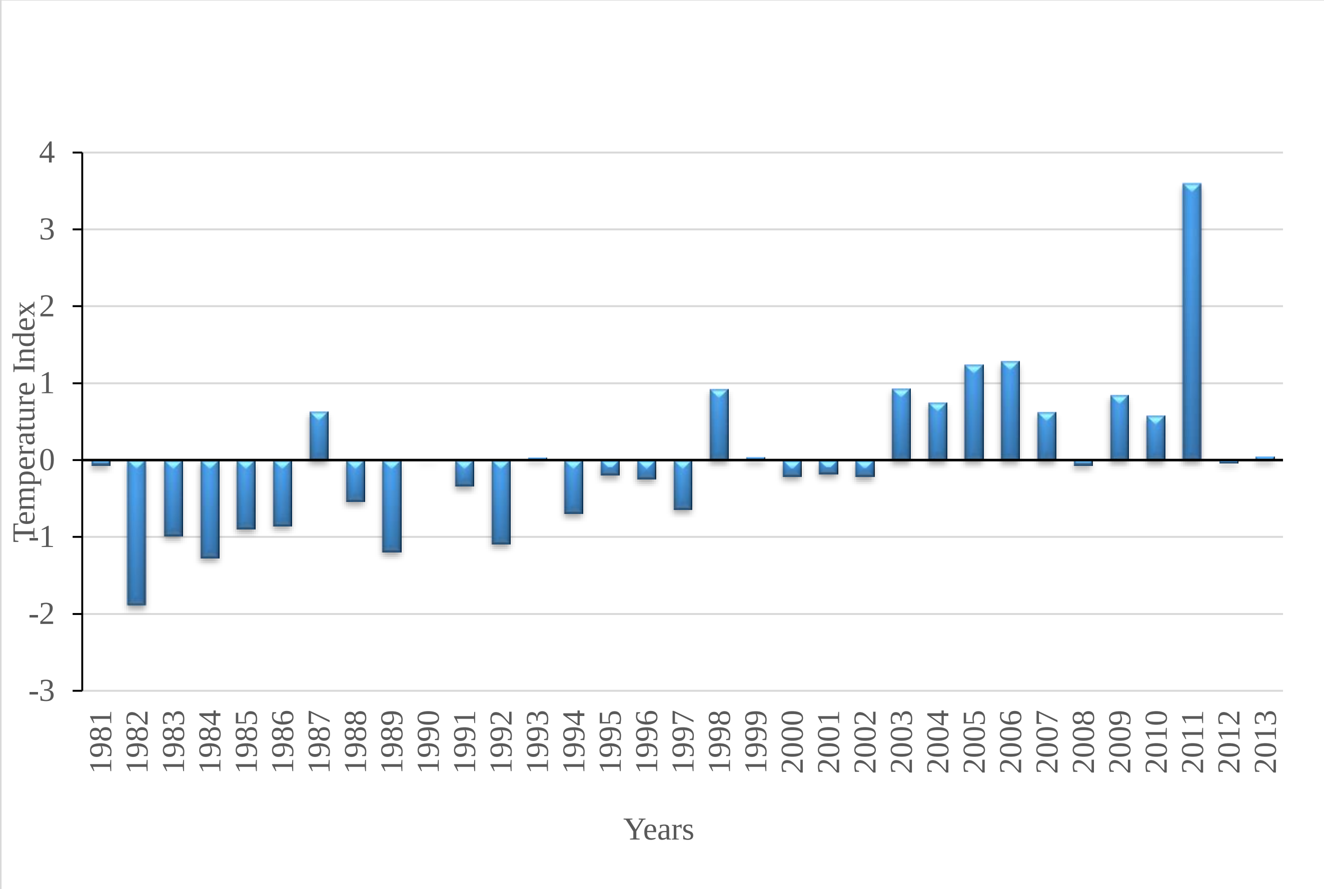

Figure 35: Annual variation in temperature at Mango meteorological station from 1981 to 2013 (Data source: National Direction of Meteorology)

The diversification of crops refers to the introduction of new crops such as maize (*Zea mays L.*), sorghum (*Sorghum bicolor* (L.) Moench), beans (*Phaseolus vulgaris* L.) and rice (*Oryza sativa* L.) in the region where millet (*Pennisetum glaucum* L.) and fonio (*Digitaria exilis*) were the main cereals in the past. The introduction of new varieties refers to within crop diversification with the selection and the introduction of more resilient and short term crops. For instance, the introduction of white maize to replace the yellow/red maize was reported in all the surveyed communities. The recessional agriculture is an out season cultivation of short term crops such as maize of two months and beans on river banks and wetlands. In these areas the crops benefit from flooding. The soil moisture is preserved for a while even during the dry season and its fertility is renewed by the alluvium. Because of the loss of crops due to climatic anomalies and the steady decrease of soil fertility, some stakeholders chose to increase their farmland in order to harvest more.

The surveyed residents can be grouped into two according the implemented strategies (Figure 39). The first group (Group A) is composed of Gangam, Lamba and Tchokossi and the second group (Group B) is composed of Gourma and Konkomba. In Group A, the reported strategies are recessional agriculture, introduction of new crops and diversification of crops (Figure 40). However, because of the existence in Tchokossi ethnic group of many respondents who reported no strategy, this community was separated from the two others. In Group B, in addition to the strategies already reported in Group A, there is the increment of farmland that is reported at different portion in both the communities composing this group. Apart from that, the plantation of *Azadirachta indica* was reported by Konkomba as a strategy to improve the regulating services of the ecosystem.

3.4.6. OKM residents' livelihood and social values ascribed to biodiversity conservation

The main activity of the residents of OKM is agriculture. The average household size is 18.8±19 persons. The average proportion of active persons in the household is 44±23%. The farmlands are usually vast and their area varies from 1 to more than 10 ha for one household. There are households with farmland of 1 to 5 ha (37.70%), 5 to 10 ha (30.20%) and more than 10 ha (32.10%). A large part of the households (79.20%) admitted that part or total of their incomes come from activities realized within the boundaries of OKM and 20.80% reported that none of their activities is linked to the protected area (Figure 41).

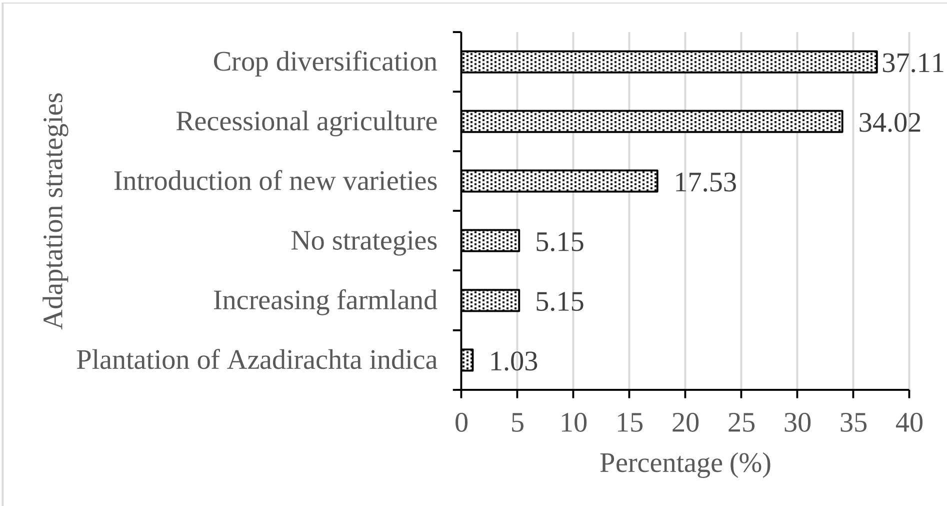

Figure 36: Adaptation strategies implemented by the residents of Oti-Keran-Mandouri

Figure 37: Cultivation of maise (a) and market gardening (b) on the banks of Oti River (Photography by Polo-Akpisso, October 2014)

Figure 38: Conservation of seeds of different varieties of maze (Photography by Polo-Akpisso, November 2015)

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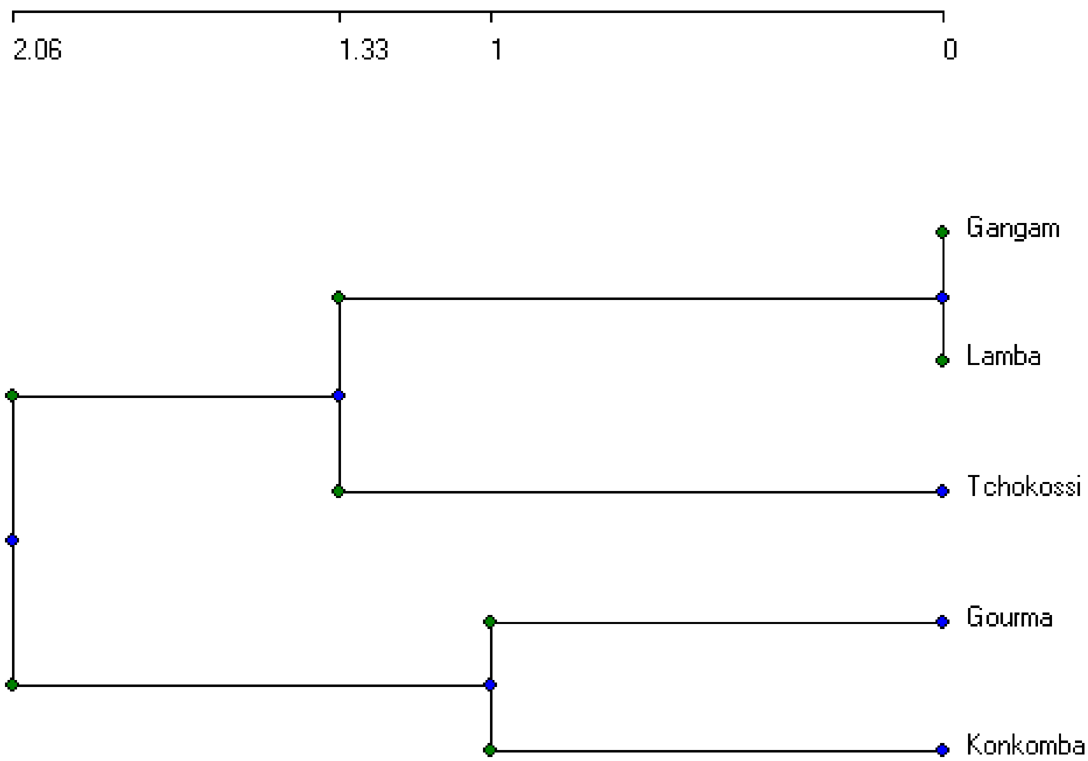

Figure 39: Ascendant hierarchical classification of the residents of Oti-Keran-Mandouri according to the implemented adaptation strategies

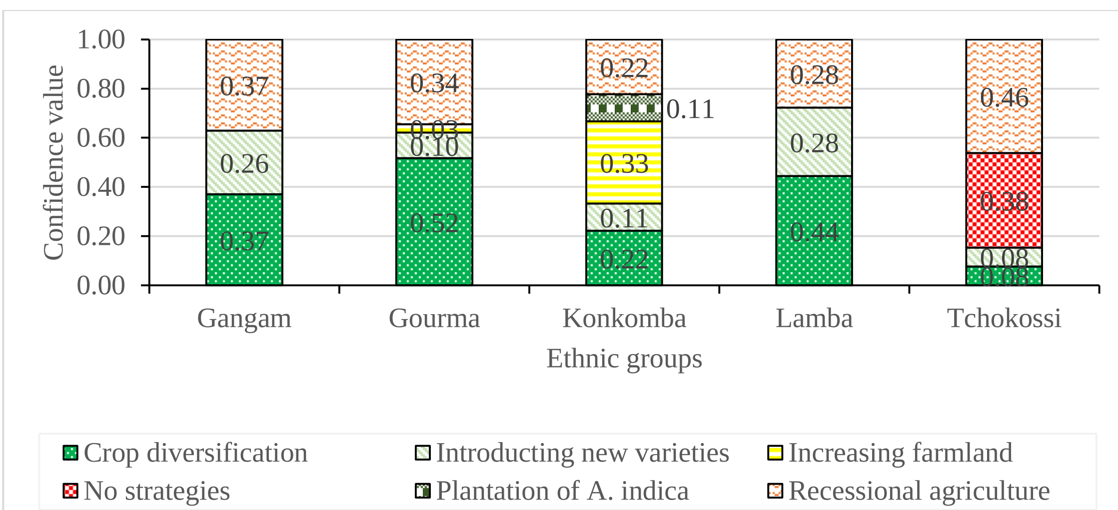

Figure 40: Climate change adaptation strategies reported among each surveyed ethnic group residents of Oti-Keran-Mandouri

The large part of the surveyed household (53.03%) has found no value in biodiversity conservation within OKM. However, some cultural, intrinsic and provision values were reported. These are learning (13.90%), spiritual (7.58%), cultural (6.06%), economic (6.06%), therapeutic (4.55%), biological diversity (3.03%) and future (1.52%) values. The reported values were significantly correlated to the access to the formal education (X^2=13.687; df=1; p<0.001) and the distance from the limits of the protected areas (X^2=14.28; df=1; p<0.001). More values were reported by educated stakeholders while those with no formal education were mostly reporting no value. On the other hand, the number of those reporting no value decreased with the distance from the protected areas (Figure 42). The spiritual and cultural values were mostly reported by the Lamba and the Gangam (Figure 43) ethnic groups. However, there was no significant correlation between the social values reported and the cultural background (ethnic groups).

About 57.58% of the surveyed residents suggested the release of the protected area for agriculture (Figure 44). Others suggested that a consensual delineation (13.64%) or a better collaboration between local communities and managers (12.12%) will enable a better conservation planning. For other residents, the sustainable management of the natural resources of this region will be enabled by the provision with the residents of the basic needs especially water supply (6.06%). The compensation of local communities because of the losses triggered by the fortress conservation system that was implemented in the past (4.55%), the sensitization (3.03%) or even the fencing of the protected areas (3.03%) were also suggested.

The local population especially those of Mango and surrounding area (Oti prefecture) are still claiming their land and refusing any rehabilitation of protected areas. Civil protest during September-November 2015 (Figure 45) costed unfortunately the life of some people.

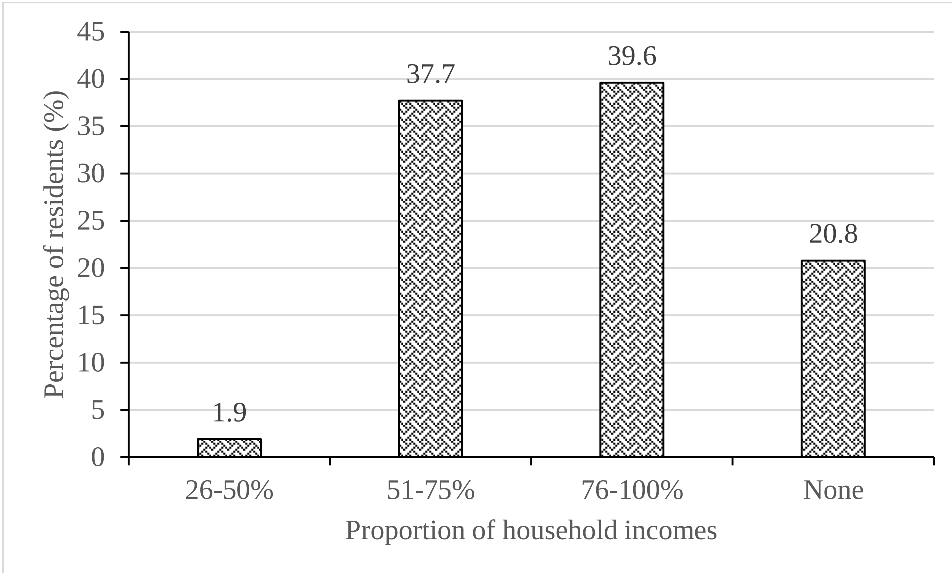

Figure 41: Proportion of household incomes earned from activities realized within the limits of Oti-Keran-Mandouri

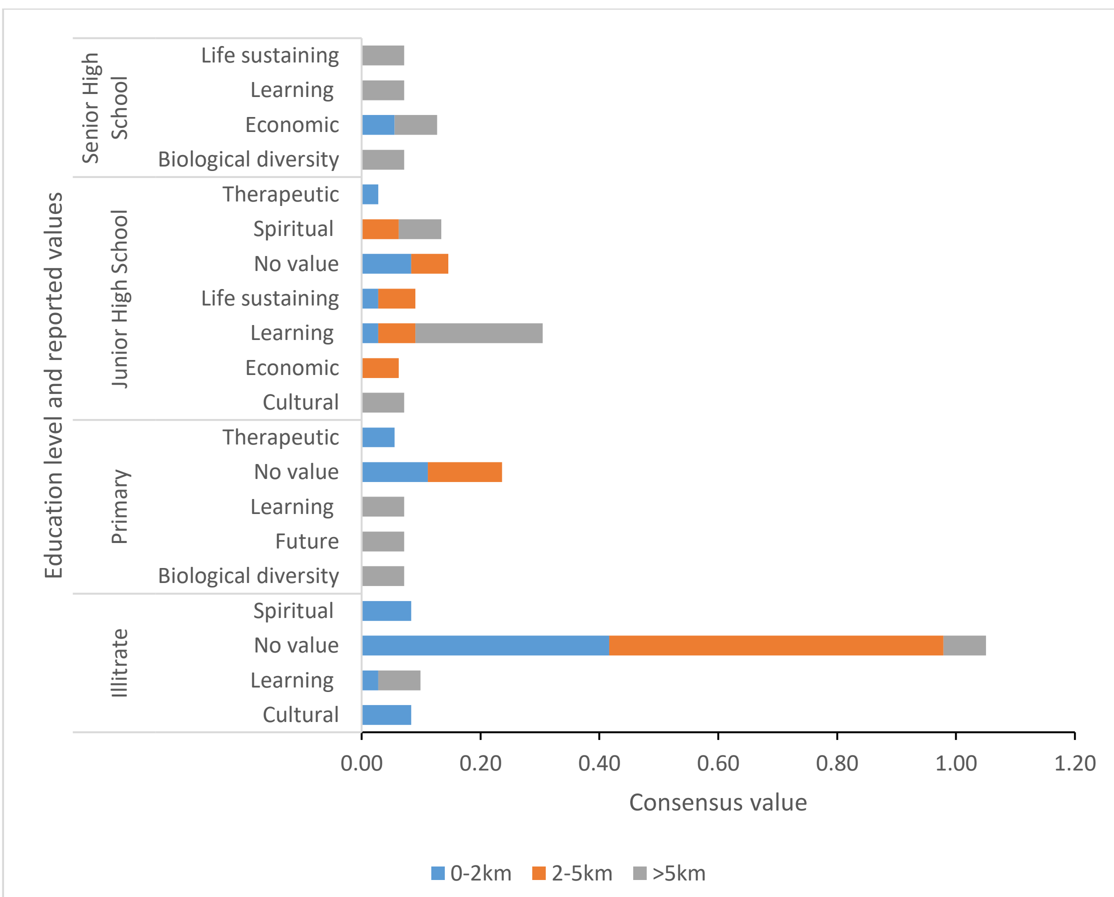

Figure 42: Social values ascribed to the complex of protected areas by residents according to their education level

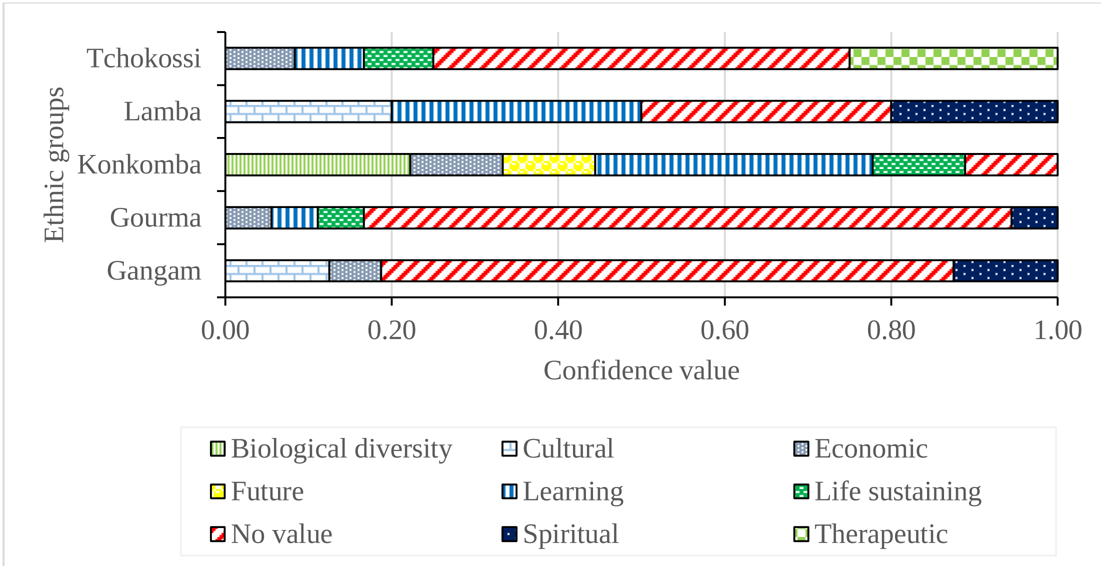

Figure 43: Social values reported by the different ethnic groups

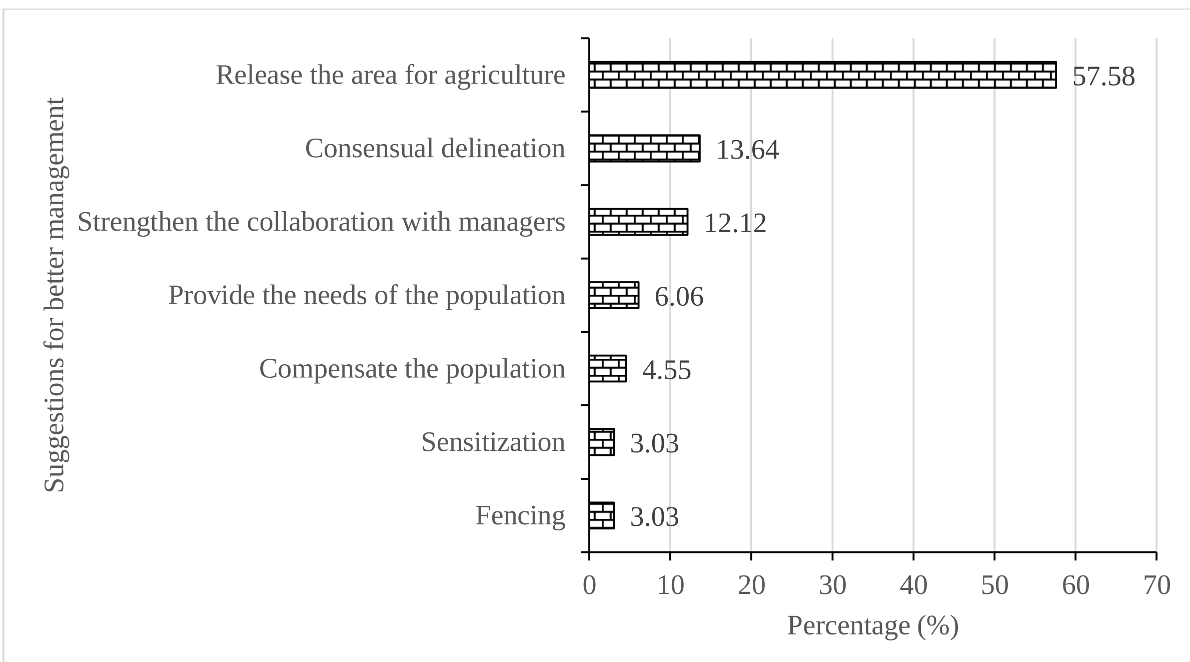

Figure 44: Suggestions for better management from the residents of Oti-Keran-Mandouri

Figure 45: Civil protest in the city of Mango (November 2015)

IV. DISCUSSION

4.1. Elephant occurrence within OKM

4.1.1. Elephant occurrence frequency

This study shows that elephants used to run through OKM even though their occurrence frequency differs from one district to another. Presence of elephant was reported for each year from 2010 to 2013 in Kpendjal whereas they were seen only once in Keran. This difference can be explained by the importance of human encroachments that are present between these two prefectures. These encroachments are deterring elephants from moving from one side of the park to another. Human population density distribution impact that of elephants. For instance, **Hoare and Du Toit (1999)** have demonstrated evidence that elephants disappear from lands at a threshold of human density. There is also evidence that water resource availability drives elephant distribution **(Bouché, 2007; Chamaillé-Jammes *et al.*, 2007)**. Occurring elephant within OKM probably originated from the complex of W-Arly-Pendjari (WAP). This complex hold the most important population of elephant in West Africa **(Bouché *et al.*, 2011)** and is located at the eastern part of OKM. In fact, **Bouché (2007)** reported that the trend in elephant population within Konkomburi Hunting Zone (KHZ) which is part of WAP ecosystem shows high fluctuations during dry season that can only be explained by seasonal migration due to water points availability. Thus, the presence of elephant within OKM could be explained by the availability of water resources. Classified as Ramsar site, there are 64 permanent water pounds distributed in this region with 31 within and 33 outside the protected areas **(Etse, 2012)**. An investment in restoration and sustainable management of OKM would allow elephants to spread their negative impacts between different segments of their range as suggested **Bouché (2007)**. Though artificial manipulation of surface water is one of the tools available for the management of elephant populations at one site **(Chamaillé-Jammes *et al.*, 2007)**, it would be good to restore large ecosystem that could benefit other wildlife species as well. On the other hand, elephants are adapted to annual migration over long distance. Across longer time scales, such mobility in large mammals enables populations to respond to stochastic events, cope with the impact of climate change and maintain the ecological integrity of the landscapes these mammals inhabit **(Graham *et al.*, 2009)**. Furthermore, wildlife movement is important for genetic exchange and the maintenance of a genetically viable population **(Noss *et al.*, 1996)**. This kind of migration could be promoted by the maintenance of OKM as a corridor between the blocks of elephant population living in the largest ecogeographical region of elephant distribution in West Africa. This corridor was proposed by **Bouché *et al.* (2011)**.

Advances in technology allow researcher currently to gain understanding in wildlife movement with high resolution radio telemetry. Despite this method is very expensive, it should be implemented to assess with high accuracy elephant corridor within OKM. The presence of elephant been reported in this area for the period covered by this study (2010 to 2013) itself can be considered an important ecological fact. Though several previous studies mentioned the sporadic occurrence of elephants in this area **(Okoumassou *et al.*, 1998; Sam *et al.*, 1998; Okoumassou *et al.*, 2004)**, an aerial count in May 2003 found no elephant in this area **(Bouché *et al.*, 2004)** meanwhile anthropogenic encroachments is increasing. Elephant are recognized to have long memories **(Foley *et al.*, 2008)**, therefore the occurring elephants could be part of the original population of this area that extirpated to neighboring countries because of high anthropogenic pressure on protected areas in Togo from the year 1990.

4.1.2. Elephant group size

The mean of the reported elephant group size is about three. Even though, higher group sizes (10 to 11 individuals) have been reported in Kpendjal, this number is negligible considering the estimated elephant population in the nearby complex WAP which is 3 969 elephants **(Thouless *et al.*, 2016)**. However, it is important to keep in mind that the reported number of elephants is just what the informants were able to see and to count. Most of the time, elephants were reported to pass during the night then farmers see only their footprints in the morning the day after their passage. Many studies have also described this feature of elephant movement mostly in anthropogenic landscape. Some authors explained this behavior by the fact that elephant want to just avoid high anthropogenic disturbance during day time **(Bouché, 2007)** whereas their movement has been described as related to lunar cycle by others **(Gunn *et al.*, 2013)**.The spatial analysis shows that elephants' free migration may be prevented by the high populated zone near the park in Kpendjal. This can explain why higher values have been reported in this prefecture and not in the others.

Indigenous knowledge gives just an insight for elephant group size. Further work is needed for a better estimation. A good estimation would be given by implementing dung count **(Hema *et al.*, 2013)** or an appropriate method of elephant number estimation for such sporadically occurring elephant. One of the objectives of the current rehabilitation project concerning OKM is not only to increase the number of elephants migrating through this ecosystem but also enable their permanent stay. OKM offers then a good site to study the impact on elephant distribution of the reversibility of human density threshold proposed by **Hoare and Du Toit (1999)**.

4.1.3. Occurrence periods

Two important periods of elephants' occurrence within and around OKM were reported. These periods were correlated to shea fruit harvest time (June) and crops' harvest time (November-December) according to the respondents. Then, apart from water availability, shea tree fructification and crops maturation play also an important role in elephant distribution within the three districts straddled by OKM. Major crop raiding events occur during (October to February). Almost the same period have been reported by **Bouché (2007)** for areas surrounding Konkomburi Hunting Zone in Burkina Faso.

Elephant presence was reported during dry season (October to February) and during the early rainy season. (May to June). Their high occurrence frequency reported in Kpendjal and Oti can be explained by the relatively high distribution of water pounds and swampy areas within these districts.

4.1.4. Human-Elephant conflict

HEC are a serious issue for residents within the study region since they are mainly farmers. The reported HEC occurred regardless to the distance from park's boundaries. No HEC management plan was reported. However, residents asserted it has a serious impact on their livelihood. This could be justified by the fact that these districts are among the poorest in Togo **(DSRP-C, 2009)**. HEC management is important not only for elephant conservation but also for a sustainable development of rural communities living near the park. There is also a need for sensitization of local people and of park rangers. Killing problem elephants as it is usually done in this area could not solve HEC but it is a very bad aspect of the strategy of elephant conservation in Togo. It will be worthy also to promote community based HEC management and improve used deterrents. The beehive fence as described by **King *et al.* (2011)** could be tested. This option is a promising one since it could enable farmers to repel elephants from their crops and all together to enhance their incomes by allowing them to produce and sell honey. On the other hand, there is currently a global crisis with bee population decreasing as described by **Core *et al.* (2012)**. Then, beehive will be a good measure to conserve bee population, to keep invaluable pollinators for crops and to provide alternative incomes for rural communities.

4.2. Elephant habitat within Oti-Keran-Mandouri

4.2.1. Overview on the vegetation within OKM

The number of species found in this study (n=320) is higher than what has been recorded in the same ecological zone I **(Folega *et al.*, 2012b)**. Indeed, they reported 274 plant species for three protected areas including Oti-Keran. However, both studies are complementary since the diversity at genera and family taxonomic levels are quite different. This study recorded 66 families and 209 genera whereas **(Folega *et al.*, 2012b)** reported 63 families and 247 genera. This variation can be linked to the sampling design. **(Folega *et al.*, 2012b)** based his study on line transect and plot size of 30 m x 30 m and 50 m x 10 m whereas the present study was based on a stratified random sampling and the standardized plot size defined by BIOTA project for large scale environmental monitoring in tropical vegetation especially for Africa **(Jürgens *et al.*, 2012)**. This same sampling design has been successfully used by **(Tehou *et al.*, 2012)** in Pendjari reserve of biosphere (Benin) where 183 species were recorded from 61 sample plots. The most important families are similar to those reported by other studies within the Sudanian ecological zone. Poaceae, Fabaceae and Rubiaceae were the most reported by **(Wala, 2010)** for the vegetation of Atakora mountain at the Eastern part of our study area whereas Fabaceae, Poaceae and Combretacea were the most reported by **(Folega *et al.*, 2012b)**. The importance of Fabaceae reflects the existence of a transition to the Guinean forest condition, while the importance of Combretaceae family is typical to Soudanian Endemism Center **(Aubreville, 1950)**. The high diversity in Poaceae reflects one of the fundamental characteristic of tropical savanna ecosystem characterized by a continuous layer of grasses **(Aubreville, 1957)**. The relative abundance of Rubiaceae can be explained by the relative density of hydrography in the study area allowing the establishment of species well adapted to Guinean forest in riparian forest along rivers. The same remark was done by previous studies **(Dimobe *et al.*, 2014; Folega *et al.*, 2014a)** in the same ecological zone.

The periods of fieldworks were set to take into account grasses. However, due to some species phenology and some fire events, most of the grass could not be identified reducing the total number of species recorded. This could explain the difference between observed (n=320) and estimated (S_{Chao2}=433±30) species richness. Nevertheless, the sampling effort, the sampling design and the collaboration among scientists should be improved for a better estimation of species richness within the study area.

The analysis of the life forms spectrum gives an idea on the phytocenosis dynamic **(Wala, 2010)** and provides information on the response of plants to local environmental conditions **(Malika *et al.*,**

2015). The predominance of phanerophytes reflects the general physiognomy of the vegetation in the study area that is structured by woody plant species. It indicates also the good condition of the soil that enables the establishment of perennial plant species. However, the importance of therophytes reveals a floristic change due to anthropogenic activities. Indeed, the conversion of savannas into cropland decreases the proportion of perennial while promoting the installation of ruderale species **(Wala, 2010)**. On the other hand, the presence of therophytes can be linked to the large areas of wetlands within Oti-Keran-Mandouri since **Malika *et al.* (2015)** explained their abundance in Wadi M'Zab (North-East of Algeria) by the strong presence of water favourable to the development of annual plant species. The relative dryness of the study area is shown by the presence of geophytes and chamaephytes. These species are well adapted to semi-arid ecosystems, drought and fire events **(Moreno and Oechel, 1994 ; Esler *et al.*, 1999)** whereas the presence of hemi-cryptophytes indicates the presence of open vegetation types **(Wala, 2010)**.

The abundance of Sudano-Zambesian (SZ) and Sudanian endemism centre (S) species is characteristic of savannah ecosystems and indicate the originality of the vegetation since the study area is located in the Sudanian endemism centre according to **White (1986)**. However, the presence of species with large scale distribution that are Pan-tropical (12.23%), Paleotroprical (10.07), and Afro-American (1.44%) indicates the anthropogenic action in transforming the ecosystem. This has been also reported by **(Wala, 2010)**. Within these species, Guinean and Guineo-Congolean are refugee species from Guinean and Congolese forests that are well distributed along rivers in riparian forest as reported by **(Folega *et al.*, 2014b)**.

The two major ecological gradients in species distribution revealed in this study are almost the same described by **(Wala, 2010)** in the Atakora mountain area where anthropogenic activities, especially agriculture, were reported as the main factors leading to change in the composition and the structure of vegetation. Another study focusing on woody vegetation in three protected areas including the southern part of our study area points out the effect of human selective practices on species composition (traditional agroforestry system) **(Folega *et al.*, 2011b)**. The relation between community and environmental variables could be used to assess climatic impact on a given habitat using the indirect modelling approach **(Bittner *et al.*, 2011)**.

4.2.2. Woody plant communities

The community types identified are very similar to the different habitat types or woody plant communities described in several studies in the Sudanian zone in terms of their floristic composition and the vegetation type **(Wala, 2010; Folega *et al.*, 2011b; Dimobe *et al.*, 2014)**. However, there is variation in term of the number of groups described. This variation is mainly due to the difference in methodological framework. Some studies were based on unconstrained ordination (indirect gradient analysis, ex. DCA) or constrained ordination (direct gradient analysis, ex. CCA) and some other on cluster analysis (agglomerative and Ward's method or TWINSPAN). All these methods are good for community data analysis but they are not based on the same statistical computation **(Leps and Smilauer, 2003; Jongman *et al.*, 2007)**. There is a need to standardize the methodological framework in landscape ecological research within this area and then enable the development of habitat mapping and monitoring program at local, regional and national levels such as the Natura 2000 habitats **(Zlinszky *et al.*, 2015)** or a comprehensive framework of ecological land units **(Cleland *et al.*, 1997)**.

The values of alpha diversity described in this study are similar to what previous studies in this area have found **(Folega *et al.*, 2011b; Dimobe *et al.*, 2014)**. *Anogeisus leiocarpus* (DC.) Guill. & Perr. and *Pterocarpus erinaceus* Poir. are reported as typical of dry forest in the Sudanian and Sudano-Guinean zones **(Hennenberg *et al.*, 2005; Kokou *et al.*, 2006; Adjonou *et al.*, 2009; Folega *et al.*, 2011b)**. Usually, the abundance of *Mitragyna inermis* (Willd.) O. Kuntze; *Pseudocedrela kotschyi* (Schweinf.) Harms; and *Terminalia sp.* indicates that the area is periodically flooded. Their importance in four out of seven site groups confirms the large distribution of wetlands within Oti-Keran-Mandouri. This is consistent with the classification of this area as Ramsar site and as Important Bird Area **(Cheke, 2001)**. All the important species and almost all the indicator species have been reported as species browsed by elephant (*Loxodonta africana*, Blumenbach, 1797) in the hunting zone of Djona (North Benin) **(Tehou and Sinsin, 2000)** and in Nazinga Game Ranch (South Burkina Faso) **(Hien, 2001)**. *Borassus aethiopum*, *Lannea acida*, *Mytragina inermis*, *Terminalia macroptera*, and *Vitellaria paradoxa* were reported as browsed by elephant in the Red Volta valley **(Adjewodah *et al.*, 2012)**. Moreover, *A. gourmaensis*, *V. paradoxa, A. digitata, B. aegyptiaca*, and *A. leiocarpus* have been reported in different groups of species occurring in habitat with high elephant concentration in Pendjari reserve of biosphere (North Benin) **(Tehou *et al.*, 2012)**. Therefore, habitats in Oti-Keran-Mandouri are well suitable for elephant because of food and water availability. This explains the seasonal occurrence of elephant within this area reported by several studies despite increasing anthropogenic pressure **(Okoumassou *et al.*,**

1998; IUCN, 2008). The influence of anthropogenic activities on plant species composition is well illustrated in G7. All the species listed in this group are multipurpose trees that are useful to farmers for food, medicine or fiber **(Atato *et al.*, 2011; Atakpama *et al.*, 2012)**. These species are intentionally left on the field while other species are cut down or burnt to produce charcoal. It creates a cultural landscape well distributed in the Sudanian zone of West Africa and described by several studies in Togo, Benin and Burkina Faso **(Wala *et al.*, 2005; Folega *et al.*, 2011a; Yameogo *et al.*, 2013; Kebenzikato *et al.*, 2014; Aleza *et al.*, 2015a; Padakale *et al.*, 2015)**. Since these species are also browsed by elephant, this sharpens human-elephant-conflict (HEC) around protected areas. Another example of human influence on species composition is the presence of *Tectona grandis L*. among indicator species in Group 2. This species has been introduced as plantation tree but it is currently invading natural habitats of the reserve.

4.2.3. Structure of the elephant habitats

Althought trees are evenly distributed in all the four distinguished habitats, the lowest woody species diversities were recorded in habitats 1 and 2. The characteristic species for Habitat 1 were mostly *P. biglobosa* and *V. paradoxa*. These are multipurpose species left on farmland by local population. These species are combined with species such as *Pteleopsis suberosa* Engl. & Diels or species of *Combretum*. Such combination is remarkable mostly on young farmlands or fallows. This habitat is a result of degradation by agricultural expansion. The presence of *Terminalia* species in Habitat 2 suggest that swampy or periodicaly flooded areas are part of this habitat type since *Terminalia* species are characteristic of such environment. The characteristic species in Habitat 3 are species of dry area and usually found at top of glacis with more or less concretionary soil. Habitat 4 is a typical forested area with a mix of dry forest and gallery forest. The most important pach of this habitat is located around the basement of park rangers in Naboulgou.

Habitat 3 and Habitat 4 appeared to be the best preserved compared to Habitat 1 and Habitat 2. This reinforces the results from the Jaccard indices computation. The stem density and height values are highest in Habitat 3 and habitat 4. In contrary, Habitat 1 is really degraded by anthropogenic activities mostly agricultural expansion. Though, there is some variation within a given habitat (27.78% ≤CvD≤57.23%), the mean diameter is almost the same in all the habitats. This suggests that the pressure on the different habitats is actually evenly distributed. Individual trees of almost the same dimeter size are pressured regardless of the type of habitat. The importance of the regrouth rate especially in degraded habitats in addition to the hight frequency of plant with small diameter suggests that the restoration of these habtats is still possible. However, the high regrowth rate in degraded habitat is to be considered carefully. The coefficient of variation for regrowth rate is very high in all the habitats especially in degraded habitats ($CvR_{Habitat\ 1}$ = 97.65%). Moreover, anthropogenic activities such as cropping reduce drastically the regrowgth rate. This fact has been reported already in the overall vegetation assessment within OKM **(Polo-Akpisso *et al.*, 2015)**

The diameter structures of habitats 2, 3 and 4 are similar to the diameter structures described for elephant habitat within Pendjari reserve of biosphere **(Tehou *et al.*, 2012)**. However, the diameter structure of habitat 1 has a bell shape such as the ones described for fields and some young fallows in northern Benin **(Aleza *et al.*, 2015b)** and in old fields in the ecological zone 1 of Togo **(Padakale *et al.*, 2015)**. Therefore, the bell shape traduces a high level of habitat degradation due to human actions.

Habitats within OKM are severely degraded. The level of fragmentation is so high that it could prevent even the restoration of this area by limiting dispersal capacity of species. Ecological responses to such changes in habitat may be gradual, as species expand, contract, or shift distribution but when systems are pushed beyond thresholds of disturbance, changes may be sudden **(Van Horne and Wiens, 2015)**. Though poarching was the primary raison elephant extirpated from OKM, their current sporadic occurrence may be due to the level of habitat fragmentation. This gives hope of possible restoration but the current habitat fragmentation level may be irreversible resulting in new habitats and ecosystems. These new habitats will require novel approaches of conservation and management.

At its current state, OKM could hardly play its roles as biodiversity refuge and as corridor for wildlife species. The issue of habitat degradation is of global importance and one of the main threats to biodiversity and ecosystem services. It has been considered as causing a biome crisis by **Hoekstra *et al.* (2005)**. There are still some patches of suitable habitat for elephant that could be considered as remnant good habitats. However, only the area located in the south-eastern part of the protected area seems to be the most conserved and could be considered as a core habitat. This area has been described by previous studies **(IUCN, 2008; Adjonou *et al.*, 2009)** and its state of conservation could be linked to the presence of park rangers' camp that is deterring the spread of anthropogenic activities in this area as noticed elsewhere in the park. Since the relatively good patches of habitat are near the stream network, a corridor connecting isolated habitats could be restored along the main rivers. This kind of corridor has been proposed in a study of elephant corridor between Côte d'Ivoire and Ghana **(Parren and Sam, 2003)**. Furthermore, gallery forests are considered to act like a natural corridor for many species and to deliver many ecosystem services **(Natta *et al.*, 2004)**. Therefore, the area next to rivers should be considered as first priority restoration areas and be kept from any anthropogenic activities. Since plant species in cultivated areas have low regrowth capacity and the river banks are subjected to recessional agriculture activities **(Polo-Akpisso *et al.*, 2015; Polo-Akpisso *et al.*, 2016)**, only an active restoration process involving resident communities could be successful. The restoration process implies the implementation of a sustainable land management system **(Bierbaum *et al.*, 2014)**. The Figure 48 shows the proposed corridor that should be considered as first priority restoration area.

Here the suitability habitat modelling was based on an expert-based model of habitat based on land cover, topographic and human disturbance factors. This type of model was preferred because of the lack of a comprehensive empirical data on elephant occurrence that could enable the implementation of a statistical or empirically based model of habitat. Although they are more difficult to validate than empirical models, expert-based models of habitat quality may be the only option in areas where empirical data is sparse or nonexistent **(Dickson *et al.*, 2013)**. Fuzzy overlay was used to avoid weighting the layers used for the habitat suitability model since this would be completely subjective. However, the thickness of water pounds' layer was used to integrate the importance of water pounds for elephants and the relative influence of their size on elephant movement.

Despite the fact that some previous study mentioned the core habitat near Naboulgou, this area is not part of the range polygon of elephant mapped by the IUCN **(IUCN, 2015)**. The range polygon of endangered mammal species of the IUCN is usually mapped according to expert knowledge on species' distribution. The elephant range polygon in Togo should be refined and updated. This could be performed using one of the methods of species range polygon refinement proposed by **Eastman (2012)**. The signs of elephant found in the core habitat suggest that a corridor between this habitat and nearby block of elephant population in the Biosphere reserve of Pendjari could be restored. This restoration is feasible due to the fact that elephants are recognized to have long memories **(McComb *et al.*, 2001; Foley *et al.*, 2008)** and the restored corridor could as well be beneficial to medium sized ungulates that can resume migration **(Bartlam-Brooks *et al.*, 2011)**. But, an effective corridor planning requires further research to provide data on candidate focal species, their home range, their daily spatial requirement, their minimum breeding patch size among others.

4.2.4. Spatial analysis of elephant movement

Elephants were reported to occur in almost all the surveyed villages regardless to the importance of human settlements (Figure 46) while their footprints were mainly recorded in the largest patch of suitable habitat located in the southern part of OKM. Although, the reported number of individuals was relatively low (one to eleven individuals), important numbers were reported even in human populated areas (eleven in Koundjoare and four in Nyandé). The occurrence of elephants within OKM and its surrounding area confirmed like previous studies by **Douglas-Hamilton *et al.* (1992)**, **Okoumassou *et al.* (1998)** and **IUCN (2008)** that this area is part of the historical range of the African savanna elephant. This area is currently considered as part of the largest ecogeographical region of elephant distribution in West Africa **(Bouché *et al.*, 2011)**.

Water availability may explain elephant movement and occurrence patterns within and around Oti-Keran-Mandouri. However, their distribution did not give much insights about their relationships with habitat that reveal habitat quality. Since highest number of elephant were recorded around highly human populated areas. The relationship between recorded number of elephant and habitat quality is not linear. This argument is defended by others authors as well. **Van Horne (1983)** stated that density is a misleading indicator of habitat quality. Individuals coukd be attracted to and occupy unsuitable habitats acting as "ecological traps''according to **Donovan and Thompson (2001)**. One factor that could explain this pattern is elephant crop raiding. Alongside with increased digestibility, higher sodium concentrations attract elephants to crops **(Rode *et al.*, 2006)**. Moreover, it is believed that the occurrence of crop-raiding emerge from habitat degradation and consequently, a decrease in resource availability **(Rood *et al.*, 2008)**.

Human population data interpolation gives an idea of anthropogenic pressure on OKM ecosystem by delineating high human populated zones. It may have an important impact on elephant movement as well. The presence of human settlements around Mandouri, Donga and even Pansieri (Kpendjal prefecture) could be the factor preventing larger number of elephants coming from Pendjari reserve of biosphere to reach the largest patch of well preserved habitat located in the southern part of OKM (Oti-Keran).

Among factors that are in favour of elephant occurrence within OKM despite the level of habitat fragmentation may be water availability. For instance, swampy areas constitute 39 267 ha and about 22% of OKM area. In addition to that, individuals that exhibit fidelity to previous breeding locations may continue to occupy those areas even after the original habitat has been drastically altered **(Wiens and**

Rotenberry, 1985). Considering this aspect, killing of problem elephant is not an option if the habitat and the persistence of elephant population within OKM are to be restored.

4.3. Changes in habitat within Oti-Keran-Mandouri between 1987 and 2013

4.3.1. Image classification and accuracy assessment

The overall accuracy assessment values are good for all the classified images compared to the fixed overall accuracy of 80% for the calculation of the number of groundtruthing points. However, there was confusion between some land categories especially settlements and croplands. This confusion might explain the poor producer's accuracy for both classes. The similar confusions were previously reported by **Folega *et al.* (2014c)**. The study area is characterized by a cultural landscape characterized by traditional agroforestry system wherein farmlands crops are associated with multipurpose trees. This cultural landscape was described by several studies **(Wala *et al.*, 2005; Folega *et al.*, 2011a; Kebenzikato *et al.*, 2014; Padakale *et al.*, 2015)**. The mixing of trees and houses in this cultural landscape is the source of the misclassification of settlements and croplands. There is even misclassification of settlements with savannas. This latter one was also noticed by **Badjana *et al.* (2014b)**. The confusion between water bodies and other land categories could be explained by the moderate resolution of Landsat imagery limiting the distinction between water bodies with surrounding vegetation. This could be the reason why suprising conversion of different land categories to wetlands were described.

4.3.2. Land use and land cover change analysis

Wetlands are the most important land category found within OKM. This is well in line with the classification of OKM as a Ramsar site **(Cheke, 2001; Adjonou, 2012)**. It is also the most converted land category into others especially croplands. There is high pressure onto wetlands that are systematically converted into large paddy fields. Agriculture is then the main driver of change in Landcover and Landuse dynamics (LCLU). It is a shifting cultivation such as elsewhere in Togo and in West Africa. This result is in line with previous studies in tropical regions and particularly in West Africa **(Lambin *et al.*, 2003; Houessou *et al.*, 2013; Wood *et al.*, 2004)**. Other studies, concluded that agriculture, population growth and indirect effects of climate change remain the main factors of land change and the main threats to biodiversity conservation **(Landmann *et al.*, 2010; Heubes *et al.*, 2012)**. Changes in populations' livelihood through the implementation of indigenous adaptation strategies **(Badjana *et al.*, 2011; Diwédiga *et al.*, 2013; Ojoyi and Mwenge Kahinda, 2015)** could be considered as the indirect effects of climate change. The implementation of recessional agriculture as an adaptive strategy in the study area shows that climate change and LCLU change are tightly linked.

Increase in settlements could be related to the annual rate of population growth in the study area. Actually, OKM is within a region where the population growth rate is the highest in Togo (3.18%) **(RGPH, 2011)**. Moreover, Kpendjal, Oti and Keran districts are the poorest in Togo **(DSRP-C, 2009)**. Therefore, there is high pressure on natural resources by local population. The intrinsic relationship between natural resources degradation and poverty has been shown by many studies **(Konaté and Linsenmair, 2010; Dimobe *et al.*, 2014)**. On the other hand, there is a particular problem of natural resource management that increases the pressure on protected areas in Togo after 1990. As described by **Folega *et al.* (2014c)**, the period from 1990 to 2000 was marked by illegal and anarchic exploitation of protected resources by residents. This situation resulted from the political, economic and social troubles of 1990 mainly due to uncontrolled democratic opening process and the semi-military and repressive management system implemented from colonial period to 1990. These illegal and anarchic anthropogenic activities led to important land conversion. This could explain the increase of croplands from 1987 to 2000. This increment is higher than the reported agricultural expansion on the national scale for a period of 25 years from 1975 to 2000 by **USGS (2013)**. While croplands increased from 0.91% in 1987 to 34.81% in 2013 of the total area of OKM, they have been reported to increase from 12.1 percent of the country's land area in 1975 to 21.8 percent in 2000.

As shown by transition maps, there is a core area of remaining natural ecosystems within OKM in Keran district. This area has been already mentioned by **IUCN (2008)** as the most conserved area. Periodic visits to this area by savanna elephant coming from bordering countries have been mentioned in several studies **(Okoumassou *et al.*, 2004; IUCN, 2008)**. This relatively conserved area is due to the existence of the casernement of park managers that is preventing anthropogenic pressure. Better management of the entire OKM is then possible if adequate means are provided. This area requires currently a particular conservation attention. Its remaining natural habitats are still under threats from some anthropogenic activities such as wood cutting **(Adjonou *et al.*, 2009)** and charcoal production **(Kokou *et al.*, 2009)**. In the centre of Benin, **Arouna *et al.* (2011)** found also that charcoal production represented the main activity leading to land cover change. Moreover, there are also threats from transhumance on which no accurate data are currently available. There are thousand heads of cattle pasturing through this area each year damaging crops and invading protected areas.

Usually, foraging plants are cut down for cattle and the savanna is burnt without any respect to the fire calendar established for this area by the national department of environment.

Considering the net change in their own area (Table XXIII), forests increased from 1987 to 2000 of 2.08% and decreased of 75.27% from 2000 to 2013. The increase of forests from 1987 to 2000 could be explained by natural regeneration since forests are located along rivers and in the well protected core area of the former Oti-Keran national park (southern part of our sutudy area). These areas were less pressured when social claims started from 1990. However, the decrease of forests from 2000 to 2013 is the result of the combined effects of increasing anthropogenic activities (wood cutting and charcoal production) and climate change. Recent studies demonstrated that climate change effects in Northern Togo are expressed by inter-annual fluctuations with declining tendency of rainfall and increasing tendency of temperature on the period from 1961 to 2010 **(Badjana *et al.*, 2011; Badjana *et al.*, 2014a)**. The deficit in rainfall could weaken plant resilience to fire events. Furthermore, one of the most adaptive strategies to climate change implemented in this area by local population is recessional agriculture. This activity consists of crop cultivation during dry season on river banks and in wetlands where crop could benefit from flooding and soil moisture. This practice involves the destruction of gallery forest **(Diwédiga *et al.*, 2013; Badjana *et al.*, 2014b)**. Recessional agriculture is categorized as a wetland agriculture and considered as one of the largest overall agriculture adaptations **(Menotti and O'Sullivan, 2013)**. It is described as been highly productive in many tropical regions **(Whitmore and Turner, 2001)**. On the other hand, the decrease of forests from 2000 to 2013 reflected the ineffectiveness of the management system of this complex of protected areas and the weakness of the current consensual rehabilitation process.

4.3.3. Habitat change processes

The changes in land cover categories, for the different periods studied, resulted from different habitat transformation processes. These transformation processes implied profound consequences on landscape structure and functioning **(Bogaert *et al.*, 2004)**. Understanding landscape structure and functioning is important to consider ecological process in its spatial context.

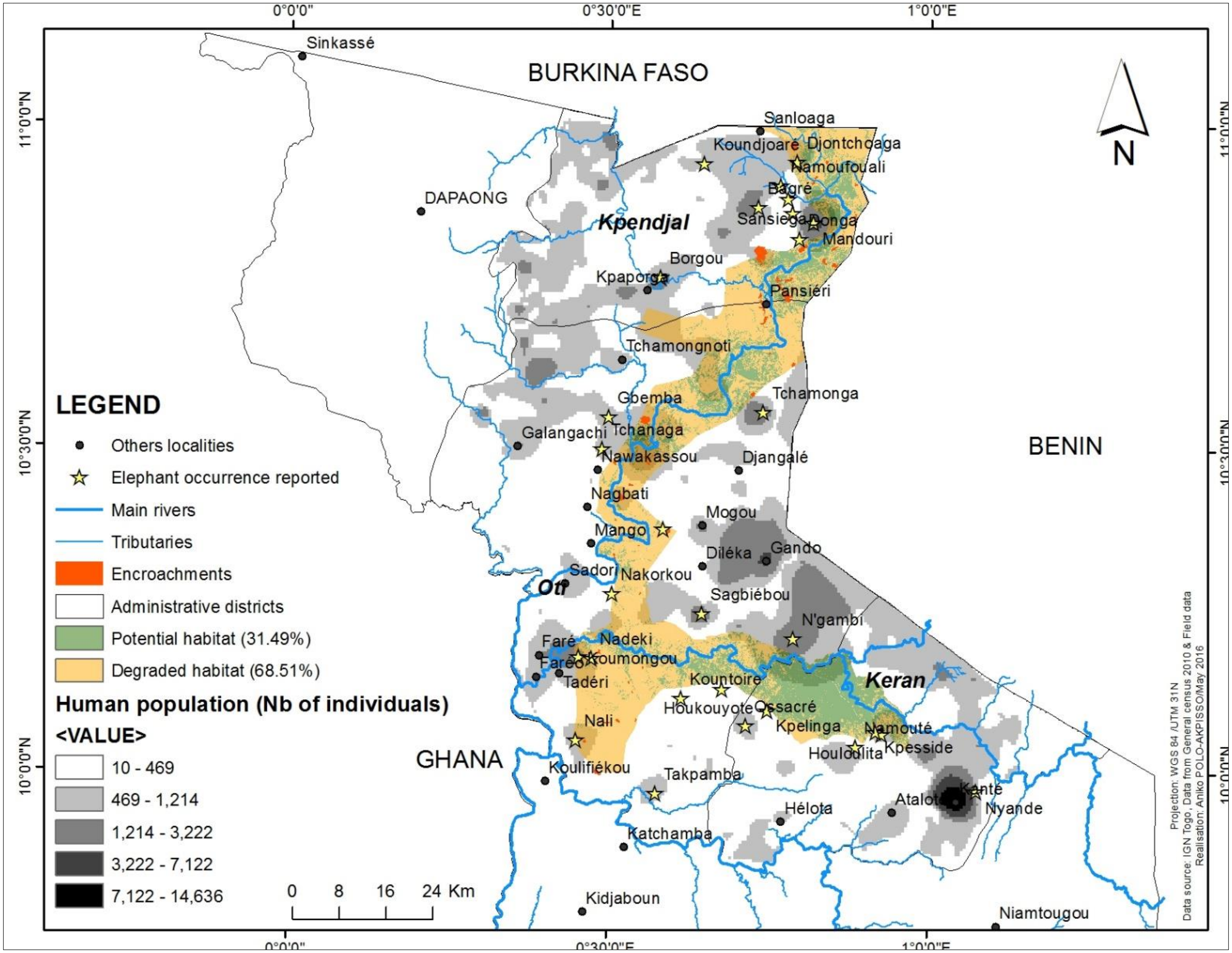

Figure 46: Elephant occurrence with regard to suitable habitat and anthropogenic pressure

Here, three main transformation processes were identified when considering the period from 1987 to 2013. These are attrition in forest and savanna, dissection in wetland and creation in cropland. But when this period is decomposed into two steps (1987-2000 and 2000-2013), then four transformation processes can be described. From 1987 to 2000, there were creation in forest and cropland, dissection in savanna and attrition in wetland. Whereas from 2000 to 2013, there were attrition in forest and savanna, dissection in wetland and aggregation in cropland. The temporal resolution is essential when designing a study for the identification of transformation processes as suggested by **Bogaert *et al.* (2004)**. According to the same authors, all the identified transformation processes characterize two main changes in the habitat configuration. Attrition and dissection indicate habitat degradation while creation and aggregation imply the appearance of new habitat units. The process of creation means the formation of new patches of a given land cover. However, depending on the considered land cover category, the process of creation could have different causes. For instance, from 1987 to 2000, the creation process in forest could be explained by colonization of bare soil, conversion from other land cover to forest. Meanwhile, the creation process in cropland is caused by anthropogenic pressure with increasing afforestation. Aggregation indicates the mergence of existing patches by physical connection. This explains well what happened in cropland from 2000 to 2013. Dissection and attrition are considered to represent different steps of the process of fragmentation. Dissection is a subdivision of the area with a minimal area loss associated with linear structure of disruption while attrition is the disappearance of patches. There is still a debate on whether to consider the transformation processes as equally equivalent or as steps of the whole process of landscape fragmentation. However, **Jaeger (2000)** considered attrition as the last of the six steps of fragmentation. Dissection is expected to be the initial step of fragmentation by **Bogaert *et al.* (2004)** and attrition is expected to occur in a patchy landscape that is the result of another pattern conversion. Considering this sequence, savanna experienced a steady process of fragmentation with a dissection (initial step) from 1987 to 2000 and attrition (last step) from 2000 to 2013. But, transformation processes were particular in both forest and wetlands. By experiencing creation from 1987 to 2000 and attrition from 2000 to 2013, the fragmentation process was very rapid in forest especially from 2000 to 2013. This period corresponds to the period of the implementation of the requalification process of protected areas. But instead of observing a decrease in the pressure on natural resources, it is marked by an increase of anthropogenic pressures. These pressures are characterized by illegal logging and intensification of charcoal production already reported by previous studies in this area **(Adjonou *et al.*, 2009; Kokou *et al.*, 2009; Dimobe *et al.*, 2014; Folega *et al.*,**

2012a). The sequence of transformation processes in wetlands (attrition from 1987 to 2000 and dissection from 2000 to 2013) indicates that the fragmentation process here is really intensive.

In summary, there are habitat loss in forest and in savanna (attrition) and habitat fragmentation in wetland (dissection). These processes are leading to anthropization process as described by **Barima *et al.* (2009)** in the forest-savanna transition zone of Côte d'Ivoire. Moreover, in concert with habitat loss, habitat fragmentation is a grave threat to species survival **(Laurance *et al.*, 2002)**.

4.4. Vulnerability of habitat patches to climate induced anthropogenic pressure

4.4.1. Livelihood and perceptions of climate change among resident communities

OKM is surrounded by highly populated landscapes. The average size of the household in this area (18 persons) is very high compared to the national estimate of the household size that is 5.1 persons **(Agbeti *et al.*, 2013)**. Though, the household size is considered to be relatively higher in "Savannes" and "Kara" regions (6.8 and 5.6 persons respectively), the sizes recorded around OKM remained very high. This indicates that natural resources inside OKM is attracting densified settlements. This highly populated landscape is threatening habitat integrity and the connectivity of OKM with other protected area. Moreover, only a small part of the population had access to formal education and the main activity of residents is agriculture characterized by slash and burn cultivation. This cultivation system is destructive for native vegetation. On another hand, the settlements around and even within the boundaries of OKM traduce the important pressure on fertile lands. This area is subjected to a long term decline in soil fertility as reported by **Kintché *et al.* (2015)**. Therefore, farmlands are expanded toward or even inside protected areas where the soil remained fertile.

Though the residents of OKM were composed of multiple cultural communities with a relatively low level of formal education, all the surveyed residents are aware of change or variations of climatic factors. Consistent variations in climatic factors were reported. For instance, the decrease in rainfall quantity, the delay and shortening of the rainy season, the increase of the drought period, the temperature and the frequency of violent winds were reported. There was also a relative increase of flood events in some areas. The changing pattern of rainfall and temperature is in line with several studies across West Africa and especially in northern Togo. This changing pattern in climatic factors was reported as the result of the impacts of climate change characterized by an increase of the temperature and a high fluctuation of rainfall. The increasing temperature is in line with the findings of **Badjana *et al.* (2014a)** in the northern part of Togo. Others studies described the same trend in northern Benin, northern Côte d'Ivoire as well as in the whole of West Africa **(Paturel *et al.*, 1995; Paturel *et al.*, 1997; Lawin *et al.*, 2012)**. The decreasing quantity of rainfall, the shortening and delay of rainy season could just be explained by the generally strong intra-annual as well as inter-annual variability of the West African Monsoon that is not yet understood **(Klein *et al.*, 2015)**.

The interpretation given to the perceived changes or variations in climatic factors were mainly linked to religious beliefs. God was responsible for 35.85% of the respondents while 32.08% reported that the lack of respect for traditional practices was the cause. However, some people (30.19%) seemed to make a link between the changing climate with anthropogenic intervention such as vegetation degradation by illegal logging or charcoal production. There is a contrast with the perceived decrease in rainfall quantity and the relative increase of flood events reported in some areas. This could be explained by the perturbation of hydrologic regime caused by Kompienga dam (Burkina Faso) located on one of the tributaries of Oti River at the North of the study site.

4.4.2. Climate change adaptation strategies and biodiversity conservation within OKM

Since agriculture is the main activity of OKM residents, the implemented adaptation strategies are linked to cultivation systems. The main strategies are crop diversification (37.11%), recessional agriculture (34.02%) and introduction of new crop varieties (17.43%). Increasing of the area of farmlands (5.15%) and the plantation of *Azadirachta indica* (1.03%) were also reported. The implemented strategies are almost all related to land use change. Thus, the implemented strategies threaten native vegetation. The loss of native vegetation involves the loss of biodiversity in this region. This link between land use change and biodiversity loss was also evocated by **Pimm *et al.* (1995)** who explained the trade-off between land use and biodiversity loss by the species-area relationship. This confirmed the hypothesis according to which climate change is one of the drivers of land cover change within OKM. Other drivers of change in vegetation cover such as demographic growth, poverty and transhumance were reported by 51%, 43% and 6% of the respondents respectively. The same driving forces were recorded elsewhere in West Africa especially in Benin around the "W" Biosphere reserve **(Houessou *et al.*, 2013)** and in Burkina Faso **(Dimobe *et al.*, 2015)** but a direct link to climate change was difficult to make **(Heubes *et al.*, 2012)**. There is also another factor, almost always elusive, that is the impact of desertification that is emphasizing the pressure on land in this area.

On another hand, adaptation strategies could be easily associated with mitigation. This is well illustrated by the plantation of some plant species like *Azadirachta indica* because of their regulating action on the ambient temperature. Adaptation would be well implemented by the promotion of an agroforestry system with native plant species mostly multipurpose trees. That system will provide residents with direct incomes with non-timber forest product harvest and regulating service of the climate. This adaptation strategy will be suitable in this area as it has been suggested for developing countries especially in West Africa by **Mbow *et al.* (2014)** and **van Noordwijk *et al.* (2014)**.

The most important part of the residents of OKM has its income coming from activities realized within the boundaries of OKM (79.20% of the respondents). People are so dependent on the land and natural resources inside OKM that they are reluctant to any conservation program. This is illustrated by the large agreement among residents (53% of respondents) on the fact that there is no value conserving biodiversity within OKM. This situation is particularly worsened by remnant bad memories from the fortress conservation implemented at the early stage of the creation of these protected areas. The lack of benefices and the impact of fortress conservation were listed as factors hampering conservation success in developing countries and especially in Africa **(Muhumuza and Balkwill, 2013)**. Contrary to the Pendjari National Park where the involvement of local residents in the management system created positive perception toward biodiversity conservation **(Vodouhê *et al.*, 2010)**, the participatory management of protected areas in Togo is still struggling to be effective. The failure of participatory approaches for protected areas management was also reported in many protected areas in West Africa because of the misunderstanding of the implications of such approaches for each actor. There is still conflict between governments and residents communities because of protected areas management in many countries in West Africa **(UICN/PACO, 2012)**. Furthermore, there is a correlation between the educational level and how people value biodiversity conservation. But unfortunately, the educational level of residents of OKM is still relatively low and people near or settled inside the boundaries of OKM seemed to be more reluctant to biodiversity conservation. This is almost the same situation everywhere in Africa **(Vodouhê *et al.*, 2010; Muhumuza and Balkwill, 2013)**. But people have successfully dealt with such issues elsewhere such as in Indonesia where people living close to remnant forest perceived more ecosystems services **(Muhamad *et al.*, 2014)** or in Cambodia where people living close to or inside protected areas have better access to non-timber forest products and therefore interact positively with protected areas **(Clements *et al.*, 2014)**.

4.4.3. Analysis of the vulnerability of the habitat of elephant within OKM to climate change

Climate change is influencing the behaviour or the livelihood of local population increasing the impacts of existing stressors such as land use change. Another existing stressor is the fire regime that is likely to change with increased drought period. The vulnerability of natural habitat to climate change is a complex combination of the impacts on the sociological system (human livelihood) and the impacts on the natural or ecological system (vegetation structure, species community and species composition) (Figure 47). The hight fluctuation in precipitation and the increasing tendancy of the temperature indicate that the habitat is exposed to the impacts of climate change. The exposure is amplificated by anthropogenic activities such as land use change (recessional agriculture) and change in fire regime. Elements of habitat sensibility include habitat fragmentation (84%), change in species composition and change in vegetation structure. The rate of plant regeneration and the occurrence of elephant (because of seed dispersal hability) within OKM can be considered as the elements of the habitat adaptive capacity. However, this adaptive capacity depends highly on the management system of OKM. Nonetheless, the vulnerability of the habitat impacts on the sensibitlity and the adaptive capacity of the elephant to climate change since its viability depends on habitat condition.

Since many wildlife conservation actions are delivered on the ground based on a habitat framework, using habitats as the target of a vulnerability assessment can be a helpful way to ensure that the results will support the needs of managers **(Glick *et al.*, 2011)**. However, climate change vulnerability assessment for habitats is really complex and there are currently numerous models to realise this assessment. For terrestrial systems, scientists frequently rely on models that can project shifts in the range of vegetation or other organisms due to changes in climatic variables, usually at relatively large regional scales **(Glick *et al.*, 2011)**. Not only, was the scale of this study relatively small considering the scale of existing bio-climatic data, the lack of empirical data on the occurrence of elephant or the occurrence of characteristics species of distinguished habitats would increase the uncertainty associated with such models.

4.5. Limits and implications of this study

4.5.1. Limits of the study

There are some limits of this study due to the metods adopted. The main limitations are described as follow.

- Vegetation sampling:

The sampling effort need to be increased to be able to describe all aspects regarding the vegetation condition in natural habitats and especially in suitable elephant habitat within OKM. Time and human resources were the limiting factors to achieve better sampling effort.

- Habitat modelling

The elephant habitat suitability model implemented was limited by the unsuffisiant empirical data on elephant occurrence within OKM. Furthermore, data on elephant home range in this specific area as well as its daily travel distance were the limiting factors that could enable the implementation of statistical based habitat model. Method such as radio telemetry would be the suitable one to be used to get the necessary data for such analysis.

- Habitat vulnerability to climate change

It was very difficult to separate climate impacts from anthropogenic pressure on the habitats within OKM. Only an indirect impact of climate change was reported by this study. The lack of empirical data on the phenology of indicator plant species did not help. Dendrochronological assessement using indicators species of the different habitats described could be a good option to overcome this limit.

4.5.2. Implications for elephant conservation

At its current state, OKM looks more like a vanishing corridor. This area will be completely degraded and all the remnant patches of suitable habitat completely lost if no action to conserve and to restore these habitats is taken. The populations of elephants in West Africa will become more and more fragemented. This will prevent gene flow and that could lead to a complete extinction of elephant from West Africa. There is a need for an active restoration process with a full implication of local population. It is absolutely necessary to take into account the needs of the local population before implementing any elephant conservation strategy. Furthermore, killing of problem animal is not an option in Togo. Occurring individuals of elephant could help in the restoration process through their seed dispersal hability by allowing the dissemination of useful plant species. Their corridor could be useful for other animal species leading to the repopulation of habitats by animals coming from nearby protected areas. In deed, the least cost path between suitable habitat (Figure 48) showed the possibility of an animal traveling from the North to the South of OKM. This gave insights for a possible corridor connecting suitable habitat patches within OKM. Planning for and protecting elephant corridors have been shown to have large benefits for biodiversity conservation by many authors in East Africa especially in Tanzania **(Epps *et al.*, 2011; Jones *et al.*, 2012)**. Furthermore, the African elephant remains a good candidate as a surrogate species for conservation planning. It encompasses all the attributes of a focal species and associated conservation needs (Table XXIII) as proposed by **Brock and Atkinson (2013)**.

An effective conservation of the elephant would require management or mitigation of almost all elements affecting the needs of the total species community and provide ecosystem-level protection. On another hand confined population of elephant exert a damaging influence on their habitat. For instance, this effect has been already described in the Biosphere reserve of Pendjari where elephants are designated to be responsible of inducing bark damage to baobab trees (*Adansonia digitata*) **(Kassa *et al.*, 2013)** and to drive spatial isolation in *Borassus aethiopum* ***(*****Salako *et al*., 2015)**. A landscape level management of elephant population in West Africa would alleviate their damaging effect in confined habitat.

Little information is available on the other proposed or designated elephant corridors but the high level of fragmentation of the habitat within OKM increases the vulnerability of the species to climate change by restricting its range, its migration and associated benefits.

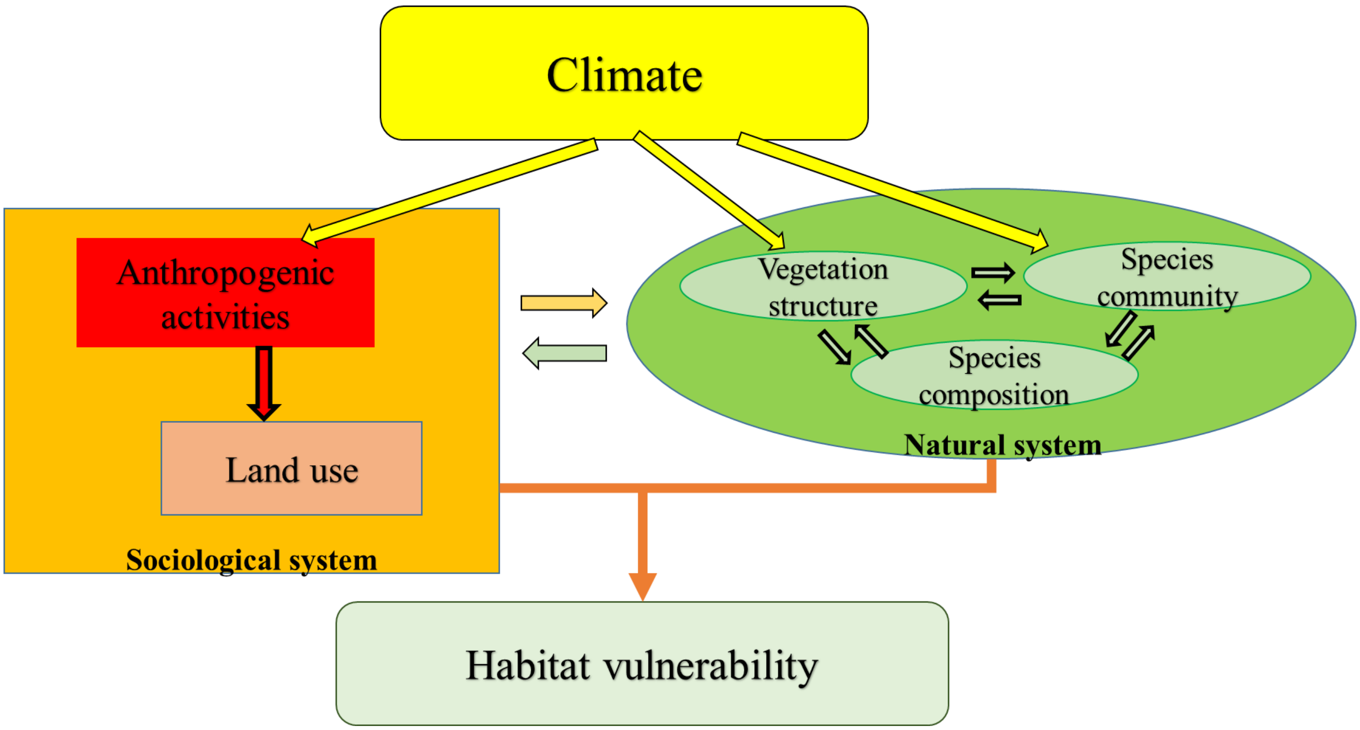

Figure 47: Illustration of the indirect impacts of climate change on the habitat within OKM

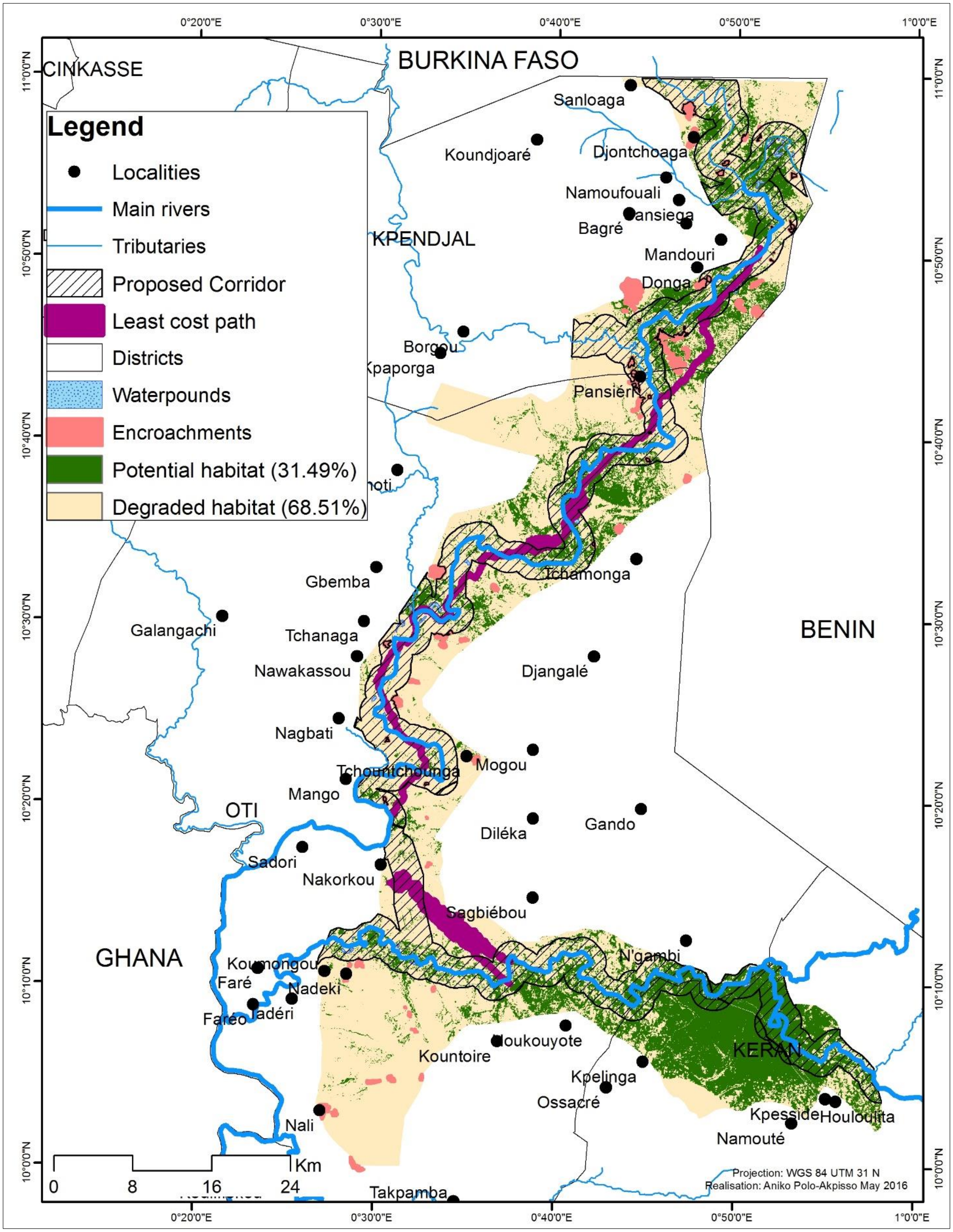

Figure 48: Least cost path for elephant and proposed corridor for first priority restoration actions

Table XXIII: Focal species attributes and selection criteria associated with conservation needs (Source: Brock and Atkinson, 2013)

Conservation need	Focal species attribute	Selection criteria
Area	Landscape species	Select large-area generalists to protect sufficient area and diversity of habitat types
Habitat	Habitat types	Make sure suite of focal species covers all major habitat types in the area
Security	Threats	Make sure suite of focal species covers all major threats that impact wildlife populations in the area
Ecological processes	Ecological processes and key species	Include key species needed to maintain natural community, and species that depend on ecological processes to sustain ecologically functional populations
Social acceptance	Socioeconomic values	Identify values that complement or conflict with conservation objectives

CONCLUSION

Occurrences of group elephants were reported in almost all the surrounding localities. There was reported presence of elephant within OKM during the period from 2010 and 2013. A group sizes from one to 11 were reported for one to four times from 2010 to 2013.

Natural habitats within Oti-Keran-Mandouri are relatively highly diverse. A total of 320 plant species belonging to 66 families and 209 genera was recorded. A total of 7 woody plant communities derived from 94 woody plant species was discriminated. The defined habitat types and their indicators or most important plant species are typical to the vegetation of the Sudanian zone in Africa and very similar to habitats currently used by the remaining population of elephants in West Africa. There are still patches of remnant good habitats within OKM of about 30% of its current area. However, this good habitat is fragmented at a rate of 81.81%.

A detailed analysis on the dynamics, direction of changes of Land cover and landscape transformation processes was performed from 1987 to 2013. There have been important changes in land cover within the protected area. Forests, savannahs and wetlands were converted into human transformed landscapes. Wetlands were the most converted land category. Croplands and settlements have increased with a high magnitude especially from 1987 to 2000. Three main transformation processes were identified from 1987 to 2013. These are attrition in forest and savanna, dissection in wetland and creation in cropland involving habitat loss in forest and in savanna (attrition) and habitat fragmentation in wetland (dissection) and leading to anthropization process. The main drivers of this degradation is agriculture expansion and population growth.

The degradation is worsened by implemented adaptation strategies to climate change that are mostly linked to land use change. The assessment of the socio-ecological system shows that there is a link between residents' livelihood, perceived impacts of climate change and values ascribed to biodiversity conservation. The former fortress conservation implemented in this area impacts also how people value nature conservation. Most of the income of residents derived from activities realized within the boundaries of OKM, therefore there is a negative consideration of conservation and hostility between residents and administrative authorities.

The outputs of this study verified all the stated hypotheses though it was difficult to show the direct impacts of climate change on the babitats. However, it was shown that impacts of climate change as perceived by local population are threatnning natural habitat quality.

OKM is currently a vanishing habitat but the reported presence of elephant makes its restoration possible. However, it appears that biodiversity conservation is not just a matter of ecology and there is a need for a deep understanding of the social context (socio-ecological system). Therefore, this area could only play its role as biodiversity refuge and elephant conservation corridor if the needs of local communities are taken into account in its management and put at the heart of the conservation system.

Regardless of anthropogenic pressure, Oti-Keran-Mandouri encompenses habitats that present an ecological value for biodiversity as well as for elephant conservation in Togo and in West Africa. A conservation plan at the landscape scale would be the one that could be a good adaptation strategy to climate change and be beneficial to other species as well.

PERSPECTIVES

Further research is needed to evaluate the opportunity of the implementation of Reducing emissions from deforestation and forest degradation (REDD+) in this area and its coopling with biodiversity conservation. The first step of this will be the estimation greenhouse gases emission in the sector of agriculture and other land use. There is a large domain of research that is yet to be conducted to derive specific emission factors.

On another hand, research on elephant habitat use and habitat preference in nearby protected areas would provide data for an integrated design of elephant conservation especially at landscape scale. Better understanding should be gained also in habitat fragementation and its impacts on ecosystems and ecosystem services. For instance, current ecosystem services and conservation values should be investigated and mapped. This would provide useful data for an effective corridor planning. With the problem raised about the little consideration of biodiversity conservation among resident communities, research is needed to explore new approaches for conservation that could integrate the needs of local populations. New tools, such as Marxan **(Beyer *et al.*, 2016)** could be used for this purpose.

Similar studies of habitat ecological characteristics should be conducted in the other designated corridors for elephant conservation in West Africa and elsewhere to assess their effectiveness. The current elephant conservation strategy in West Africa will be then updated with findings from such studies by taking into account the current land use, the socio-ecological system and climate change impacts.

There is also, the need to enhance the understanding of the coupling mechanism of land use system and climatic system. Modelling approach such as the land use change dynamics model **(Zhan *et al.*, 2014)** could help assess land use impacts on regional climate.

RECOMMENDATIONS

Actions to improve biodiversity conservation in Togo and especially within Oti-Keran-Mandouri are needed essentially from three mains actors: local population, scientific community and the government.

A- Recommendations to the local population

For a better management of natural habitats and natural resources as well, the local population need to change their behavior regarding natural resource management. For instance, they should develop environmental friendly livelihood by implementing good practices in land use especially in agriculture. On another hand, they need to be opened to take part in projects related to natural resource managenement in their area.

B- Recommendation to the scientific community

The scientific community has a major role to play to improve biodiversity conservation and deepen understanding of ecosystem functioning, wildlife-habitat relationship, and ecosystem services. Therefore, there is a need to make available useful and updated scientific data on plant and animal species, their habitats, the role of protected areas, ecosystem dynamics and socio-ecological systems. Conducting ecological monitoring will provide with long term data needed for better conservation planning. There is also a need to update species' monography and promote research in landscape ecology, conservation biology, wildlife-habitats relationship, restoration ecology, climate change and its impacts, agroecology. It is important to help build the capacity of the managers of protected areas in ecology, biodiversity management, climate system, agroforestry systems, sociology, in geographic information system… Developping short training in ecology and in environmental management for stakeholders and governmental agents would be one of the first steps to take. Another one would be to inform and sensitize NGOs and local population on the best practices in natural resource management.

C- Recommendations for the government

There is a need of a strong political will to change the ongoing degradation of natural resources. The government need to integrate sustainable management of natural resources in all development policies. Governmental actions need to be coordinated to promote complementarity between the ministry departments of education, planification and land management, agriculture, environement and forest resources. All effort should be done to create a good partnership with local NGOs working in the field of conservation and rural development. The integration of the management of protected areas in the national budget would be important to alleviate the problem of the financial support of conservation. A tax system to support biodiversity conservation could be promoted. It would be important to integrate the aspirations and perceptions of local population in any development plan and promote projects aiming at poverty alleviation. It is necessary to develop an integrated policy for land, water and natural resource management and promote a sustainable agriculture. A good education policy for local population is needed. All effort should be made to reach an agreement with local population on natural resource management and land planification. Improving drink water supply to resident communities of protected areas would alleviate pressure on natural resources. The elaboration of a good management plan for the protected areas and providing them with sufficient means and well trained human resources will improve biodiversity conservation. A good collaboration with the scientific community and the local authorities and stakeholders will also be beneficial to conservation. The decentralization process is an important issue that could help local population to get involve and be responsalized in taking conservation actions.

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APPENDICES

APPENDICE 1 : LIST OF PLANT SPECIES RECORDED WITHIN OTI-KERAN-MANDOURI

Species	Life forms	Biogeographical Type
Acanthaceae		
Asystasia gangetica (L.) T. Anders	Ph	SZ
Lepidagathis alopecuroides (Vahl) R.Br. ex Griseb.	Ge	S
Lepidagathis anobrya Nees	Ge	S
Lepidagathis collina (Endl.) Morton	Ge	S
Monechma ciliatum (Jacq.) Milne-Redh.	Ch	AT
Phaulopsis barteri T.Anderson	Ch	PRA
Amaranthaceae		
Celosia laxa Schumach. & Thonn.	Th	GC
Pandiaka angustifolia (Vahl) Hepper	Th	PRA
Pandiaka involucrata (Moq.) Hook.f.	Th	S
Anacardiaceae		
Haematostaphis barteri Hook.f.	Ph	S
Lannea acida A. Rich.	Ph	PRA
Lannea barteri (Oliv.) Engl.	Ph	PRA
Lannea kerstingii Engl. & K. Krause	Ph	PRA
Lannea microcarpa Engl. & K. Krause	Ph	SZ
Mangifera indica L.	Ph	Pan
Ozoroa insignis Del.	Ph	S
Ozoroa pulcherrima (Schweinf.) R. & A. Fernandes	Ph	S
Sclerocarya birrea (A. Rich.) Hochst.	Ph	AT

Species	Life forms	Biogeographical Type
Annonaceae		
Annona glauca Schum. & Thonn.	Ph	SZ
Annona senegalensis Pers.	Ph	PRA
Hexalobus monopetalus (A.Rich.) Engl. & Diels	Ph	SZ
Uvaria chamae P.Beauv.	Ph	PRA
Anthericaceae		
Chlorophytum blepharophyllum Schweinf. ex Baker	He	PRA
Chlorophytum macrophyllum (A. Rich.) Aschers.	He	GC
Apocynaceae		
Holarrhena floribunda (G.Don) Durant & Schinz	Ph	SG
Landolphia owariensis P.Beauv.	Ph	SG
Saba comorensis (Boj.) Pichon	Ph	PRA
Steganotaenia araliacea Hochst.		
Strophanthus sarmentosus DC.	Ph	GC
Araceae		
Amorphophallus abyssinicus (A. Rich.) N.E.Br.	Ge	G
Amorphophallus dracontioides (Engl.) N.E.Br.	Ge	G
Anchomanes difformis (Bl.) Engl.	Ge	G
Stylochaeton hypogeum Lepr.	Ge	S
Stylochaeton lancifolus Kotschy & Peyr.	Ge	S
Araliaceae		
Cussonia arborea Hochst. ex A. Rich.	Ph	SZ
Borassus aethiopum Mart.	Ph	SZ
Asclepiadaceae		

Tacazzea apiculata Oliv.	Ph	AT
Asparagaceae		
Asparagus africanus Lam. Lam.	Ph	SZ
Asparagus flagellaris (Kunth) Baker	Ph	SZ
Asparagus warneckei (Engl.) Hutch.	Ph	GCW
Asteraceae		
Ageratum conyzoides L.	Th	Pan
Aspilia helianthoides (Schumach. & Thonn.) Oliv. & Hiern	Th	SZ
Aspilia rudis Oliv. & Hiern	Th	SZ
Chromolaena odorata (L.) R.M. King		
Eclipta prostrata (L.) L.	Th	Pan
Synedrella nodiflora (L.) Gaertn	Th	Pan
Tridax procumbens L.	Th	Pan
Vernonia ambigua Kotschy & Peyr.	Th	SZ
Vernonia amygdalina Delile	Ph	G
Vernonia cinerea (L.) Less.	Th	SZ
Vernonia nigritiana Oliv. & Hiern	Ch	SZ
Bignoniaceae		
Kigelia africana (Lam.) Benth.	Ph	GC
Markhamia tomentosa (Benth.) K.Schum. ex Engl.		
Stereospermum kunthianum Cham.	Ph	SG
Bombacaceae		
Adansonia digitata L.	Ph	SZ
Bombax costatum Pellegr. & Vuill.	Ph	S
Ceiba pentandra (L.) Gaert.	Ph	Pan
Caesalpiniaceae		

Afzelia africana Sm.	Ph	SZ
Burkea africana Hook.	Ph	AT
Cassia sieberiana DC.	Ph	AT
Chamaecrista mimosoides (L.) Greene	Th	Pal
Daniellia oliveri (Rolfe) Hutch. & Dalz.	Ph	SZ
Detarium microcarpum Guill. & Perr.	Ph	S
Dialium guineense Willd.	Ph	GC
Isoberlinia doka Craib & Stapf	Ph	S
Piliostigma thonningii (Schumach.) Milne-Redhead	Ph	AT
Senna obtusifolia (L.) H.S.Irwin & Barneby	Th	Pan
Tamarindus indica L.	Ph	Pan
Capparaceae		
Capparis sepiaria L.		
Crataeva adansonii DC.	Ph	Pal
Celastraceae		
Gymnosporia senegalensis (Lam.) Loes.		
Celtidaceae		
Celtis toka (Forssk.) Hepper & J.R.I. Wood		
Celtis zenkeri Engl.		
Trema orientalis (L.) Blume		
Chrysobalanaceae		
Parinari curatellifolia Planch. ex Benth.	Ph	SZ
Cochlospermaceae		
Cochlospermum planchoni Hook. f.	Ph	SZ
Cochlospermum tinctorium A. Rich.	Ge	S
Colchicaceae		

Gloriosa superba L.		
Combretaceae		
Anogeisus leiocarpus (DC.) Guill. & Perr.	Ph	PRA
Combretum aculeatum Vent.	Ph	
Combretum acutum Laws.	Ph	SZ
Combretum adenogonium Steud. ex A. Rich.	Ph	
Combretum collinum Fresen.	Ph	S
Combretum glutinosum Perr. ex DC.	Ph	SZ
Combretum indicum (L.) DeFilipps.	Ph	
Combretum micranthum G. Don	Ph	S
Combretum molle R. Br. Ex G. Don	Ph	AT
Combretum nigricans Lepr. Ex Guill. & Perr.	Ph	S
Pteleopsis suberosa Engl. & Diels	Ph	PRA
Terminalia avicenioides Guill. & Perr.	Ph	S
Terminalia glaucescens Planch. ex Benth.	Ph	SG
Terminalia laxiflora Engl. & Diels	Ph	S
Terminalia macroptera Guill. & Perr.	Ph	S
Terminalia mollis M.A.Lawson	Ph	PRA
Commelinaceae		
Commelina benghalensis L.	Th	Aam
Commelina erecta L.	Ch	AT
Palisota hirsuta (Thunb.) K.Schum.		
Connaraceae		
Rourea coccinea (Thonn. ex Schum) Benth.	Ph	AT
Convolvulaceae		
Ipomoea aquatica Forssk.	Th	Pan

Ipomoea argentaurata Hallier f.	Th	S
Ipomoea asarifolia (Desr.) Roem. & Schult.		
Ipomoea cairica (L.) Sweet		
Cyperaceae		
Cyperus esculentus L.	Ge	Pan
Cyperus haspan L.	Ge	Pan
Fimbristylis ferruginea (L.) Vahl	He	Pan
Fuirena ciliaris (L.) Rottb.	Th	PRA
Kyllinga pumila Michx.		
Rhynchospora corymbosa (L.) Britt.	He	Pan
Scleria verrucosa Willd.	Th	AT
Dioscoreaceae		
Dioscorea bulbifera L.	Ge	Pan
Dioscorea cayenensis Lam.	Ge	At
Dioscorea dumetorum (Kunth) Pax	Ge	SZ
Dioscorea praehensilis Benth.	Ge	S
Dioscorea togoensis Knuth	Ge	S
Ebenaceae		
Diospyros mespiliformis Hochst. ex A. DC.	Ph	SZ
Diospyros monbuttensis Gürke	Ph	SZ
Euphorbiaceae		
Antidesma venosum E. Mey. ex Tul.		
Bridelia ferruginea Benth.	Ph	PRA
Bridelia micrantha (Hochst.) Baill.	Ph	Pal
Bridelia scleroneura Müll. Arg.	Ph	S
Euphorbia convolvuloides Hochst. ex Benth.	Th	S

Euphorbia heterophylla L.	Th	Pan
Euphorbia kouendenensis Beille	Th	S
Flueggea virosa (Roxb. ex Willd.) Voigt	Ch	Pal
Hymenocardia acida Tul.	Ph	SZ
Margaritaria discoidea (Baill.) Webster	Ph	AT
Phyllanthus amarus Schumach. & Thonn.	Th	Pan
Phyllanthus muellerianus (O. Ktze) Exell	Ph	AT
Phyllanthus pentandrus Schumach. & Thonn.	Th	PRA
Sapium grahamii (Stapf) Pain	Ge	S
Tragia benthamii Bak.	Ph	SZ
Tragia senegalensis Müll. Arg.	Ge	S
Fabaceae		
Abrus precatorus L.	Ph	Pan
Alysicarpus ovalifolius (Schum. & Thonn.) J. Léonard	Th	Pal
Alysicarpus rugosus (Willd.) DC.	Th	AM
Crotalaria glauca Willd.	Th	At
Crotalaria graminicola Taub. ex Bak.f.	Th	S
Crotalaria macrocalyx Benth.	Th	S
Crotalaria retusa L.	Th	Pan
Desmodium gangeticum (L.) DC.	Ch	Pal
Desmodium velutinum (Wild.) DC.	Ch	PRA
Eriosema griseum Baker		SZ
Erythrina senegalensis DC.	Ph	SG
Indigofera bracteolata DC.	Th	S
Indigofera dendroides Jacq.	Th	AT
Lonchocarpus sericeus (Poir.) H.B. & K.	Ph	PRA

Neorautanenia mitis (A.Rich.) Verde.	Th	PRA
Pericopsis laxiflora (Benth.) van Meeuwen	Ph	S
Philenoptera cyanescens (Schumach. & Thonn.) Roberty		
Philenoptera laxiflora (Guill. & Perr.) Roberty		
Pterocarpus erinaceus Poir.	Ph	SZ
Pterocarpus santalinoides DC.	Ph	PRA
Sesbania sesban (L.) Merr.	Th	SZ
Tephrosia bracteolata Guill. & Perr.	Th	SZ
Tephrosia linearis (Willd.) Pers.	Th	PRA
Tephrosia nana Schweinf.	Th	SZ
Tephrosia villosa (L.) Pers.	Th	At
Tephrosisa vogelii Hook.f.	Th	
Uraria picta (Jacq.) DC.	Th	Pal
Xeroderris stuhlmannii (Taub.) Mendonça & Sousa	Ph	SZ
Flacourtiaceae		
Flacourtia indica (Burm.f.) Merr.	Ph	PRA
Oncoba spinosa Forsk.	Ph	SZ
Hypoxidaceae		
Curculigo pilosa (Schumach. & Thonn.) Engl.	Ge	PRA
Icacinaceae		
Hydrolea macrosepala A.W. Benn.	Th	Pan
Lamiaceae		
Hoslundia opposita Vahl		
Hyptis spicigera Lam.	Th	Pal
Hyptis suaveolens Poir.	Th	Pal
Leonotis nepetifolia (L.) Aiton f.		

Tinnea barteri Gürke	Ch	SZ
Liliaceae		
Smilax kraussiana Meisn.	Ge	AT
Loganiaceae		
Spigelia anthelmia L.	Th	AA
Strychnos innocua Delile	Ph	SZ
Strychnos spinosa Lam.	Ph	AM
Loranthaceae		
Agelanthus dodoneifolius (DC.) Polh. & Wiens	Ep	AT
Tapinanthus sessilifolius (P.Beauv.) Tiegh.	Ep	SG
Malvaceae		
Abutilon mauritianum (Jacq.) Medik.	Th	
Cienfuegosia heteroclada Sprague	Th	S
Hibiscus asper Hook. f.	Th	AT
Hibiscus surattensis L.	Ch	Pan
Sida acuta Burm.f. *ssp. carpinifolia* (L.f.) Borss.Waalk.	Ch	
Sida acuta Burm. f.	Ch	Pan
Sida linifolia Juss. ex Cav.	Ch	AA
Sida rhombifolia L.	Ch	
Sida urens L.	Ch	GC
Urena lobata L.	Ch	Pan
Marantaceae		
Thalia geniculata L.	Hyd	PRA
Meliaceae		
Azadirachta indica A. Juss.	Ph	Pal
Khaya senegalensis (Desr.) A. Juss.	Ph	S

Pseudocedrela kotschyi (Schweinf.) Harms	Ph	S
Trichilia emetica Vahl	Ph	SZ
Mimosaceae		
Acacia amythethophylla Steud. ex A. Rich.		
Acacia ataxacantha DC.	Ph	SZ
Acacia dudgeoni Craib. ex Holl.	Ph	S
Acacia gourmaensis A. Chev.	Ph	S
Acacia mellifera (Vahl) Benth.		
Acacia nilotica (L.) Wild. ex Delile		
Acacia polyacantha Willd. *ssp. campylacantha* (Hochst. ex A. Rich.) Brenan	Ph	SZ
Acacia seyal Delile	Ph	S
Acacia sieberiana DC.	Ph	SZ
Dichrostachys cinerea (L.) Wight & Am.	Ph	AT
Entada abyssinica Steud. ex A. Rich.	Ph	AT
Entada africana Guill. & Perr.	Ph	PRA
Faidherbia albida (Delile) A. Chev.	Ph	SZ
Leucaena leucocephala (Lam.) De Wit	Ph	Pan
Mimosa pigra L.	Ph	Pan
Parkia biglobosa (Jacq.) R. Br. ex G Don f.	Ph	Pal
Prosopis africana (Guill. & Perr.) Taub.	Ph	SZ
Molluginaceae		
Triclisia subcordata Oliv.	Ph	SG
Moraceae		
Ficus capreifolia Del.	Ph	SZ
Ficus gnaphalocarpa (Miq.) Steud. ex A. Rich.	Ph	SZ

Ficus sur Forssk.	Ph	SG
Myrtaceae		
Syzygium guineense (Willd.) DC.	Ph	AT
Nyctaginaceae		
Boerhavia diffusa L.	Th	Pan
Onagraceae		
Ludwigia decurrens Walt.	Th	
Ludwigia hyssopifolia (G.Don) Exell	Th	AT
Ludwigia octovalvis (Jacq.) Raven	Th	AT
Opiliaceae		
Opilia amentacea Roxb.	Ph	SZ
Pedaliaceae		
Ceratotheca sesamoides Endl.	Th	PRA
Poaceae		
Andropogon chinensis (Nees) Merr.	He	S
Andropogon gayanus var *bisquamulatus* Hochst.	He	S
Andropogon schirensis Hochst. ex A. Rich.	He	PRA
Brachiaria deflexa (Schumach.) C. E. Hubbard ex Rob	Th	Pal
Chasmopodium afzelii (Hack.) Stapf	Th	SZ
Ctenium newtoni Hack.		
Cymbopogon giganteus (Hochst.) Chiov.	He	AT
Cymbopogon schoenanthus (L.) Spreng.	He	AT
Echinochloa pyramidalis (Lam.) Hitchc. & Chase		
Eragrostis tremula (Lam.) Steud.	Th	Pal
Euclasta condylotricha (Steud.) Stapf	Th	Pal
Heteropogon contortus (L.) P.Beauv.	Th	Pal

Hyparrhenia involucrata Stapf	Th	S
Imperata cylindrica (L.) Raeuschel	Ge	Pan
Loudetia simplex (Nees) C.E. Hubbard	He	SZ
Loudetiopsis kerstingii (Pilg.) Conert	He	SZ
Paspalum conjugatum Berg.	He	Pal
Paspalum scrobiculatum L.	He	Pal
Pennisetum glaucum (L.) R.Br. *ssp. violaceum* (Lam.) Rich.	Th	Pal
Pennisetum pedicellatum Trin.	Th	Pal
Pennisetum polystachyon (L.) Schult.	Th	Pal
Rhytachne triaristata (Steud.) Stapf	Th	Pal
Rottboellia cochinchinensis (Lour.) W. D. Clayton	Th	Pan
Sacciolepis africana C.E.Hubb. & Snowden		
Schizachyrium sanguineum (Retz.)	He	PRA
Setaria barbatac (Lam.) Kunth	Th	AT
Setaria megaphylla (Steud.) T.Durand & Schinz	Th	AT
Setaria pumila (Poir.) Roem. & Schult.	Th	AT
Sporobolus festivus Hochst. ex A.Rich.	He	PRA
Sporobolus pyramidalis P.Beauv.	He	SZ
Urelytrum muricatum C.E.Hubb.	He	S
Vetiveria nigritana (Benth.) Stapf	He	SZ
Polygalaceae		
Securidaca longepedunculata Fres.	Ph	AT
Persicaria senegalensis (Meisn.) Soják		
Polygala arenaria Willd.		
Pteridaceae		
Adiantum lunulatum Burm. f.		

Rhamnaceae		
Ziziphus abyssinica A. Rich.	Ph	At
Ziziphus mauritiana Lam.	Ph	Pal
Ziziphus mucronata Willd.	Ph	PRA
Rubiaceae		
Argocoffeopsis rupestris (Hiern) Roddrecht	Ph	SG
Crossopteryx febrifuga (G. Don) Benth.	Ph	SZ
Diodia sarmentosa Sw.	Ph	Pan
Fadogia cienkowskii Schweinf.	Ch	SZ
Fadogia erythrophloea (K. Shum. & K. Krause) Hutch. & Dalziel	Ph	S
Feretia apodanthera Del.	Ph	SZ
Gardenia aqualla Stapf & Hutch.	Ph	SZ
Gardenia erubescens Stapf & Hutch.	Ph	S
Gardenia ternifolia Schum. & Thonn.	Ph	Pal
Macrosphyra longistyla (DC.) Hiern	Ph	SG
Mitracarpus hirtus (L.) DC.	Th	AT
Mitragyna inermis (Willd.) O. Kuntze.	Ph	SZ
Pavetta crassipes K. Schum.	Ph	AT
Psydrax horizontalis (Schumach. & Thonn.) Brisdson		
Rytigynia senegalensis Blume	Ph	SG
Sarcocephalus latifolius (Smith) Bruce	Ph	AT
Spermacoce radiata (DC.) Hiern	Th	SZ
Spermacoce ruelliae DC.	Th	
Spermacoce stachydea DC.	Th	SZ
Spermacoce verticillata L.	Th	AT

Sapindaceae		
Allophylus africanus P. Beauv.	Ph	AT
Paullinia pinnata L.	Ph	AA
Sapotaceae		
Pouteria alnifolia (Back.) Roberty	Ph	GC
Vitellaria paradoxa C. F. Gaertn.	Ph	S
Scrophulariaceae		
Scoparia dulcis L.	Ch	AT
Striga hermonthica (Delile) Benth.	Th	Pal
Simaroubaceae		
Hannoa undulata Planch.	Ph	S
Solanaceae		
Schwenckia americana L.	He	AA
Sterculiaceae		
Cola laurifolia Mast.	Ph	GC
Melochia corchorifolia L.	Ch	Pan
Sterculia setigera Del.	Ph	SZ
Waltheria indica L.	Ch	Pan
Taccaceae		
Tacca leontopetaloides (L.) Kuntze	Ge	Pan
Tiliaceae		
Corchorus fascicularis Lam.	Th	Pal
Corchorus tridens L.	Th	SZ
Grewia carpinifolia Juss.	Ph	GC
Grewia cissoides Hutch. & Dalziel	Ge	S
Grewia lasiodiscus K. Schum.	Ph	S

Grewia venusta Fresen	Ph	S
Grewia villosa Willd.	Ph	
Triumfetta cordifolia A.Rich.	Th	Pan
Triumfetta rhomboidea Jacq.	Th	pan
Verbenaceae		
Clerodendrum capitatum Schum & Thonn.	Ph	PRA
Clerodendrum thyrsoideum Gürke	Ph	
Lantana camara L.	Ch	Pan
Lantana ukambensis (Vatke) Verde.	Ch	
Lippia multiflora Moldenken	Ph	SZ
Tectona grandis L.	Ph	Pal
Vitex chrysocarpa Planch. ex Benth.		
Vitex doniana Sweet	Ph	AT
Vitex madiensis Oliv.	Ph	SZ
Vitaceae		
Ampelocissus leonensis (Hook. F.) Planch.	Ph	S
Cayratia ibuensis (Hook. f.) Suess.	Th	SZ
Cissus aralioides (Welw.ex Back.) Planch.	Ph	AT
Cissus cornifolia (Baker) Planch.		
Cissus palmatifida (Baker) Planch.	Ph	SG
Cissus populnea Guill. & Perr.	Ph	PRA
Cissus quadrangularis L.	Ph	Pal
Cyphostemma adenocaule (Steud.) Desc.	Ph	S
Cyphostemma sokodense (Gilg & Brandt) Desc.	Ph	S
Zingiberaceae		
Aframomum sceptrum (Oliv. & D. Hanb.) K. Shum.	Ge	

Siphonochilus aethiopicus (Schweinf.) B.L.Burtt	Ge	AT
Zygophyllaceae		
Balanites aegyptiaca (L.) Del.	Ph	SZ

APPENDICE 2: ABRÉGÉ DE LA THÈSE EN FRANÇAIS

Thème: Les caractéristiques écologiques de l'habitat de l'éléphant (*Loxodonta africana*, Blumenbach 1797) dans le complexe d'aires protégées Oti-Kéran-Mandouri au Togo

INTRODUCTION

Les services écosystémiques rendus par la biodiversité sont essentiels à la vie sur Terre. Cependant, à cause de la croissance démographique, il y a une pression croissante sur la diversité biologique. Il devient essentiel de conserver une partie de cet acquis naturel pour maintenir les services écosystémiques dans la nature et pour le bénéfice de l'être humain. De nos jours, les aires protégées restent l'outil principal pour la conservation de la biodiversité. Dans les pays en développement, en particulier en Afrique, la conservation formelle a commencé au cours de la période de la colonisation. Malheureusement, bon nombre des aires protégées a échoué à conserver efficacement les espèces et leur habitat naturel menant à l'extinction des espèces ou à leur extirpation de plusieurs régions. Par exemple, il y a eu une réduction de moitié à l'échelle du continent dans l'abondance des grands mammifères dans les aires protégées d'Afrique depuis les années 1970 **(Craigie *et al.*, 2010)**. Les causes principales de cette diminution sont la chasse excessive et la conversion de l'habitat **(Baillie *et al.*, 2004)** qui sont dues à la croissance rapide de la population humaine, la consommation des ressources et les conséquences de la conservation répressive dans certaines régions **(Tchamié, 1994; Muhumuza and Balkwill, 2013)**. Néanmoins, les aires protégées sont appelées à jouer un rôle important dans l'adaptation des communautés locales aux impacts du changement climatique **(Dudley *et al.*, 2010)**. Par conséquent, il a été proposé que la gestion des aires protégées soit considérée à l'échelle du paysage, y compris la planification de leur dynamique de concert avec la matrice environnante et d'autres aires protégées **(Lovejoy and Hannah, 2005)**. Par exemple, en Afrique de l'Ouest, où il y a eu une réduction de 90% de l'aire de répartition de l'éléphant (*Loxodonta africana*, Blumenbach 1797), la stratégie pour la conservation de ces mammifères a proposé plusieurs aires protégées transfrontalières et des corridors de conservation. Le plus important de ces corridors de conservation comprend la réserve de faune Oti-Mandouri et le parc national de la Kéran qui constituent le complexe Oti-Kéran-Mandouri (OKM) dans le Nord du Togo. Cette zone fait partie de la plus vaste région écogéographique de distribution de l'éléphant en Afrique de l'Ouest. Il est répertorié comme un site Ramsar, comme une zone importante pour les oiseaux et comme l'une des 10 aires protégées prioritaires actuellement en cours de rehabilitation au Togo. Par conséquent, il y a un besoin de données scientifiques sur la dynamique et les caractéristiques actuelles des habitats dans cette région.

En outre, des données sur le système socio-écologique peut permettre une meilleure compréhension des menaces qui pèsent sur la biodiversité et améliorer les connaissances en matière de gestion durable. En considérant l'éléphant comme une espèce parapluie, la conservation effective de son habitat bénéficiera également à d'autres espèces. Aussi, cette étude vise-t-elle à améliorer la conservation de la biodiversité au Togo en fournissant des données sur les caractéristiques des habitats de Oti-Kéran-Mandouri en prenant l'éléphant comme l'espèce focale. Il s'agira plus spécifiquement de:

1. évaluer la fréquence d'occurrence de l'éléphant au sein de Oti-Kéran-Mandouri de 2010-2013;
2. analyser l'habitat de l'éléphant au sein de Oti-Kéran-Mandouri;
3. évaluer la dynamique de l'habitat de 1987 à 2013;
4. évaluer la vulnérabilité de l'habitat face à la pression anthropique favorisée par le changement climatique.

MATÉRIEL ET MÉTHODES

Zone d'étude

Cette étude porte sur Oti-Kéran-Mandouri (OKM), un complexe d'aires protégées couvrant environ 179 000 ha. Il est composé de deux parties (la réserve de faune Oti-Mandouri et le parc national Oti-Kéran). Il est situé dans les plaines du bassin de la rivière Oti dans le Nord du Togo.

Méthodes

Cette étude a été réalisée sur la base d'une approche multidisciplinaire impliquant les sciences sociales, la télédétection, la botanique et le système d'information géographique (SIG).

Collecte de données

Une enquête sociale sur la base de questionnaire a été réalisée pour évaluer le système socio-écologique dans les villages environnant OKM. La carte d'occupation du sol dérivée de la classification de la scène de Landsat (Octobre 2013), le NDVI et d'autres données thématiques de la zone d'étude ont été combinés pour une évaluation multicritère afin de déduire l'habitat favorable à l'éléphants. Les changements d'affectation des terres et les processus de changement des habitats de 1987 à 2013 ont été évalués par les scènes de Landsat de différentes dates (1987, 2000 et 2013). L'échantillonage de la végétation a été effectué dans 182 parcelles de 50m x 20m pour évaluer la richesse specifique des végétaux, les principaux gradients écologiques qui influencent la distribution des espèces végétales et les communautés végétales.

L'enquête sociale a été réalisée en deux étapes. La première étape a concerné l'évaluation de l'occurrence de l’éléphant dans OKM et ses environs de 2010 à 2013. La deuxième étape a concerné un groupe plus restreint, composé des dignitaires qui prennent souvent part à la prise de décision au niveau local. Cette dernière évaluation a conserné la vulnérabilité de l'habitat au changement climatique et les valeurs attribuées à la conservation de la biodiversité au sein de OKM par les communautés riveraines.

Les relevés de végétation ont été effectués dans des placeaux installés au niveau des points de vérification terrain selectionnés pour la classification de la scène de Landsat d’Octobre 2013. Les données floristiques, des mesures dendrométriques (hauteur totale et diamètre des espèces ligneuses à hauteur de poitrine (DBH) égale ou supérieure à 10 cm) et 17 variables environnementales ont été recueillies dans ces parcelles de 50 m x 20 m. Les espèces herbacées quant à elle, ont été enregistrées dans des sous placeaux de 10 m x 10 m au centre de la grande parcelle **(Tehou *et al.*, 2012)** et les juvéniles (espèces ligneuses avec DBH<10 cm) ont été comptés dans trois petites parcelles de 5 m x 5 m installées en diagonal dans la grande placette. Les données floristiques ont été recueillies selon l'échelle phytosociologique de Braun-Blanquet. Les coordonnées géographiques de chaque point d’échantillonnage et toute caractéristique environnementale ou écologique pertinente ont été enregistrées en utilisant un récepteur GPS.

L'analyse des données

Les données recueillies au cours de l'enquête sociale ont été traitées à l'aide du logiciel de statistiques pour les sciences sociales (SPSS 20) et la feuille de calcul Microsoft Excel 2013. Les statistiques descriptives ont été réalisées pour des données de la taille du groupe d'éléphant et leur fréquence d’occurrence. L'accord entre les personnes interrogées concernant un sujet donné a été évalué en utilisant une formule adaptée de **Monteiro *et al.* (2006)**

L'évaluation multicritère a été réalisée grace à des techniques de superposition (fuzzy overlay et raster calculator) mises en œuvre dans ArcGIS Model Builder. Le niveau de fragmentation de l'habitat a été évalué à l'aide de GUIDOS Toolbox **(Vogt, 2016)**.

Les caractéristiques générales de la végétation ont été décrites et différents habitats ont été distingués suivant leur qualité. Le logiciel EstimateS (version 9) a été utilisé pour estimer la richesse totale des espèces végétales en utilisant l'estimateur Chao 2 **(Colwell *et al.*, 2012)**. Les espèces végétales ont, en outre, été classées en fonction de leurs types phytogéographiques et de leurs types morphologiques. Les gradients écologiques majeurs influençant la distribution des espèces ont été évalués par une analyse de gradient direct en utilisant le logiciel CANOCO (Analyse Canonique des Correspondances (CCA)) avec une matrice de 161 placeaux x 312 espèces avec 17 variables environnementales. Une autre matrice de 123 x 94 parcelles d'espèces ligneuses a été soumise à une classification hiérarchique en utilisant le logiciel CAP. La diversité alpha a été évaluée avec le calcul des indices de diversité pour chaque communauté de plantes ligneuses identifiées et des types d'habitats distingués. L'analyse des espèces caractéristiques a été faite en utilisant le package " Indicspecies " du logiciel statistique R **(De Cáceres and Legendre, 2009)**.

La cartographie de l'habitat favorable à l'éléphant et la simulation d'un couloir reliant les fragments d'habitat favorable à l'éléphant ont permis de faire l'analyse des facteurs pouvant influencer le déplacement des éléphants au sein de OKM et de ses environs.

En supposant que l'habitat favorable à l'éléphant peut être considéré comme les types de végétation naturelle. Une classification supervisée en utilisant l'algorithme du maximum de vraisemblance a été réalisée sur les images Landsat (1987, 2000 et 2013). Les analyses de changement d'affectation des terres ont été effectuées sur la base d'une comparaison pixel par pixel en utilisant le logiciel Change Modeler intégré dans IDRISI **(Eastman, 2012)**. Les processus de changement dans les différentes catégories ont été identifiés suivant la procédure de **Bogaert *et al.* (2004)**. Le nombre de taches (fragments) a été ensuite calculé pour chaque couverture terrestre en utilisant Lecos **(Jung, 2013)**.

RÉSULTATS

Connaissances sur le mouvement des éléphants

L'enquête a porté sur 292 personnes dans 18 villages autour de OKM. Sur toute la période allant de 2010 à 2013, il a été rapporté que des groupes d'éléphants ont été apperçus de 1 à 4 fois selon la préfecture où l'enquête est réalisée. Les éléphants ont été apperçus une fois surtout dans la préfecture de la Kéran et dans la préfecture de l'Oti alors qu'ils l'ont été trois fois dans la prefecture de Kpendjal. Il y a une forte fluctuation de la taille du groupe d'éléphants vus. Les valeurs rapportées sont comprises entre 1 et 11. Il est généralement rapporté 3 individus, suivie de 4 individus. Toutefois, des groupes composés de 10 à 11 individus ont été rapportés dans la préfecture de Kpendjal (10 et 11). Les éléphants sont signalés principalement aucours de deux périodes dans la prefecture de Kpendjal : de Mai à Septembre avec un accent sur Juin et de Janvier à Février. Dans la prefecture de l'Oti, les éléphants arrivent surtout en Avril et en Novembre alors que dans la prefecture de la Kéran, les mois les plus rapportés pour le passage des éléphants sont Octobre et Décembre. Les éléphants ne sont presents que pendant la saison sèche dans la prefecture de la Kéran alors qu'ils sont présents pendant les saisons pluvieuse et sèche dans les prefectures de l'Oti et de Kpendjal. Les conflits homme-éléphant (CHE) ne se produisent pas toujours mais ils sont signalés dans certains villages puisque les periods de passage d'éléphants coïncident parfois avec la période de récolte des noix de karité (*Vitellaria paradoxa* CF Gaertn.) (Mai-Juin) ou du sorgho (*Sorghum bicolor* (L.) Moench.) (Novembre-Décembre). La population humaine, les points d'eau et la distribution des zones marécageuses peuvent expliquer les habitudes de déplacement des éléphants.

L'habitat des éléphants dans OKM

L'inventaire floristique dans 182 parcelles a révélé 320 espèces végétales reparties dans 209 genres et 66 familles. Les espèces végétales les plus fréquentes sont *Piliostigma thonningii* (Schumach.) Milne-Redhead (2,90%), *Pterocarpus erinaceus* Poir. (2,90%), *Combretum glutinosum* Perr. ex DC. (2,34%), *Anogeisus leiocarpus* (DC.) Guill. & Perr. (2,09%), et *Terminalia laxiflora* Engl. & Diels (2,09%). L'estimation de la richesse des espèces basée sur l'estimateur Chao 2 donne un total de 433 ± 30 espèces pour la zone d'étude. Il y a une forte variation entre la richesse spécifique observée et la richesse spéficique estimée. Les espèces végétales les plus importantes dans les données enregistrées sont les phanérophytes (50,52%), suivie par les thérophytes (26,30%) et les géophytes (8,65%). Le spectre phytogéographique est dominé par des espèces de la région soudano-zambézienne (SZ) (21,94%) et du centre d'endémisme soudanien (S) (18,35%). Il y a une bonne représentation des espèces à grande échelle de distribution : Pan-tropical (12,23%), Paleotroprical (10.07), et Afro-américaine (1,44%). Il existe une relation significative entre les axes canoniques, les espèces et les facteurs écologiques. Les quatre premiers axes canoniques du CCA expriment 9,4% de la variance dans la distribution des espèces et 50,4% de la variance par rapport à la relation espèces-environnement. L'inertie totale est de 19.66%. La plus importante variation dans les données sur les espèces (3,5%) et dans la relation espèces-environnement (37,7%) est exprimé par le premier axe. Deux principaux gradients écologiques influençant la répartition des espèces ont été révélés. Il s'agit du gradient de dégradation de l'habitat et du gradient du sol.

L'analyse hiérarchique a distingué sept groupes de communautés de plantes ligneuses. Leur richesse spécifique va de 9 espèces de plantes ligneuses dans le groupe des parcs agroforestiers à *Borassus eathiopum* (G7) à 54 espèces végétales ligneuses dans les savanes arborées (G4). Selon l'analyse des espèces indicatrices 22 espèces sont significativement associées aux divers groupes sur un total de 94 espèces. Ainsi, les communautés végétales discriminées partagent de nombreuses espèces. Parmi ces 22 espèces, 4 espèces sont associées au groupe 1 (G1), 8 espèces au groupe 2 (G2), 1 espèce au groupe 3 (G3), 2 espèces au groupe 4 (G4), 5 espèces au groupe 5 (G5), et 1 espèce au groupe 6 (G6) comme au groupe 7 (G7).

L'habitat favorable à l'éléphant est très fragmenté (81,81%), mais la corrélation n'est pas linéaire entre la fréquence d'occurrence d'éléphant dans un milieu et la qualité de l'habitat. Les éléphants ont été reportés dans des zones très peuplées.

Dynamique de l'habitat potentiel des éléphants dans OKM entre 1987 et 2013

Les catégories d'occupation du sol telles que les zones humides, la savane et la forêt ont été considérées comme des substituts de l'habitat favorable à l'éléphant. Elles ont régressé au profit des types de couvertures anthropiques que sont les terres cultivées et les établissements humains. En général, de 1987 à 2013, les forêts, les savanes et les zones humides ont diminué à un pourcentage annuel moyen de 5,74%, 3,94% et 2,02% respectivement par rapport à leur superficie de depart. Alors que les terres cultivées ont augmenté à un taux annuel moyen de 285,39%. Les processus dominants de changement de l'habitat de 1987 à 2013 sont l'attrition dans les forêts et les savanes, la dissection dans les zones humides et la création dans les terres cultivées. Ces processus conduisent à la dégradation de l'habitat naturel avec la perte de l'habitat dans les forêts et les savanes et la fragmentation des habitats dans les zones humides.

La vulnérabilité de l'habitat au changement climatique et à la pression anthropique

Un total de 53 dignitaires et chefs de ménage, a été enquêté dans 17 villages environnants OKM. Il a éé rapporté que la quantité des pluies a diminué ces dernières décennies (94,30% des enquêtés), la saison des pluies est retardée (71,70%), non stable (24,5%) et écourtée (90.60%). Tous les répondants ont trouvé que la période de sécheresse a augmenté au fil des années de même que la température qui a augmenté pour 81.10% des enquêtés. Les dégâts dûs aux vents violents ont augmenté (81.10%). Il existe trois grandes interprétations pour tous ces changements. La première est que Dieu est responsable de ces changements et cette idée est soutenue par 35,80% des enquêtés. La seconde est qu'il y a de plus en plus de manque de respect pour les traditions locales (32,10%). Enfin, 30,20% des enquêtés signalent que la dégradation de la végétation constitue la cause de tous ces changements. Les principales stratégies utilisées pour faire face aux changements constatés sont la diversification des cultures (37.11%), l'agriculture de contre-saison (34.02%), l'introduction de nouvelles variétés (17,53%) et l'augmentation des terres agricoles (5,15%). Une grande partie des ménages (79.20%) a admis qu'une grande partie ou le total de leurs revenus provient d'activités réalisées dans les limites de OKM. Il n'y a pas d'intérêt à conserver la biodiversité au sein de OKM pour 53,03% des enquêtés. Toutefois les valeurs rapportées pour la conservation de la biodiversité sont significativement corrélées à l'accès à l'éducation formelle ($X2 = 13,687$; $df = 1$; $p < 0,001$) et la distance des villages par rapport aux limites des aires protégées ($X2 = 14,28$; $df = 1$; $p < 0,001$). Une importante partie des enquêtés (57,58%) a suggéré la libération de la zone protégée pour l'agriculture. D'autres ont plutot souhaité une délimitation consensuelle (13,64%) ou une meilleure collaboration entre les communautés locales et les gestionnaires (12,12%) pour un meilleur plan de conservation de la biodiversité.

DISCUSSION

Présence d'éléphant dans OKM

Cette étude a montré que les éléphants font des passages sporadiques dans OKM et ses environs mais leur fréquence d'occurrence diffère d'une prefecture à une autre. L'occurrence de éléphants au sein de OKM peut être lié à leur population dans le complexe transfrontalier W-Arly-Pendjari (WAP) situé à proximité et au Nord-Est de OKM, la disponibilité en eau et le comportement de l'animal. Cette présence de l'animal a déjà été rapportée par des études antérieures **(IUCN, 2008)**.

L'habitat des éléphants

Le nombre d'espèces végétales (n=320) recensé est relativement élevé. La différence entre le nombre d'espèces observé et celui estimé pourait être due aux limites de la technique d'échantillonnage. Cela indique également qu'il y a nécessité d'un travail plus approfondi pour la description de la flore de cette zone. Les communautés végétales identifiées sont très similaires aux différents types d'habitats ou de communautés de plantes ligneuses décrits dans plusieurs études dans la zone soudanienne en fonction de leur composition floristique, leur chorologie et le type de formations végétales. Les deux principaux gradients écologiques influançant la distribution des espèces révélées dans cette étude sont presque les mêmes décrits par **Wala (2010)** sur la chaîne de l'Atakora au Nord du Bénin.

Toutes les espèces importantes et presque toutes les espèces indicatrices ont été signalées comme des espèces broutées par l'éléphant (*Loxodonta africana*, Blumenbach, 1797) dans la zone de chasse de Djona (Nord Bénin), au ranch de Nazinga (Sud Burkina Faso), dans la vallée de la Volta Rouge et dans la réserve de biosphère de la Pendjari **(Hien, 2001; Adjewodah *et al.*, 2012; Tehou *et al.*, 2012)**. Sans influence anthropique, les habitats dans Oti-Kéran-Mandouri sont bien adaptés pour les éléphants en raison, notamment, de la disponibilité en nourriture et en eau.

La presence des éléphants a été signalée dans certaines zones très peulées. Cela traduit le fait que leur présence n'est pas directement liée à la qualité de l'habitat actuel, mais peut être liée à la disponibilité de l'eau, la disponibilité des cultures et la mémoire particulièrement longue de l'éléphant. Cela donne de l'espoir pour une éventuelle restoration des habitats. Mais alors, l'abattage des animaux à problème ne peut être considerer comme une option pour résoudre le problème de dégâts sur les cultures causés par l'éléphant.

Dynamique des habitats dans OKM entre 1987 et 2013

Il y a une forte pression sur les formations naturelles et sur les zones humides en particulier. Elles sont transformées en des formations anthropiques (les terres cultivées) et en des établissements humains. Des tendances similaires ont été signalés autour et à l'intérieur des aires protégées au Togo et ailleurs en Afrique de l'Ouest **(Dimobe *et al.*, 2015)**. Les processus de transformation du paysage identifiés caractérisent deux principaux changements dans la configuration de l'habitat. Attrition et dissection indiquent la dégradation de l'habitat naturel alors que la création et l'agrégation impliquent l'apparition de nouvelles unités d'habitat. Ces processus conduisent à un processus d'anthropisation comme l'a décrit **Barima *et al.* (2009)** dans la zone de transition forêt-savane de la Côte d'Ivoire. Ceci n'est pas favorable pour la conservation de la biodiversité car de concert avec la perte d'habitat, la fragmentation de l'habitat est une grave menace pour la survie des espèces selon **Laurance *et al.* (2002)**.

La vulnérabilité de l'habitat aux changements climatiques et à la pression anthropique

OKM est entouré par des paysages très peuplées. La taille des ménages enregistrée est beaucoup plus élevée que la moyenne nationale. Ceci menace l'intégrité de l'habitat et la connectivité de OKM avec d'autres aires protégées puisque l'activité principale des habitants est l'agriculture.

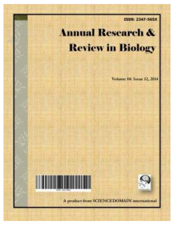
Tous les riverains interrogés sont au courant des changements ou des variations des facteurs climatiques. Le changement dand les précipitations et la température est en conformité avec plusieurs études à travers l'Afrique de l'Ouest et en particulier dans le nord du Togo **(Badjana *et al.*, 2014a; Klein *et al.*, 2015)**. Les habitats de OKM sont donc exposés aux fluctuations des facteurs climatiques.

L'opinion majoritaire des riverains (53% des enquêtés) sur le fait qu'il n'y a pas de valeur à conserver la biodiversité au sein de OKM est particulièrement aggravée par les mauvais souvenirs de la conservation répressive mise en œuvre au stade précoce de la création de ces aires protégées. Les situations conflictuelles autour des aires protégées ont également été signalées dans de nombreux autres pays d'Afrique de l'Ouest (UICN / PACO, 2012). Mais les gens ont traité avec succès ces questions ailleurs, comme en Indonésie ou au Cambodge **(Clements *et al.*, 2014; Muhamad *et al.*, 2014)** en donnant plus de place aux communautés locales dans le système de gestion et de conservation de la biodiversité. La sensibilité des habitats aux facteurs climatiques est agravée par le taux de fragmentation et de dégradation. Le manque d'intérêt pour la conservation exprimé par les populations vient accentuer la vulnérabilité des habitats aux effets néfastes du changement climatique.

CONCLUSION

La présence des éléphants est signalée par les riverains de OKM. Les habitats au sein de Oti-Kéran-Mandouri sont relativement diversifiés. Il y a encore des reliques d'habitat favorable à l'éléphant. Cependant, cet habitat est fortement degradé et fragmenté. Les principaux facteurs de cette dégradation sont l'expansion de l'agriculture et la croissance de la population. La dégradation est aggravée certaines stratégies d'adaptation mises en œuvre par les populations riveraines pour faire face au changement climatique comme l'agriculture de contre saison. Cette zone ne peut jouer son rôle de refuge de la biodiversité et de couloir de conservation des éléphants que si les besoins des communautés locales sont pris en compte dans sa gestion. D'autres recherches sont nécessaires pour évaluer les émissions dues au changement d'affectation des terres et l'opportunité de la mise en œuvre de la REDD + dans cette region. D'un autre côté il faudra évaluer l'impact de la fragmentation sur la conservation de la biodiversité dans un context de changement climatique.

APPENDICE 3 : PUBLICATIONS



Annual Research & Review in Biology
7(5): 283-299, 2015, Article no.ARRB.2015.129
ISSN: 2347-565X

SCIENCEDOMAIN *international*
www.sciencedomain.org

Plant Species Characteristics and Woody Plant Community Types within the Historical Range of Savannah Elephant, *Loxodonta africana* Blumenbach 1797 in Northern Togo (West Africa)

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Authors' contributions

This work was carried out in collaboration between all authors. Author APA wrote the protocol, performed data analysis, interpreted the data and produced the initial draft. Authors KW, TY and KA designed the study. Authors AA, WA and MN anchored the field study and gathered the initial data. While authors YAW, SO and MC managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ARRB/2015/19271
Editor(s):
(1) George Perry, Dean and Professor of Biology, University of Texas at San Antonio, USA.
Reviewers:
(1) Souare Konsala, Faculty of Science, University of Maroua, Cameroon.
(2) Anonymous, University of Cape Coast, Ghana.
Complete Peer review History: http://sciencedomain.org/review-history/10088

Original Research Article

Received 1st June 2015
Accepted 22nd June 2015
Published 8th July 2015

**Corresponding author: E-mail: anikopolo@gmail.com;*

ABSTRACT

Aims: Assessment of plant species diversity and habitat typology.
Study Design: Stratified random sampling design according to defined land categories of a land cover map.
Place and Duration of Study: Complex of protected areas Oti-Keran-Mandouri (Northern Togo) from March to December 2014.
Methodology: Floristic data, forest measurements (total height and diameter of woody species with diameter at breast height (DBH) greater than 10 cm) and 17 environmental variables were collected in plots of 50 m X 20 m; herbaceous species were recorded in subplot of 10 m X 10 m at the center of the big plot and juveniles (woody species with DBH<10 cm) were counted in three subplots of 5 m X 5 m installed diagonally. Floristic data were collected according to the phytosociological scale of Braun-Blanquet. After deletion of outliers, two different matrices were considered for canonical correspondence analysis (CCA) and .for hierarchical cluster analysis.
Results: A total of 320 plant species were recorded in 182 plots and grouped in 209 genera and 66 families. The most frequent species were *Piliostigma thonningii* (2.90%), *Pterocarpus erinaceus* (2.90%), *Combretum glutinosum* (2.34%), *Anogeissus leiocarpus* (2.09%), and *Terminalia laxiflora* (2.09%). The species' distribution was influenced by two major ecological gradients: habitat degradation and soil. The first four canonical axes of the CCA express 9.4% of the variance in species distribution and 50.4% of the variance in species-environment relation with a total inertia of 19.66%. Seven groups of woody plant communities were distinguished according to their species composition (0.35 ≤H≤1.43 and 0.37≤E≤0.83).
Conclusion: Species composition and distribution are influenced by environmental variables especially anthropogenic activities. However, dominant species are relevant to large herbivores such as the African savannah elephant. Management system should be improved to maintain this important corridor.

Keywords: Biodiversity; habitat; conservation; Oti-Keran-Mandouri; Togo.

1. INTRODUCTION

Ecosystem and habitat assessment particularly in the face of the changing climate become important challenges in the fields of landscape ecology and conservation biology. Habitat lost and degradation is one of the most important threat to biodiversity conservation especially in developing countries. Habitat degradation appears to be related to the social and economic changes in rural areas across African continent in last decades [1] as well as to climate change [2,3].

The large wetlands of Oti River and its tributaries present important biotopes for migrating birds [4] and large mammals such as the African savannah elephant [5-7]. Therefore, large portions of this area have been put under protection for biodiversity conservation. Some of these protected areas are Oti-Keran National Park located 9º55'-10º20 North and 0º25-1º East and Oti-Mandouri Wildlife Reserve located 10º18'-11º North and 0º30' - 0º47' East. They are part of the most important protected areas in Togo [8] and are listed as RAMSAR sites (Oti-Kéran in 1997 and Oti-Mandouri in 2007). They have been recently considered as biosphere reserves in 2011. Oti-Keran National Park and Oti-Mandouri Wildlife reserve are currently considered as a complex of protected areas Oti-Keran-Mandouri (OKM) [9]. OKM is considered to be part of one of the most important corridors for elephant migration that lies across four countries: Burkina Faso, Benin, Niger and Togo [10]. At a wider range, OKM can be considered as a link between two large blocks of African elephant population including many protected areas. The first block, at the East, includes the protected areas of the tripartite WAP complex (Parks W, Arly and Pendjari) and the second block includes the protected areas of Po, Nazinga, and Sissili (PONASI) that are located in South-West Burkina Faso near the Northern boundary of Ghana. This area can be considered as one of the most important eco-geographical region for the West African elephant migration.

From 1970 to 1990, Oti-Keran-Mandouri (OKM) was considered as the largest and continuous habitat for savannah elephant in Togo [7]. Unfortunately, during social and political claims from 1990, natural resources within protected areas were the target of huge anthropogenic pressure [1]. Therefore this historical range of elephant is converted into croplands and small patches of natural habitat. Recent studies in this area reported high fluctuations in rainfall [11] and an increasing pressure on protected areas [12,13]. However, OKM has been considered as a first priority corridor for elephant migration in West Africa [14]. On the other hand, this complex of protected areas has also been considered at the national level as a priority ecosystem to be manage to enhance biodiversity conservation in Togo [9].

Corridors provide the hope of reversing deleterious consequences of habitat fragmentation [15]. They are also of critical importance for maintaining the viability of isolated populations and conserving ecosystem functionality [16]. Since the African savannah elephant is considered as a keystone species of the savannah ecosystem [17], taking the elephant as a focal species in conservation planning will enable the designing of a management plan that will benefit other species as well. Therefore a better understanding of habitats characteristics and their species composition will enable a better planning.

The aims of nature conservation and planning can be partly met by scientific knowledge about hydrological processes, succession, isolation and population structure, and partly by field research directed at particular problems [18]. Biotic communities and environmental data are among the most important data needed in such planning.

Portions of OKM have been surveyed in previous studies [13,19]. However, ecological data of this habitat taken as a whole are still lacking. Thus, this study aims at improving biodiversity conservation within OKM by assessing plant species diversity and habitat typology through biodiversity indexes calculation and multivariate analysis.

2. MATERIALS AND METHODS

2.1 Study Area

Oti-Keran-Mandouri (OKM) is a complex of protected areas covering about 179 000 ha [9] and located in the northern flat plains of Oti river basin in Northern Togo (Fig. 1). It straddled three districts namely Kpendjal, Oti and Kéran. This area belongs to the eco-floristic zone I of Togo [20]. It is characterized by a tropical climate with a rainy season from June to October and a dry season between November and May. The annual average rainfall is between 800 and 1000 mm and the temperature vary from 17 to 39ºC during the dry season and from 22 to 34ºC during the rainy season. The predominant vegetation is Sudanian savannah, with some dry forest patches and gallery forests along rivers.

Agriculture is the principal activity in the surrounding area and occupies around 70 to 80% of the active population in these districts [21]. The most cultivated crops are sorghum (*Sorghum bicolor* (L.) Moench.),maize (*Zea mays* L.), rice (*Oryza sativa* L.), yams (*Dioscorea sp*), and cassava (*Manihot esculenta* Crantz.). There is currently increasing interest in cash crop production that is cotton (*Gossypium hirsutum* L.). Consequently, there is a great pressure to access fertile lands. This leads to over-exploitation and degradation of soils and natural habitats even within protected areas. Other rural activities in this area include collection of timber and fuelwood [22,23] and non-timber products (fruits, medicinal plants, straw), charcoal production [12,24], hunting and fishing [25]. International livestock transhumance constitutes also an important threat to biodiversity in this area.

2.2 Data Collection

Vegetation survey was based on a land cover map derived from a supervised classification of Landsat 8 image of October 2013. Land categories were defined and ground truth data were collected during field prospection in November 2013. Therefore, a stratified random sampling was designed according to defined land categories. Fieldworks were done from March to December 2014. Floristic data, dendrometric measurements (total height and diameter of woody species with diameter at breast height (DBH) greater than 10 cm) and 17 environmental variables were collected in plots of 50 m X 20 m; herbaceous species were recorded in subplot of 10 m X 10 m at the center of the big plot [26] and juveniles (woody species with DBH<10 cm) were counted in three subplots of 5 m X 5 m installed diagonally. Floristic data were collected according to the phytosociological scale of Braun-Blanquet [27]. Dendrometric

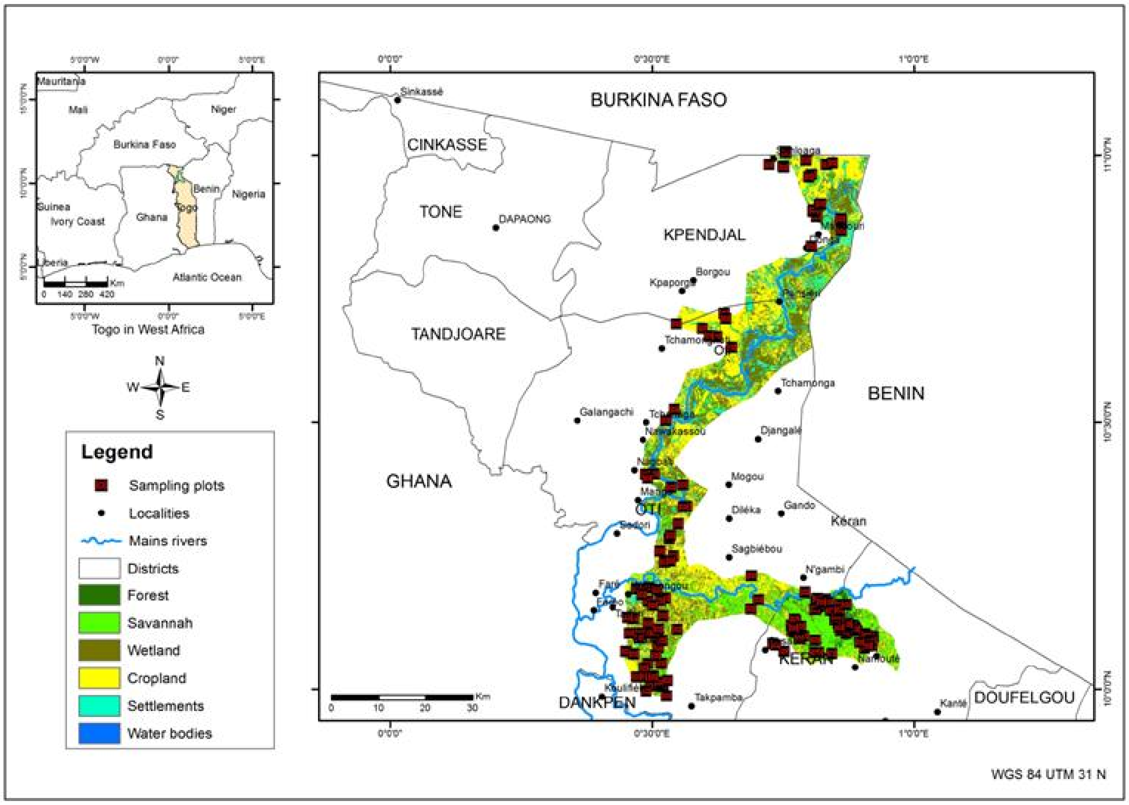

Fig. 1. Study area: distribution of sampling plots

measurements concerned total height and diameter of woody species with diameter at breast height equal or greater than 10 cm (DBH ≥10 cm) [13,26]. Three 5 m X 5 m subplots were installed diagonally to assess plant regrowth (two at the angles and one at the center of the 50 m X 20 m plot). Environmental variables described canopy cover, topographic position, slope, soil type, water availability and anthropogenic footprints such as cropping, wood cutting, fire, charcoal production etc. The geographic coordinates of each sample and any relevant environmental or ecological feature were recorded using a handheld Global Positioning System receiver (GPS GARMIN GPS Map 62stc).

2.3 Data Analysis

All plant species encountered in the overall 182 sampling plots of this study were named and categorised into their respective genera and families according to those set by [28,29]. EstimateS (version 9) was used to estimate the total species richness by constructing sample-based species accumulation curves using Chao 2 estimator with 100 randomization as recommended by the user's guide [30]. Plant species were furthermore classified according to their phytogeographical types [31] and their life forms [32]. Major ecological gradients in species distribution and species-environment relationship were assessed by a direct gradient analysis using Canoco software (Canonical Correspondence Analysis (CCA)) [33]. After the first run, outlier samples were deleted and this analysis was finally performed on a matrix of 161 samples X 312 species with 17 environmental variables. The analysis was performed using a log transformed plant species abundance data recorded according to the scale of Braun-Blanquet with inter-species scaling, Hill's distance and downweighting of rare species.

The habitats were distinguished based on woody species. Therefore, a matrix of 123 plots x 94 woody species was submitted to a hierarchical clustering using presence-absence data following Ward's method and Euclidian distance measure with the Community Analysis Package (CAP 2.15) software [34].

Alpha diversity indices were computed for each woody plant community identified. These are species richness (S), Shannon-Wiener diversity index (H) and Pielou evenness index (E). The Pielou's evenness measures the similarity in the abundance of the different woody species sampled. Its value varies between 0 and 1. The value tends to 0 when one or few species have higher abundance than others and 1 in the situation where all species have equal abundance. High values of H would be representative of more diverse communities [35].

The formulas of these indexes are:

$$H = -\sum_{i=1}^{s} p_i \, log_2 p_i \text{ with } p_i = \frac{r_i}{r} \quad (1)$$

Where r_i is the number of individuals belonging to the species i, r the total number of all individuals in the considered plot and s is the species richness in the plot.

$$E = \frac{H}{H_{max}} \text{ with } H_{max} = log_2 s \quad (2)$$

Where H represents the Shannon-Wiener's diversity index, H max is the maximum value of the diversity index and S is the number of species recorded in the considered plant community.

Furthermore, a thorough characterization of each plant community was done by computing the Indicator value index (IndVal) and the species Importance Value Index (IVI).

The indicator analysis was computed using R package ''Indicspecies'' [36]. This package provide a set of functions to assess the strength and statistical significance of the relationship between the species occurrence or abundance and site groups, which may represent habitat types, community types, disturbance states, etc. The indicator value index is the product of two components, referred to as 'A' and 'B' [37]. Component 'A' is the probability that the surveyed site belongs to the target site group given the fact that the species has been found. This conditional probability is called the specificity or the positive predictive value of the species as indicator of the site group. Component 'B' is the probability of finding the species in sites belonging to the site group. This second conditional probability is called the fidelity or sensitivity of the species as indicator of the target site group [38].

The Importance Value Index (IVI) [39] characterizes the place occupied by each species within vegetation, compared with the other species. Its formula is:

$$IVI = FREQesp + DENSesp + DOMesp \quad (3)$$

The relative frequency of a species (FREQesp) is the ratio of its specific frequency (a number of plots in which it is present) over the sum of the specific frequencies of all species. The relative density of a species (DENSesp) is the ratio of its absolute density over the sum of the absolute densities of all species. Relative dominance of a species (DOMesp) is the quotient of its basal area with the sum of basal areas of all species.

The basal area of the stand (G) is the sum of the cross-sectional area at 1.3 m above the ground level of all trees on a plot, expressed in m² per ha:

$$G = \frac{\pi}{4} \sum_{i=1}^{n} 0.0001 d_i^2 \quad (4)$$

Where n is the number of trees found on the plot, and d_i the diameter (in cm) of the *i*-th tree. Species regeneration rate was estimated for each woody plant species in each plant community.

3. RESULTS

3.1 Floristic Analysis

The floristic inventory in 182 plots (18.2 ha) revealed 320 plant species grouped in 209 genera and 66 family. The most frequent plant species are *Piliostigma thonningii (Schumach.) Milne-Redhead* (2.90%), *Pterocarpus erinaceus Poir.* (2.90%), *Combretum glutinosum Perr. ex DC.* (2.34%), *Anogeisus leiocarpus (DC.) Guill. & Perr.* (2.09%), and *Terminalia laxiflora Engl. & Diels* (2.09%) (Fig. 2). The most important families in term of percentage of species richness are Poaceae (9.69%), Fabaceae (9.06%), Rubiaceae (6.25%), Euphorbiaceae (5.31%) and Combretaceae (5%). The most diversified genera in term of species richness are *Combretum* (2.81%) and *Acacia* (2.5%).

The estimation of the species richness based on Chao 2 estimator gives a total of 433±30 species for the study area (Fig. 3). There is a high variation between the observed and the estimated species richness.

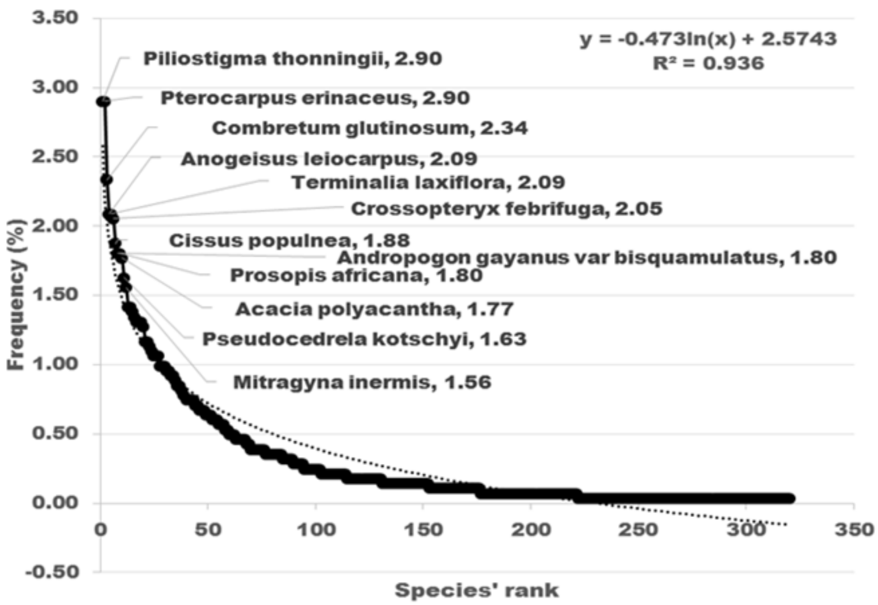

Fig. 2. Species-rank curve of all species recorded in 182 plots within OKM

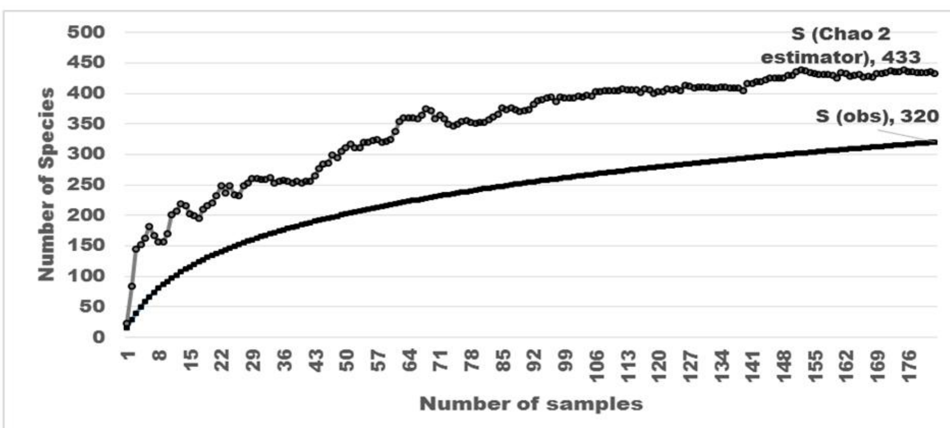

Fig. 3. Species accumulation curve

The most important plant species in the recorded data are phanerophytes (50.52%) followed by therophytes (26.30%) and geophytes (8.65%). The least represented plants are hydrophytes (0.34%) and epiphytes (0.69%) (Fig. 4).

The phytogeographical spectrum is dominated by species from the Sudano-Zambesian (SZ) (21.94%) and the Sudanian endemism centre (S) (18.35%) types (Fig. 5). There is a good representation of a large distribution scale species: Pan-tropical (12.23%), Paleotroprical (10.07), and Afro-American (1.44%). Species with a continental scale distribution are also well represented. These are, Afro-Tropical (14.39%), African multi-regional (11.15%), Sudano-guinean (4.32%), Guineo-Congolian (3.60%), Afro-Malgach (1.08%), and Guinean (1.08).

3.2 Species-environment Relationship

There is a significant relationship between canonical axes, species, and ecological factors. The first four canonical axes of the CCA express 9.4% of the variance in species distribution and 50.4% of the variance in species-environment relation. The total inertia is 19.66%. The most important variance in species data (3.5%) and in species-environment relation (37.7%) are only expressed by the first axe (Table 1).

Both of the performed significance test (Monte Carlo permutation) on the first axis and on all axes (trace) are highly significant (P = 0.002 with 499 permutations). However, the F value is much higher for the test on the first axis (F=5.263) than for the test on the trace (F=1.927) meaning that the first axis explains more than the second, third, and fourth axes combined.

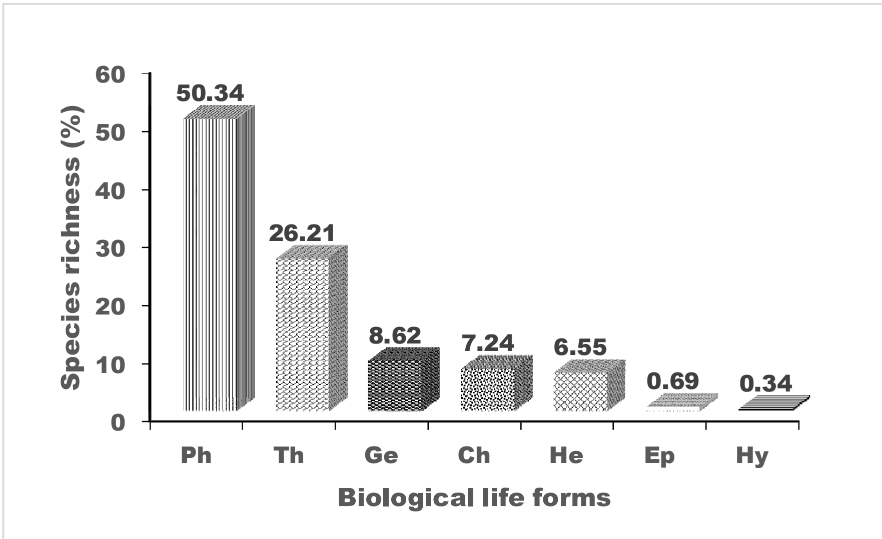

Fig. 4. Life forms spectrum of recorded plant species in 182 plots within OKM (Ph: Phanerophytes, Th: Therophytes, Ge: Geophytes, Ch: Chamaephytes, He: Hemicryptophytes, Ep: Epiphytes and Hy: Hydrophytes)

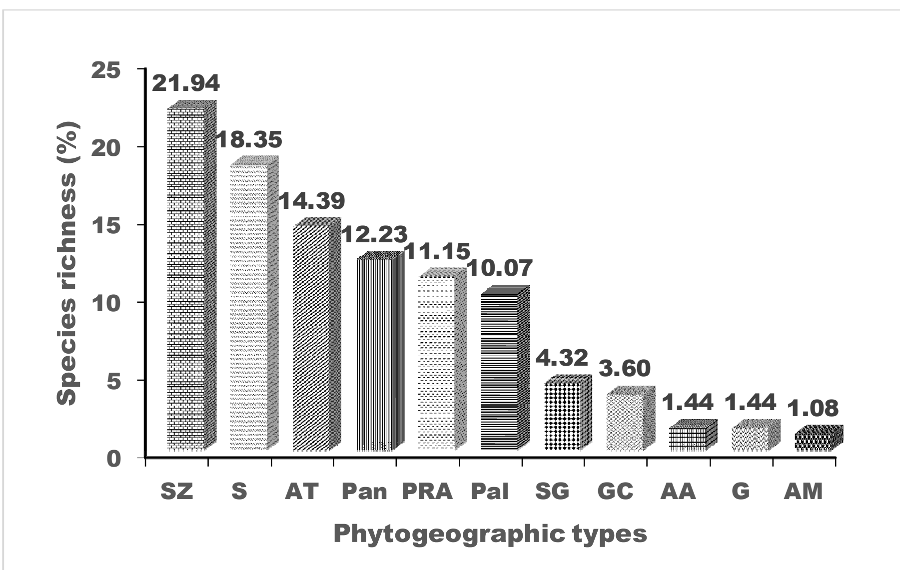

Fig. 5. Phytogeographical types of plant species (SZ: Sudano-Zambesian, S: Sudanian, AT: Afro-tropical, Pan: Pan-tropical, PRA: Pluri-regional in Africa, Pal: Paleo-tropical, SG: Sudano-Guinean, GC: Guineo-Congolian, AA: Afro-American, G: Guinean and AM: Afro-Malgash)

Table 1. Statistical synthesis of the CCA (161sample X 312 species X 17 environmental variables)

Axes	1	2	3	4	Total inertia
Eigenvalues :	0.698	0.439	0.395	0.313	19.656
Species-environment correlations :	0.903	0.777	0.773	0.751	
Cumulative percentage variance					
of species data :	3.5	5.8	7.8	9.4	
of species-environment relation:	19	31	41.8	50.4	
Sum of all eigenvalues					19.656
Sum of all canonical eigenvalues					3.663

Table 2. Weighted correlation between environmental variables and ordination axes of the CCA

Label	Significance	Axe 1 (species)	Axe 2 (species)	Canonical axe 1 (environmental variables)	Canonical axe 2 (environmental variables)
VegeOpen	Vegetation openness	-0.0566	0.1645	-0.0627	0.2119
TreeC20m	Tree cover of individual with at least h=20 m	0.6557	-0.311	0.726	-0.4004
TreeC720	Tree cover of individual with at least h between 7-20 m	0.419	0.0459	0.464	0.0591
TreeC.7m	Tree cover of individual with at least h=7 m	-0.1509	-0.2809	-0.167	-0.3617
HerbC	Herbaceous cover	-0.6234	-0.2147	-0.6902	-0.2765
HTree	Tree height	0.3403	-0.106	0.3768	-0.1365
Hshrub	Shrub tree height	-0.1433	-0.2842	-0.1587	-0.366
Hherb	Herbaceous plant height	-0.4194	-0.2943	-0.4643	-0.379
Topograp	Topography	-0.2957	0.3063	-0.3274	0.3944
EdaphSub	Edaphic substratum	-0.2142	-0.2021	-0.2371	-0.2602
Submers	Submersion (presence of water)	-0.2983	-0.2406	-0.3303	-0.3098
Fire	Fire occurrence	-0.3154	0.2502	-0.3493	0.3222
Grazing	Pastureland of grazing activity	-0.3753	0.2154	-0.4156	0.2773
Cropping	Existence of cropland	-0.0368	0.3695	-0.0407	0.4758
Wood-cut	Wood cutting activity	-0.1007	0.4424	-0.1115	0.5697
Swab	Bark or other plant organ harvesting	0.0226	0.4193	0.025	0.5399
Charcoal	Charcoal production	-0.0191	0.1433	-0.0211	0.1846

The analysis of Table 2 above shows that the first axis is positively correlated with high tree cover and negatively with shrubs and small trees. It is also correlated with the edaphic substratum. Here the soil varies from clayed soil on the right to sandy soil on the left. The latter is favourable to the bottom. The canopy cover increases as

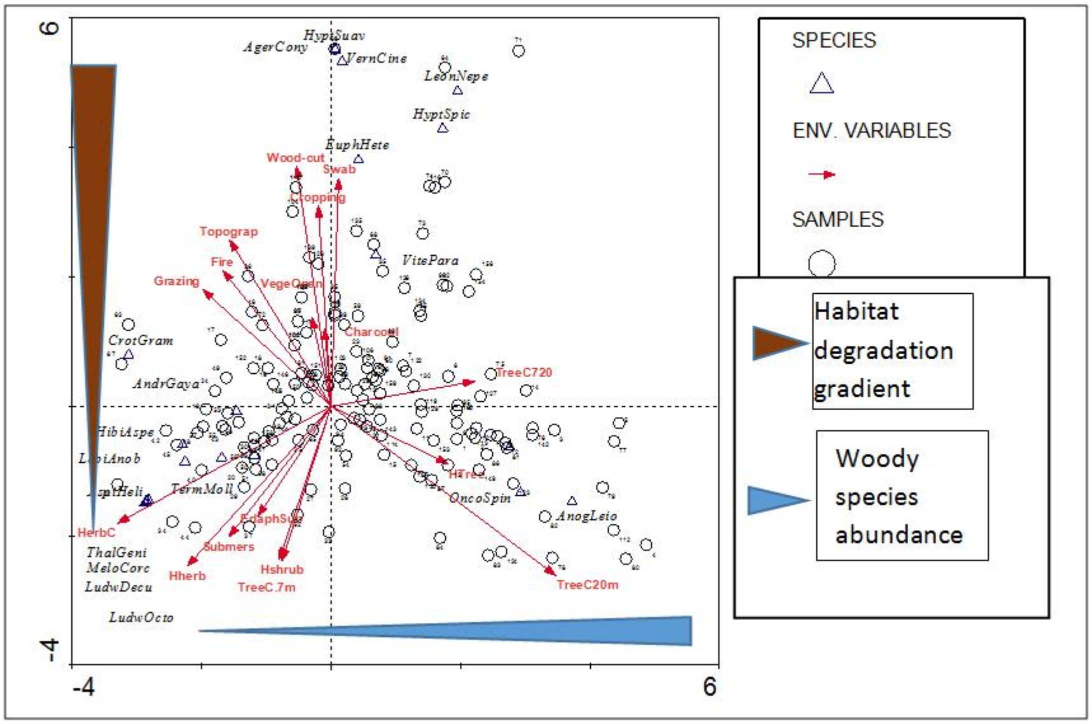

Fig. 6. CCA diagram of 161 samples X 312 species X 17 environmental variables

well as woody species abundance from the left to the right of the diagram. This indicates a gradient of soil enabling the establishment of perennial plants. This second gradient is linked to the first axis (horizontal axis).

The analysis of Table 2 shows that the first axis is positively correlated with high tree cover and negatively with shrubs and small trees. It is also correlated with the edaphic substratum. Here the soil varies from clayed soil on the right to sandy soil on the left. The latter is favourable to the establishment of woody vegetation type, usually a dry forest characterized by the abundance of *Anogeisus leiocarpus (DC.) Guill. & Perr.* The second axis is positively correlated to vegetation openness, topography and all the anthropogenic activities but it is negatively correlated with herbaceous cover and water availability (submersion).

3.3 Habitat Typology

The cluster analysis distinguished seven groups of woody plant communities (Fig. 7). The first group (G1) is composed of samples from gallery forests distributed along the major rivers, the second one (G2) is composed of samples from dry forests and woodland savannahs mostly on dry and sandy soil. The third group (G3) is composed of samples from shrub savannahs mostly on wet and clayed soil, the fourth (G4) is composed of samples from tree savannahs that is widely distributed, the fifth group (G5) is another group of gallery forests along minor rivers or tributaries. The sixth group (G6) is a mosaic group composed of samples from thorny woodland savannahs, samples from gallery forests and some shea tree parklands that are mostly located in periodically flooded areas and well represented in the North-Eastern part of OKM. The last group (G7) is composed of samples from *Borassus aethiopum Mart.* stands that are almost all the time in monospecific bands and usually transformed into parklands by surrounding residents.

Table 3. Alpha diversity in the different woody plant communities discriminated within OKM

	S	H (bits)	E
G1	49	1.06	0.63
G2	49	1.27	0.75
G3	33	1.18	0.78
G4	54	1.43	0.83
G5	33	1.25	0.82
G6	29	1.14	0.78
G7	9	0.35	0.37

The species diversity in each of these groups is reflected by the value of the species richness (S), Shannon-Wiener diversity index (H) and Pielou evenness index (E) (Table 3 above). The species richness range from 9 woody plant species in *B. eathiopum* parklands (G7) to 54 woody plant species in tree savannahs (G4). Both Shannon-Wiener diversity index and Pielou's evenness showed low species diversity within *B. eathiopum* parkland (G7) (H=0.35 and E=0.37) whereas the species diversity and distribution were more or less even in the other woody plant communities (1.06 ≤H≤1.43 and 0.63≤E≤0.83). The gallery forest along major rivers (mostly Oti River) was more diverse (S=49; H=1.06 and E=0.63) than the second one (S=33; H=1.25 and E=0.82) which is located along tributaries (mostly Koumongou River). However, species are more evenly distributed in the latter than in the former. Since anthropogenic activities are the main factor influencing species composition in theses habitats, the gallery forests along Oti River are more pressured than those along Koumongou River.

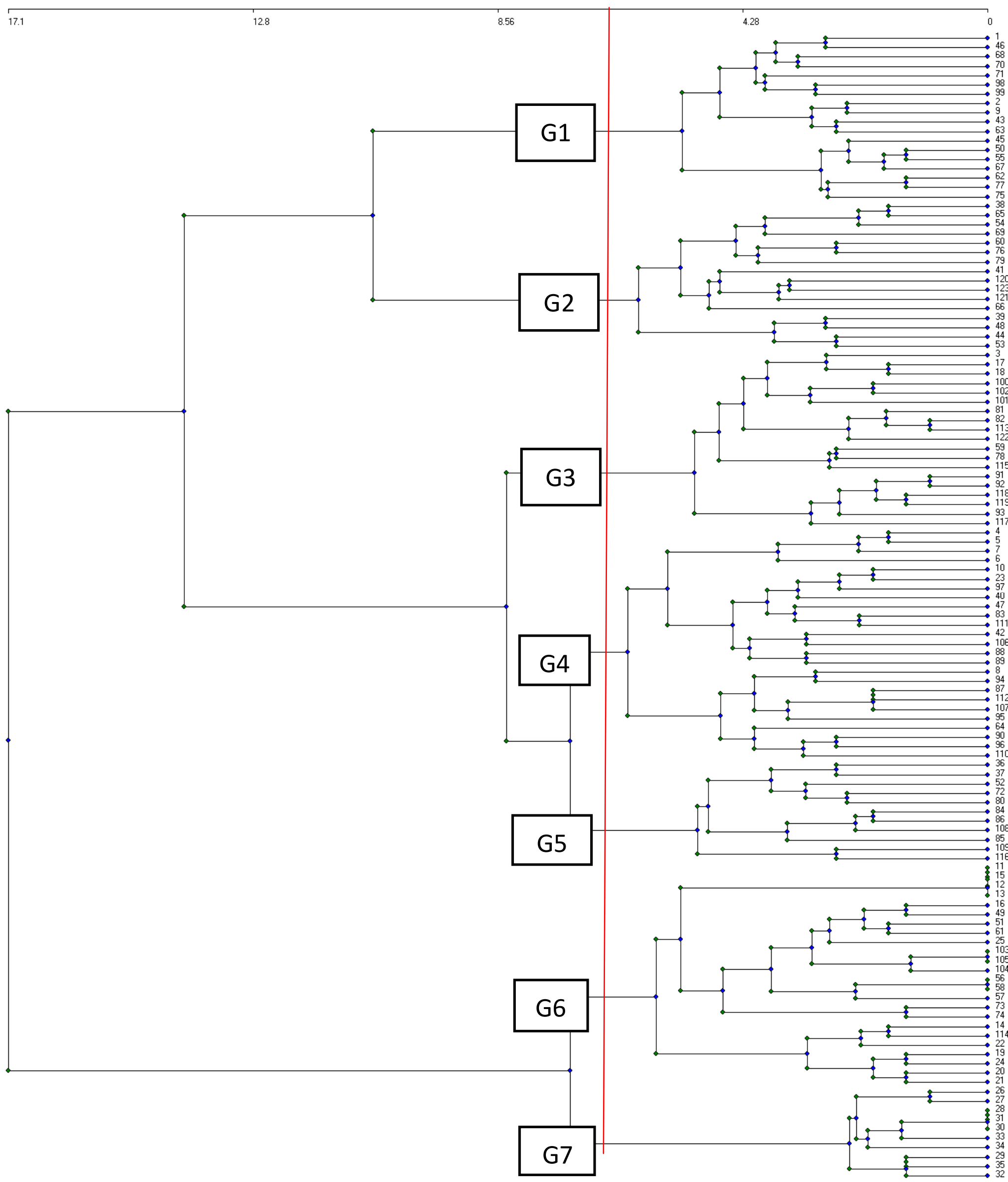

Fig. 7. Dendrogram of the Hierarchical Cluster Analysis (HCA) performed on woody plant species from 123 samples within OKM

Table 4. Most important woody plant species in each group and their estimated regrowth rate

Group	Species	Rde	Rdo	CVI	RF	IVI	Reg/ha
G1	*Anogeisus leiocarpus* (DC.) Guill. & Perr.	31.88	1.83	33.72	12.14	45.86	4156
	Diospyros mespiliformis Hochst. ex A. DC.	12.91	1.66	14.57	10.71	25.28	3100
	Tamarindus indica L.	14.93	1.14	16.07	7.14	23.21	544
	Mitragyna inermis (Willd.) O. Kuntze.	11.98	1.08	13.05	8.57	21.62	200
	Pterocarpus santalinoides DC.	0.31	13.76	14.07	0.71	14.79	0
G2	*Bombax costatum* Pellegr. & Vuill.	0.74	43.58	44.32	2.16	46.48	31
	Anogeisus leiocarpus (DC.) Guill. & Perr.	20.19	2.24	22.43	7.03	29.45	1005
	Crossopteryx febrifuga (G. Don) Benth.	18.15	0.70	18.85	7.03	25.88	431
	Pterocarpus erinaceus Poir.	7.59	2.32	9.92	5.95	15.86	595
	Vitellaria paradoxa C. F. Gaertn.	8.15	1.53	9.68	4.86	14.54	1477
G3	*Acacia gourmaensis* A. Chev.	29.29	4.66	33.95	6.59	40.55	1032
	Pseudocedrela kotschyi (Schweinf.) Harms	11.62	13.67	25.29	5.49	30.78	688
	Combretum glutinosum Perr. ex DC.	8.59	6.11	14.70	14.29	28.99	3039
	Lannea acida A. Rich.	5.56	7.62	13.17	7.69	20.87	84
	Balanites aegyptiaca (L.) Del.	7.07	6.28	13.36	3.30	16.65	196
G4	*Pterocarpus erinaceus* Poir.	7.05	3.22	10.27	9.66	19.93	47
	Prosopis africana (Guill. & Perr.) Taub.	7.81	4.37	12.18	4.35	16.53	63
	Terminalia macroptera Guill. & Perr.	11.05	2.15	13.20	2.90	16.09	973
	Lannea microcarpa Engl. & K. Krause	6.48	2.55	9.03	4.83	13.86	55
	Pseudocedrela kotschyi (Schweinf.) Harms	6.48	2.02	8.49	5.31	13.81	361
G5	*Anogeisus leiocarpus* (DC.) Guill. & Perr.	23.28	4.43	27.71	4.76	32.47	1947
	Lannea barteri (Oliv.) Engl.	5.29	8.73	14.02	9.52	23.54	293
	Parkia biglobosa (Jacq.) R. Br. ex G Don f.	4.76	8.85	13.61	7.14	20.75	0
	Prosopis africana (Guill. & Perr.) Taub.	4.23	6.33	10.57	8.33	18.90	133
	Pterocarpus erinaceus Poir.	8.47	3.82	12.28	5.95	18.24	27
G6	*Adansonia digitata* L.	0.61	48.48	49.10	3.28	52.38	12
	Mitragyna inermis (Willd.) O. Kuntze.	12.68	1.00	13.68	11.48	25.16	909
	Anogeisus leiocarpus (DC.) Guill. & Perr.	13.50	5.33	18.83	4.92	23.75	0
	Acacia polyacantha Willd. ssp. *campylacantha* (Hochst. ex A. Rich.) Brenan	11.04	0.82	11.87	11.48	23.34	12
	Pterocarpus santalinoides DC.	13.91	1.44	15.34	3.28	18.62	0
G7	*Borassus aethiopum* Mart.	82.35	8.54	90.89	47.62	138.51	381
	Adansonia digitata L.	1.18	61.42	62.60	4.76	67.36	0
	Parkia biglobosa (Jacq.) R. Br. ex G Don f.	3.53	8.62	12.15	9.52	21.67	0
	Vitex doniana Sweet	4.71	4.51	9.21	9.52	18.74	19
	Lannea microcarpa Engl. & K. Krause	1.18	11.92	13.09	4.76	17.86	0

Rde=Relative density; Rdo=Relative dominance; CVI=Cover Value Index; RF=Relative Frequency; Reg/ha=Regrowth rate per hectare

According to the indicator species analysis (multilevel pattern analysis using R) 22 species are significantly associated to just one group on a total of 94 species. Thus the discriminated habitats share many species. Among these 22 species, 4 species are associated to G1, 8 species to G2, 1 species to G3, 2 species to G4, 5 species to G5, and 1 species to both G6 and G7. The list of species associated to each group is presented below. The most important species in each of these groups are presented in Table 4 above with their relative values of density (Rde), dominance (Rdo) and frequency (RF) and their regrowth rate.

Multilevel pattern analysis

Association function: IndVal.g
Significance level (alpha): 0.05
Total number of species: 94
Selected number of species: 40
Number of species associated to 1 group: 22
Number of species associated to 2 groups: 9
Number of species associated to 3 groups: 8
Number of species associated to 4 groups: 1
Number of species associated to 5 groups: 0
Number of species associated to 6 groups: 0

List of species associated to each combination:

Group 1 #sps. 4
Diospyros mespiliformis 0.789 0.001 ***
Tamarindus indica 0.721 0.001 ***
Khaya senegalensis 0.394 0.027 *
Feretia apodentera 0.333 0.043 *
Group 2 #sps. 8
Crossopteryx febrifuga 0.748 0.001 ***
Combretum collinum 0.589 0.001 ***
Hymenocardia acida 0.569 0.003 **
Vitellaria paradoxa 0.548 0.002 **
Bridelia ferruginea 0.473 0.007 **
Tectona grandis 0.433 0.013 *
Gardenia aqualla 0.383 0.018 *
Grewia carpinifolia 0.368 0.046 *
Group 3 #sps. 1
Terminalia avicenioides 0.397 0.029 *
Group 4 #sps. 2
*Grewia venusta 0.600 0.001 ****
*Lannea microcarpa 0.548 0.002 ***
Group 5 #sps. 5
*Oncoba spinosa 0.568 0.002 ***
*Acacia sieberiana 0.554 0.002 ***
*Parkia biglobosa 0.540 0.003 ***
*Ficus gnaphalocarpa 0.471 0.004 ***
*Securidacca longepedunculata 0.386 0.030 **

Group 6 #sps. 1
*Acacia amythetophyla 0.408 0.02 **
Group 7 #sps. 1
Borassus aethiopum 1 0.001 ***

*Signif. codes:0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*

While the indicator species analysis shows the specific relationship between species and site groups, the importance value index (IVI) shows well the physiognomy of each group. The abundance of shared species is revealed and indicates that at a certain level the habitats within Oti-Keran-Mandouri are more or less fuzzy. Some species such as *Anogeisus leiocarpus* (DC.) Guill. & Perr. and *Pterocarpus erinaceus* Poir. are well distributed in this area. The former is well distributed with high regrowth rate in gallery forests while the latter is present in gallery forests as well as in dry forests.

4. DISCUSSION

4.1 Floristic Diversity

The number of species (320) found in this study is higher than what has been recorded in the same ecological zone I by [19] who reported 274 plant species for three protected areas including Oti-Keran. However, both studies are complementary since the diversity at genera and family taxonomic levels are quite different. This study recorded 66 families and 209 genera whereas [19] reported 63 families and 247 genera. This variation can be linked to the sampling design. [19] based his study on line transect and plot size of 30 m X 30 m and 50 m X 10 m whereas the present study was based on a stratified random sampling and the standardized plot size defined by BIOTA project for large scale environmental monitoring in tropical vegetation especially for Africa [40]. This same sampling design has been successfully used by [26] in Pendjari reserve of biosphere (Benin) where 183 species were recorded from 61 sample plots. The most important families are similar to those reported by other studies within the Sudanian ecological zone. Poaceae, Fabaceae and Rubiaceae were the most reported by [41] for the vegetation of Atakora mountain at the Eastern part of our study area whereas Fabaceae, Poaceae and Combretacea were the most reported by [19]. The importance of Fabaceae reflects the existence of a transition to the Guinean forest condition, while the importance of Combretaceae family is typical to Soudanian Endemism Center [42]. The high diversity in Poaceae reflects one of the fundamental characteristic of tropical savanna ecosystem characterized by a continuous layer of grasses [43]. The relative abundance of Rubiaceae can be explained by the relative density of hydrography in the study area allowing the establishment of species well adapted to Guinean forest in riparian forest along rivers. The same remark was done by previous studies [13, 44] in the same ecological zone.

The periods of fieldworks were set to take into account grasses. However, due to some species phenology and some fire events, most of the grass could not be identified reducing the total number of species recorded. Nevertheless, the sampling effort, the sampling design and the collaboration among scientists should be improved for a better estimation of species richness within the study area.

The analysis of the life forms spectrum gives an idea on the phytocenosis dynamic [41] and provides information on the response of plants to local environmental conditions [45]. The predominance of phanerophytes reflects the general physiognomy of the vegetation in the study area that is structured by woody plant species. It indicates also the good condition of the soil that enables the establishment of perennial plant species. However, the importance of therophytes reveals a floristic change due to anthropogenic activities. Indeed, the conversion of savannahs into cropland decreases the proportion of perennial while promoting the installation of ruderale species [41]. On the other hand, the presence of therophytes can be linked to the large areas of wetlands within Oti-Keran-Mandouri since [45] explained their abundance in Wadi M'Zab (North-East of Algeria) by the strong presence of water favourable to the development of annual plant species. The relative dryness of the study area is shown by the presence of geophytes and chamaephytes. These species are well adapted to semi-arid ecosystems, drought and fire events [46, 47] whereas the presence of hemi-cryptophytes indicates the presence of open vegetation types [41].

The abundance of Sudano-Zambesian (SZ) and Sudanian endemism centre (S) species is characteristic of savannah ecosystems and indicate the originality of the vegetation since the study area is located in the Sudanian endemism centre according to [31]. However, the presence of species with large scale distribution that are Pan-tropical (12.23%), Paleotroprical (10.07), and Afro-American (1.44%) indicates the anthropogenic action in transforming the ecosystem. This has been also reported by [41]. Within these species, Guinean and Guineo-Congolean are refugee species from Guinean and Congolese forests that are well distributed along rivers in riparian forest as reported by [48].

The two major ecological gradients in species distribution revealed in this study are almost the same described by [41] in the Atakora mountain area where anthropogenic activities, especially agriculture, were reported as the main factors leading to change in the composition and the structure of vegetation. Another study focusing on woody vegetation in three protected areas including the southern part of our study area points out the effect of human selective practices on species composition (traditional agroforestry system) [49]. The relation between community and environmental variables could be used to assess climatic impact on a given habitat using the indirect modelling approach [50].

4.2 Habitat Types

The community types identified are very similar to the different habitat types or woody plant communities described in several studies in the Sudanian zone in terms of their floristic composition and the vegetation type [13,41,49]. However, there is variation in term of the number of groups described. This variation is mainly due to the difference in methodological framework. Some studies were based on unconstrained ordination (indirect gradient analysis, ex. DCA) or constrained ordination (direct gradient analysis, ex. CCA) and some other on cluster analysis (agglomerative and Ward's method or TWINSPAN). All these methods are good for community data analysis but they are not based on the same statistical computation [18,33]. There is a need to standardize the methodological framework in landscape ecological research within this area and then enable the development of habitat mapping and monitoring program at local, regional and national levels such as the Natura 2000 habitats [51] or a comprehensive framework of ecological land units [52].

The values of alpha diversity described in this study are similar to what previous studies in this area have found [13,49]. *Anogeisus leiocarpus* (DC.) Guill. & Perr. and *Pterocarpus erinaceus* Poir. are reported as typical of dry forest in the Sudanian and Sudano-Guinean zones [22,49, 53,54]. Usually, the abundance of *Mitragyna inermis* (Willd.) O. Kuntze; *Pseudocedrela kotschyi* (Schweinf.) Harms; and *Terminalia sp.* indicates that the area is periodically flooded. Their importance in 4 out of 7 site groups confirms the large distribution of wetlands within Oti-Keran-Mandouri. This is consistent with the classification of this area as Ramsar site and as Important Bird Area [4]. All the important species and almost all the indicator species have been reported as species browsed by elephant (*Loxodonta africana*, Blumenbach, 1797) in the hunting zone of Djona (North Benin) [55] and in Nazinga Game Ranch (South Burkina Faso) [56]. *B. aethiopum*, *L. acida*, *M. inermis*, *T. macroptera*, and *V. paradoxa* were reported as browsed by elephant in the Red Volta valley [57]. Moreover, *A. gourmaensis*, *V. paradoxa*, *A. digitata*, *B. aegyptiaca*, and *A. leiocarpus* have been reported in different groups of species occurring in habitat with high elephant concentration in Pendjari reserve of biosphere (North Benin) [26]. Therefore, habitats in Oti-Keran-Mandouri are well suitable for elephant because of food and water availability. This explains the seasonal occurrence of elephant within this area reported by several studies despite increasing anthropogenic pressure [7,8]. The influence of anthropogenic activities in plant species composition is well illustrated in G7. All the species listed in this group are multipurpose trees that are useful to farmers for food, medicine or fiber [58,59]. These species are intentionally left on the field while other species are cut down or burnt to produce charcoal. It creates a cultural landscape well distributed in the Sudanian zone of West Africa and described by several studies in Togo, Benin and Burkina Faso [23,60-64]. Since these species are also browsed by elephant, this sharpens human-elephant-conflict (HEC) around protected areas. Another example of human influence on species composition is the presence of *Tectona grandis L.* among indicator species in Group 2. This species has been introduced as plantation tree but it is currently invading natural habitats of the reserve.

5. CONCLUSION

A total of 320 plant species belonging to 66 families and 209 genera was recorded within Oti-Keran-Mandouri. A total of 7 woody plant communities derived from 94 woody plant species was discriminated. The defined habitat types and their indicators or most important plant species are typical to the vegetation of the Sudanian zone in Africa and very similar to habitats currently used by the remaining population of elephants in West Africa. This explains the seasonal occurrence of these large mammals within OKM. However, habitats seem fuzzy due to anthropogenic activities leading to change in species composition. The management system of this area should be improved to enhance biodiversity conservation. A good management of this area could enable a repopulation of large mammals such as elephant and this would be benefic for the restoration of the ecosystem since this species is known to be a very good seed dispersal. Findings from this study may be used for better conservation planning. They provide also the mean to assess climate change impacts on these habitats by indirect modelling using their species composition.

ACKNOWLEDGEMENTS

This study was funded through the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) by the German Federal Ministry Department of Education and Research (BMBF). We gratefully acknowledge the Laboratory of Botany and Plant Ecology of the University of Lomé (Togo), the Department of Geography and Urban Planning of the University of Wisconsin, Oshkosh (USA) and the Ministry of environmental resources of Togo for their technical assistance and all the local communities for their hospitality. We are also grateful to all the anonymous reviewers who improved the quality of the first draft of this paper.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/10088

Climate Change Management

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Fátima Alves *Editors*

Implementing Climate Change Adaptation in Cities and Communities

Integrating Strategies and Educational Approaches

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Series editor
W. Leal Filho, Hamburg, Germany

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ISSN 1610-2010 ISSN 1610-2002 (electronic)
Climate Change Management
ISBN 978-3-319-28589-4 ISBN 978-3-319-28591-7 (eBook)
DOI 10.1007/978-3-319-28591-7

Library of Congress Control Number: 2016940373

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

Preface

Parallel to mitigation measures, which are essential to slow down the release of CO_2 emissions and hence reduce the speed with which global warming is taking place, there is a pressing need for climate change adaptation measures. Indeed, it is widely acknowledged that if we are to ameliorate the suffering of millions of people who are currently experiencing the impacts of climate change in sectors as varied as agriculture, land use, or infrastructure, adaptation is an important component part of the process.

This book has been prepared based on the need to better understand and explore ways to implement adaptation measures in cities and regions. It contains a set of papers presented at the World Symposium on Climate Change Adaptation, held in Manchester, United Kingdom, on 2–4 September 2015. The event, attended by over 200 experts from 40 countries, explored some theoretical components of climate change adaptation and introduced various practical examples of projects and initiatives, which are documented here.

The focus of this publication is a demonstration of how to pursue and implement adaptation initiatives in cities, communities, and regions.

Part I of the book deals with matters related to adaptation in cities and communities and offers an overview of issues pertaining to adaptation not only on an urban but also on a rural level. It also discusses the different degrees to which communities are exposed to climate variability and to climate change, with examples and case studies from across the world.

Part II focuses on both the integration of adaptation strategies and educational approaches. In this section, the papers discuss matters related to adaptation and livelihoods, describe a set of initiatives at the local and regional level, and introduce the role played by capacity-building as one of the various tools which can support climate change adaptation efforts. To this purpose, various projects and case studies aimed at raising awareness of local inhabitants of villages and farmers are presented.

We thank the authors for their willingness to share their knowledge, know-how, and the information they gathered from their work and from their field projects.

Contents

Part I
Climate Change Adaptation in Cities and Communities

Chapter 1
Changes in Land Cover Categories within Oti-Kéran-Mandouri (OKM) Complex in Togo (West Africa) between 1987 and 2013

Aniko Polo-Akpisso, Kpérkouma Wala, Soulemane Ouattara, Fousseni Foléga, and Yao Tano

Abstract Oti-Kéran-Mandouri (OKM) is a complex of protected areas with national and international ecological importance. It is located in the flood plain of the Oti River in Togo. Unfortunately, this area is under anthropogenic pressure. In order to enhance biodiversity conservation, this study aims to assess the spatial changes in land cover within OKM. Landsat images from different missions spanning the time steps 1987, 2000 and 2013 were used to produce land cover maps involving six classes. The classification was based on the maximum likelihood algorithm and the change analyses were performed using Land Change Modeler software integrated in Idrisi GIS and Image Processing system. From 1987 to 2013, wetlands, forests and savannahs diminished while cropland and settlements expanded. Considering the overall area of OKM, wetlands decreased from 43.05 % in 1987 to 31.71 % in 2013. Meanwhile, croplands increased from 0.91 % in 1987 to 34.81 % in 2013. Considering their earlier areas in 1987, forests, savannahs and wetlands have experienced an average annual loss of 5.74 %, 3.94 % and 2.02 %, respectively, while croplands increased at an average annual rate of 285.39 %. The main drivers of these changes appear to be the inadequacy of the

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W. Leal Filho et al. (eds.), *Implementing Climate Change Adaptation in Cities and Communities*, Climate Change Management, DOI 10.1007/978-3-319-28591-7_1

management system and increasing anthropogenic pressures. These are intensified by climate change since adaptive strategies, such as recessional agriculture, play an important role in land cover change. The ongoing process of rehabilitation should be strengthened to enable this protected area to play its roles as Ramsar site, biosphere reserve and priority corridor for the migration of the West African savannah elephant. Data from this study could be used to guide conservation planning, further landscape pattern assessment and land cover modelling in the framework of climate change.

Keywords Land cover change • Recessional agriculture • Conservation • Oti-Kéran-Mandouri • Togo

Introduction

Conservation planning and landscape design are important challenges for ecologists and conservation biologists. One of the clues to overcome these challenges is to gain better understanding of land cover/land use (LCLU) dynamics as well as habitat use by focal animal species. LCLU at any given time form the basis for assessing the pattern of degradation in any ecosystem (Craighead and Convis 2013). Habitat loss and degradation are threats to biodiversity conservation in developing countries where the need to balance conservation and human development is imminent. Habitat degradation due to anthropogenic activities causes biodiversity erosion in African countries (Konaté and Kampmann 2010; Folega et al. 2012). An illustrative example of habitat degradation is the current conversion of species' historical range into small patches of habitat. This is the case of flagship animal species such as the lion, *Panthera leo leo* Linnaeus, 1758 (Henschel et al. 2014) or the savannah elephant, *Loxodonta africana africana* Blumenbach, 1797 (Bouché et al. 2011). These species are categorised as vulnerable species (Blanc 2008; Bauer et al. 2012). The social and economic changes in rural areas across African continent in last decades (Folega et al. 2014b) as well as climate change (Heubes et al. 2012; Diwédiga et al. 2013) are driving the degradation of their natural habitat.

Oti-Kéran-Mandouri (OKM) is a complex of protected areas located in the plain of the Oti River in Togo. The protected areas comprises Oti-Kéran National Park and Oti-Mandouri Wildlife Reserve. This area is an important eco-geographical region for the migration of the West African elephant which unfortunately is under anthropogenic pressure. Kéran National Park and the wildlife reserve of Oti-Mandouri are listed as Ramsar sites (Convention on Wetlands of International Importance) in 1995 and 2008. They are also listed in the top ten priority protected areas currently under rehabilitation process in Togo (UICN 2008). Recent studies in the area show high inter-annual fluctuations with declining tendency of rainfall within the period from 1961 to 2010 (Badjana et al. 2011). These changes are felt by local rural population who implement different indigenous strategies to cope with them. Diwédiga et al. (2013) reported that recessional agriculture is one of the most important climate change adaptation strategies implemented by farmers in this area. Recessional agriculture is an out season cultivation of crop on river sides and wetlands. Crops benefit from soil moisture and organic matter provided by floods. The reasons why farmers implement this activity, as reported by the same study, are the adaptation to shortage period, the compensation to crop lost due to severe delay in rainfall or to flooding and the possibility for double harvest in the same year. However, large part of the wetlands and main rivers are located within the borders of OKM. Previous investigation by the United States Geological Survey (USGS 2013) on LCLU in Togo reported that agricultural expansion is encroaching into Togo's protected areas. However, there is no accurate and detailed data available on such phenomenon for OKM. There is also no data available on the current status of natural habitats within this complex. Up to date land cover data on this area would be a valuable source of information to enhance the management of the protected areas.

Land cover maps at moderate scales enable researchers to characterize spatial-distribution patterns of land cover in order to understand habitat quality. This can be achieved by integrating remote sensing (RS) and geographic information systems (GIS) tools. RS and GIS have revolutionized the scope and power of conservation planning because of their ability to accommodate, integrate, and analyse physical, biological, cultural, social, economic, and political data (Craighead and Convis 2013). They are useful for long term habitat monitoring by enabling the analysis of satellite data provided by Landsat mission archives. In order to promote biodiversity conservation, this study aims to assess the spatial changes in land cover within OKM using remote sensing and GIS. It will provide baseline and detailed data on land cover that will be important for the biological conservation goal of this protected area. These outputs of the study could enhance the management plan design and could be used for modelling LCLU in the framework of climate change for a long-term management program.

Method

Study Area

Oti-Kéran-Mandouri (Fig. 1.1) straddles three districts: Kpendjal, Oti and Kéran. This area is located in the eco-floristic zone I of Togo (Ern 1979). It is characterized by tropical climate with a rainy season from June to October and a dry season between November and May. The annual average rainfall is between 800 and 1000 mm and the temperature vary from 17 to 39 °C during the dry season and from 22 to 34 °C during the rainy season (UICN 2009). The predominant vegetation is Sudanian savannah, with some dry forest patches and gallery forests along rivers (Dimobe et al. 2014; Folega et al. 2014a). This area is a flat plain characterized by

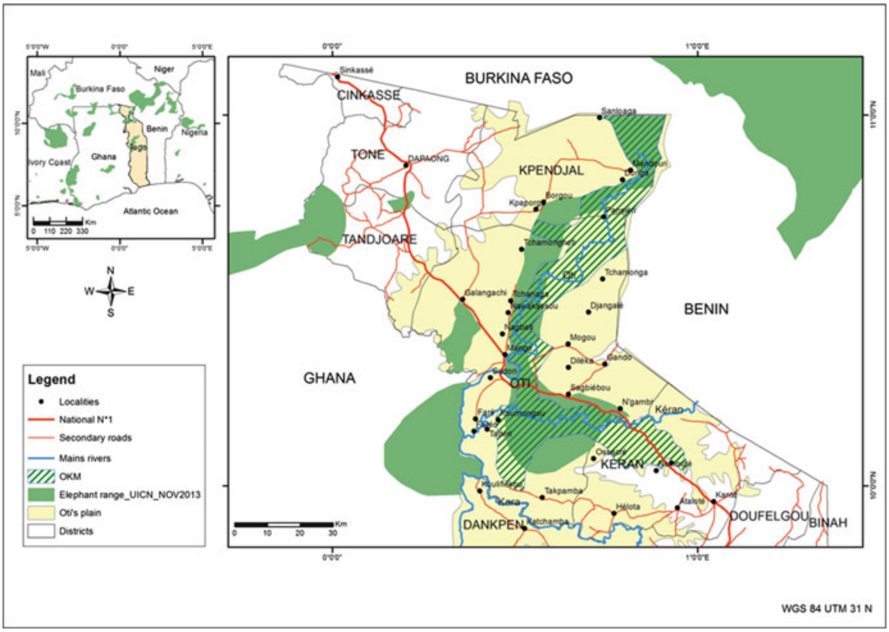

Fig. 1.1 The Oti-Kéran-Mandouri (OKM) study area, with protected areas and district subdivisions discussed in the text

indurate tropical ferruginous soils and swampy tropical ferruginous soils (Dimobe et al. 2014). The large wetlands of the Oti River and its tributaries are important biotopes for migrating birds (Cheke 2001) and large mammals such as the African savannah elephant (Burrill and Douglas-Hamilton 1987; Douglas-Hamilton et al. 1992; Okoumassou et al. 1998). Large portions of this area have been put under protection for biodiversity conservation. Some of these protected areas are Oti-Kéran National Park (9°55′–10°20′ North and 0°25′–1°00′ East) and Oti-Mandouri Wildlife Reserve (10°18′–11° North and 0°30′–0°47′ East). They are part of the most important protected areas in Togo (UICN 2008) and are listed as Ramsar sites (Oti-Kéran in 1997 and Oti-Mandouri in 2007). They have been recently considered as biosphere reserves in 2011. Unfortunately, these protected areas are under continuous anthropogenic pressure that significantly transformed their biotopes into degraded habitats.

Data Acquisition

Landsat images of 30 m spatial resolution were downloaded from the United States Geological Survey via Global Visualization platform (USGS/GloVis). The images were acquired within the time frame of 1987, 2000 and 2013. These time frames

Table 1.1 Landsat image characteristics

Image	Path	Row	Sensor	Date of acquisition	Cloud cover (%)
1	193	053	Landsat 4 Thematic Mapper	1987-10-30	0.00
2	193	052	Landsat 4 Thematic Mapper	1987-10-30	10.00
3	193	053	Landsat 7 Enhanced Thematic Mapper	2000-12-04	0.00
4	193	052	Landsat 7 Enhanced Thematic Mapper	2000-12-30	0.00
5	193	53	Landsat 8 Operational Land Imager	2013-10-29	0.43

were selected because they characterize three important periods in the dynamic of protected areas in Togo as described by Folega et al. (2014b). The first period from colonial to 1990 is marked by strict biodiversity protection; the second period from 1990 to 2000 is marked by anarchic exploitation; and the third period from 2000 characterized by a process of consensual rehabilitation. All the dates of the downloaded images were within the beginning of the dry season to avoid cloud cover and also account for healthy vegetation. The images were already pre-possessed and georeferenced and have not been subjected to further radiometric corrections. Their characteristics are presented below in Table 1.1. Even though the second image (1987) has 10 % of clouds, the study area was not affected.

Image Classification

Landsat 4 scenes (Images 1 and 2) and Landsat 7 scenes (Images 3 and 4) were mosaicked to create a larger image composite. This process was done by matching their radiometric characteristics by equalizing the means and variances of recorded values across the set of images, based on an analysis of comparative values in overlap areas (Eastman 2012). The resulting composites were registered to the Landsat 8 scene with size of 185-km-cross-track-by-180-km-along-track (Lira and Taborda 2014) to enable one scene to cover the entire study area.

The classification scheme was based on the framework recommended by the Intergovernmental Panel on Climate Change (IPCC) for national greenhouse gases emission inventories in Land Use, Land use change and Forestry sector (IPCC 2003). Training sites were defined on the basis of colour infrared composition (Lowry et al. 2005) for six land categories (Table 1.2) distinguished during field campaigns from 11th to 30th November 2013. Based on the defined training sites, a supervised classification using maximum likelihood algorithm was performed on the Landsat the images. Maximum likelihood is one of the most commonly used algorithm in remote sensing image classification (Richards 2013) and therefore the use in this study would facilitate comparison of findings with other studies. The classifications were run with all bands except Band 6 and Band 8 for TM and ETM

Table 1.2 Land categories' definition

N*	Land category	Definition
1	Forest	Vegetation dominated by trees above 7 m of height and with closed canopy. Shrubs or herbaceous may be present
2	Savannah	Vegetation with a continuous grass cover. Trees and shrubs may be present but scattered
3	Wetland	Marshland or areas covered permanently or temporary by water
4	Cropland	All open lands and pastures exploited to grow crops and livestock including traditional agroforestry systems and parklands
5	Settlements	Transportation infrastructure, human settlements of any size, and bare soils
6	Water bodies	Any stretch of water including rivers and water ponds

images. For OLI images, the classification was completed using all bands except Bands 1, 6, 8, 9, 10 and 11. It was performed using Idrisi GIS and Image Processing software.

Accuracy Assessment

The accuracy assessment was done based on Cohen's Kappa (Cohen 1960; Congalton et al. 1983) as well as on user's, producer's and overall accuracies (Liu et al. 2007). The binomial distribution was used to determine the appropriate sample size to obtain unbiased ground reference for a valid statistical testing of the land cover map accuracy. This is recognized as an appropriate mathematical model to use in determining an adequate sample size for accuracy assessment (Hord and Brooner 1976; Hay 1979; Rosenfield and Melley 1980; Fitzpatrick-Lins 1981; Rosenfield 1982). The equation is:

$$N = \frac{z^2 pq}{E^2}$$

where,

N = Number of samples

p = Expected or calculated accuracy (in percentage)

q = 100-p

E = Allowable error

Z = Standard normal deviate for the 95 % two-tail confidence level (1.96).

The allowable error E was set to 5 % for an overall expected accuracy of 80 %. The minimum sample size was then calculated and apportioned to the different land cover categories. A minimum threshold of 20 sample points has been set for each land category (van Genderen and Lock 1977).

Table 1.3 Minimum sample size per land category for image 5

Image 5 from October 2013					
Class	Categories	Area (ha)	%Area	Estimated sample	Final sample size
1	Forests	4038.21	2.24	5.50	20
2	Savannahs	33,255.18	18.41	45.29	46
3	Wetlands	57,267.00	31.71	78.01	80
4	Croplands	62,858.07	34.81	85.62	90
5	Settlements	18,454.86	10.22	25.134	27
6	Water bodies	4721.49	2.61	6.43	7
	Total	180,594.80	100	246	270

Reference data have been generated differently for each image. They were based on ground verification data for the recent image (Table 1.3) while generated from the national topographic map established in 1980, the national vegetation map (Afidégnon et al. 2002) and other available maps for the historical images (2000 and 1987).

Ground verification points were generated in ERDAS IMAGINE by applying a stratified random sampling scheme with a window kernel of 3×3 pixels and on the basis of a majority rule. This results in selection of a sample point only if a clear majority threshold of six pixels out of nine in the window belonged to the same class (Maingi et al. 2002). The generation of sample points in this manner ensured that points were extracted from areas of relatively homogenous land cover class.

Change Analysis

Change analyses were performed using Land Change Modeler fully integrated software in the Idrisi GIS and Image Processing system (Eastman 2012). Maps were compared for change detection as following: 1987 and 2000, 2000 and 2013, and 1987 and 2013. Maps were produced with the combination of Land Change Modeler and ArcGIS 10.2.2.

Results

Classification Accuracy

The overall accuracy of the land cover in 1987 is 79.28 %, 2000 is 73.33 %, and the recent image of 2013 is 79.06 %. There is a good agreement of the classification results and reference data with values of Kappa statistics of 0.69, 0.65 and 0.72 as respective overall classification accuracy. However there were low producer's accuracies for earlier land covers (1987 and 2000): settlements and water bodies

Table 1.4 Classification accuracy

Landcover	1987		2000		2013	
	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)
Forests	100	61.11	82.22	78.72	83.87	89.66
Savannahs	82.47	86.02	81.82	60	68	72.34
Wetlands	81.31	87	83.72	70.59	87.10	69.23
Croplands	50	33.33	62.96	85	84.62	91.67
Settlements	26.32	62.50	14.29	100	75	57.14
Water bodies	100	36.36	16.67	100	35.71	83.33
Overall accuracy	79.28 %		73.33 %		79.06 %	
Kappa	0.69		0.65		0.72	
	PA = Producer's accuracy			UA = User's accuracy		

for ETM 2000 (14.29 and 16.67 %) and settlements for TM 1987 (26.32 %). In contrast, user's accuracy was low for cropland and water bodies for TM 1987 (Table 1.4).

Land Cover Dynamics

Wetland was the most represented land cover type. From 1987 to 2013, wetlands, forests and savannahs decreased in areal cover, while cropland and settlements increased (Fig. 1.2). Figure 1.3 shows the change in percentage of the overall area of OKM in each land cover type in 1987, 2000 and 2013. Wetlands decreased in percentage of the overall area from 43.05 % in 1987 to 36.30 % in 2000 and to 31.71 % in 2013. Savannah decreased from 37.72 % in 1987 to 26.34 % in 2000 and to 18.41 % in 2013. Forests increased from 8.84 % in 1987 9.03 % in 2000 but decreased to 2.24 % in 2013. Meanwhile, croplands increased from 0.91 % in 1987 to 13.75 % in 2000 and to 34.81 % in 2013. Settlements decreased from 7.74 % in 1987 to 13.22 % in 2000 and to 10.22 % in 2013. Water bodies decreased from 1.74 % in 1987 to 1.36 % in 2000 but increased to 2.61 % in 2013.

Change Analysis

From 1987 to 2000, the most important changes in land cover were losses in wetland and gains in cropland. Table 1.5 shows the transition in each land category in percentage of the overall area of OKM. Forests were chiefly converted to savannah (3.28 %) and wetlands (2.68 %), and only a minor component was converted to cropland (0.30 %) and settlements (0.18 %). Savannahs were mostly converted to wetlands (14.50 %) and croplands (4.29 %) whereas wetlands were mostly converted to settlements (8.53 %) and savannahs (8.50 %). Some portions of

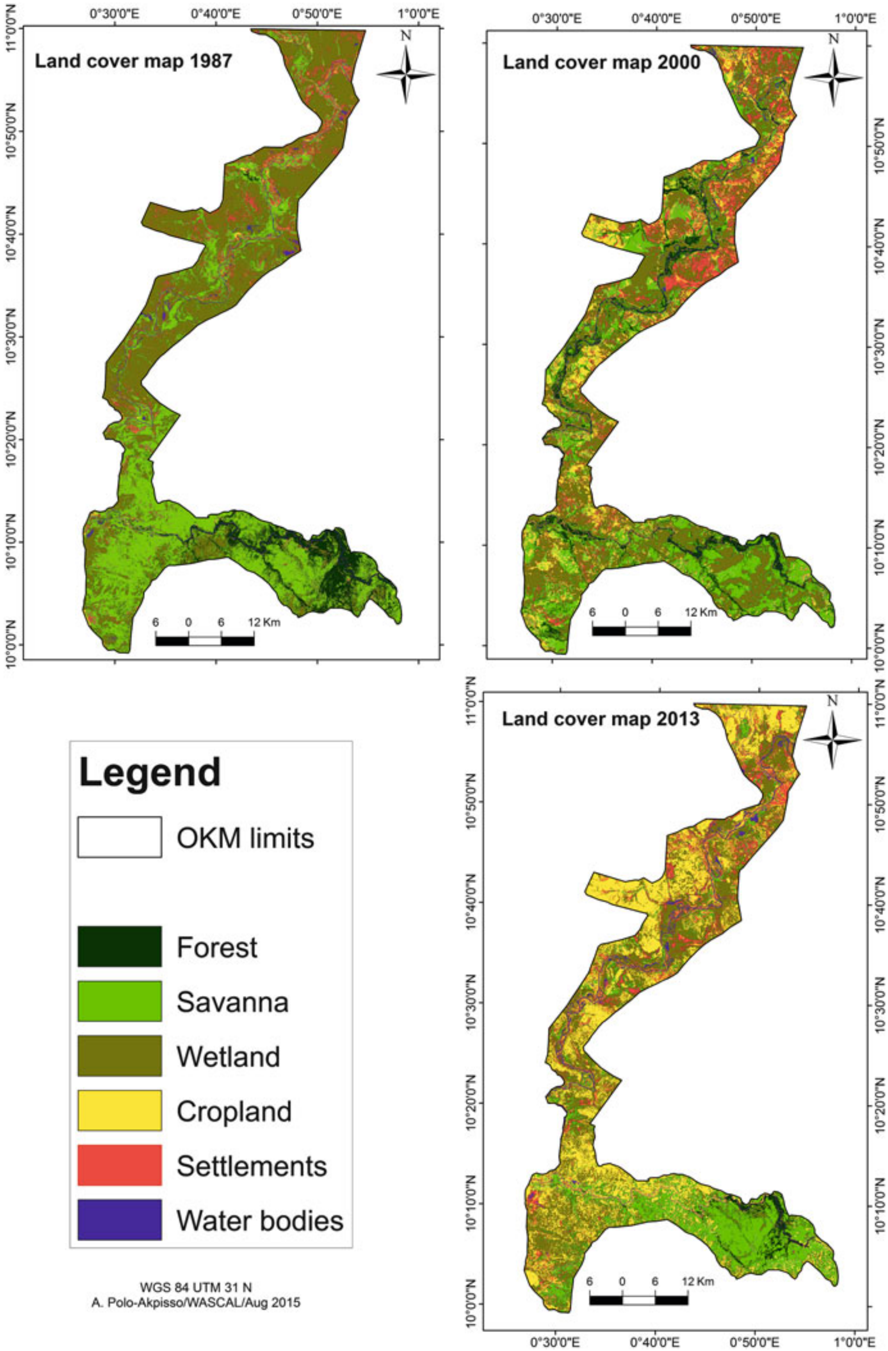

Fig. 1.2 Land cover maps of OKM for 1987, 2000 and 2013

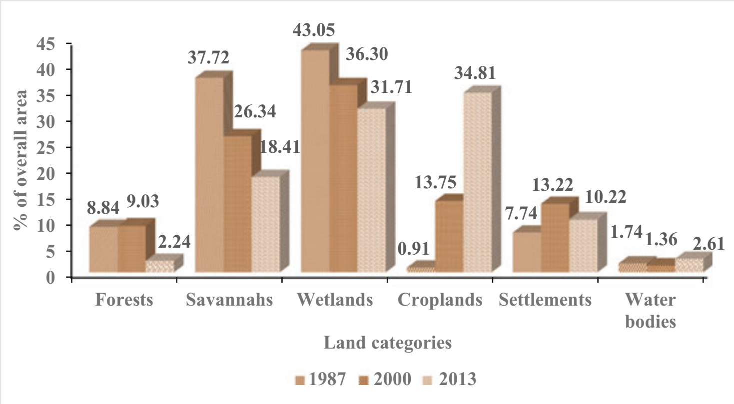

Fig. 1.3 Changes in land categories within OKM complex in Togo from 1987 to 2013

Table 1.5 Transition matrix in percent (%) of overall area from 1987 to 2000 within OKM

		2000					
From	To	Forests	Savannahs	Wetlands	Croplands	Settlements	Water bodies
1987	Forests	2.31	3.28	2.68	0.30	0.18	0.10
	Savannahs	3.29	12.39	14.50	4.29	2.85	0.40
	Wetlands	2.09	8.50	15.92	7.69	8.53	0.32
	Croplands	0.17	0.15	0.30	0.13	0.12	0.04
	Settlements	0.64	1.77	2.62	1.19	1.37	0.16
	Water bodies	0.53	0.27	0.28	0.14	0.18	0.34

croplands were also converted to wetlands (0.30 %) and forests (0.17 %). Settlements were mostly converted to wetlands (2.62 %) and savannahs (1.77 %). Much less change was observed for water bodies, and this largely comprised conversion to forests (0.53 %) and wetlands (0.28 %).

From 2000 to 2013, croplands and wetlands remained land categories that changed most and wetlands remained the land category where changes have been more important. The transition in each land category in percentage of overall area of OKM is shown in Table 1.6. Forests were mostly converted in wetlands (2.02 %) and in croplands (1.95 %). Savannahs were mostly converted in wetlands (7.47 %) and in croplands (7.40 %) while 11.74 % and 6.92 % of wetlands were converted in croplands and in savannahs respectively. Part of croplands were also converted in others land categories: 3.70 % were converted in wetlands, 1.51 % in settlements

Table 1.6 Transition matrix in percent (%) of overall area from 2000 to 2013 within OKM

		2013					
From	To	Forests	Savannahs	Wetlands	Croplands	Settlements	Water bodies
2000	Forests	1.05	1.79	2.02	1.95	1.30	0.92
	Savannahs	0.67	8.13	7.47	7.40	2.21	0.45
	Wetlands	0.46	6.92	13.78	11.74	3.04	0.37
	Croplands	0.02	0.81	3.70	7.57	1.51	0.15
	Settlements	0.02	0.69	4.50	5.91	1.96	0.14
	Water bodies	0.02	0.07	0.23	0.24	0.20	0.60

and 0.81 % in savannahs. Water bodies were mostly converted in croplands (0.24 %) and in wetlands (0.23 %).

The overall change between 1987 and 2013 showed high variation in wetlands and croplands. Figure 1.4 shows land cover changes from 1987 to 2013 and Table 1.7 reports the transition in each land category. Wetlands were predominantly converted to croplands (16.84 %) and to settlements (6.19 %). There was also transition of savannahs to wetlands (11.33 %) and croplands (12.80 %). Forests were converted to savannahs (4.02 %) and croplands (1.71 %), and less so to wetlands (0.83 %) and water bodies (0.05 %). Croplands were also converted to wetlands (0.28 %), settlements (0.14 %), water bodies (0.08 %), savannahs (0.06 %) and forests (0.01 %). Settlements were mostly converted to croplands (2.85 %) and wetlands (2.81 %). Water bodies were converted to settlements (0.28 %) and croplands (0.27 %) to a greater extent than they were converted to wetlands (0.18 %), savannah (0.06 %) and forests (0.01 %).

The net change in each land category i.e., the result of taking the earlier land cover areas, adding the gains and then subtracting the losses (Eastman 2012) is reported in Table 1.8. Croplands and settlements increased at an average of 108.13 % and 5.45 % respectively, of the proportion of their own area from 1987 to 2000. From 2000 to 2013, croplands gained from all other land categories and continue then to increase but at a rate of 11.77 % per year of their own area. Forests and savannahs decreased at an annual average rate by 5.79 % and 2.32 %, respectively of their own area. Globally from 1987 to 2013, forests, savannahs and wetlands have decreased at an average annual percentage of their own area by 5.74 %, 3.94 % and 2.02 %, respectively, while croplands increased at an average annual rate of 285.39 %.

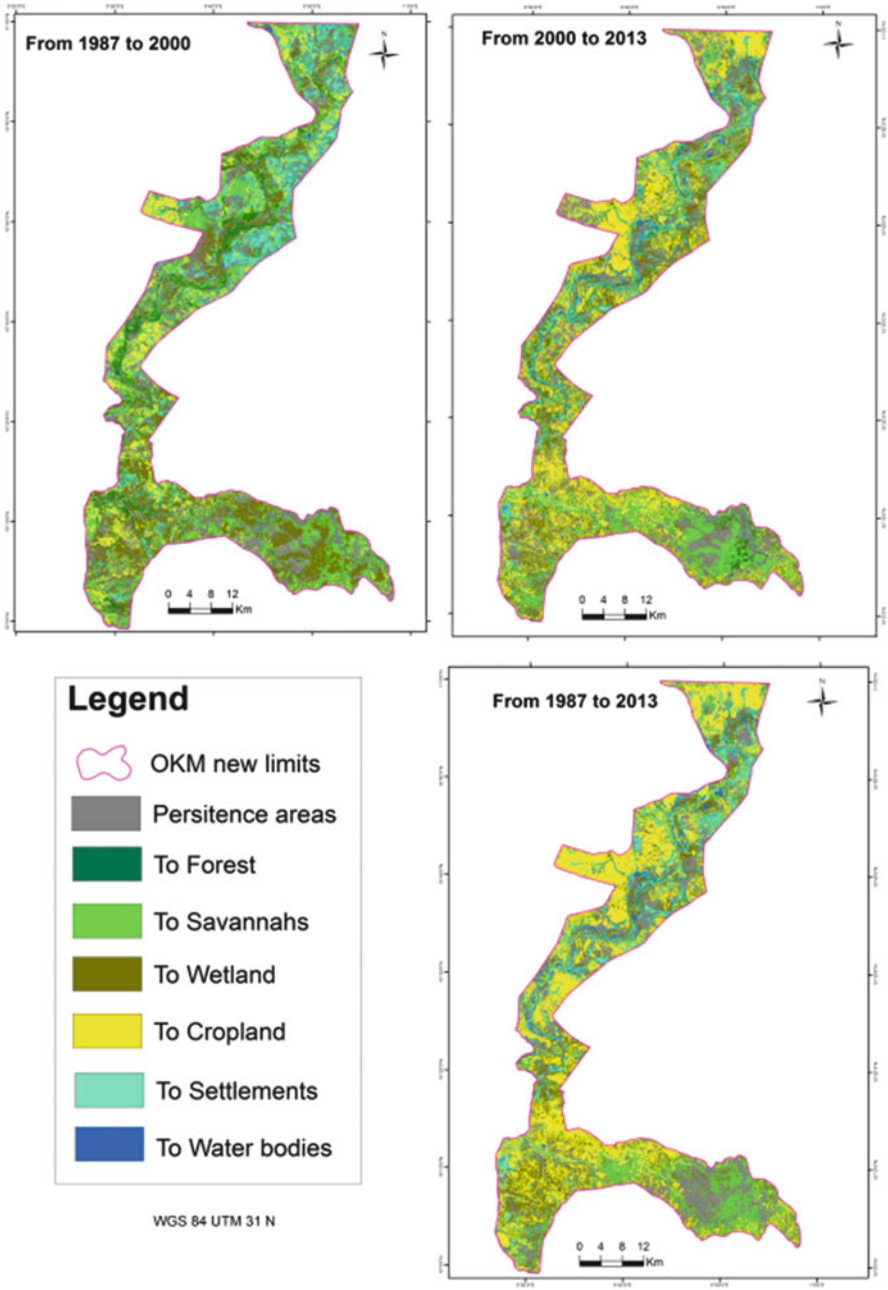

Fig. 1.4 Land cover change maps within OKM from 1987 to 2013

Table 1.7 Transition matrix in percent (%) of overall area from 1987 to 2013 within OKM

		2013					
From	To	Forests	Savannahs	Wetlands	Croplands	Settlements	Water bodies
1987	Forests	2.00	4.02	0.83	1.71	0.24	0.05
	Savannahs	0.16	10.67	11.33	12.80	2.23	0.54
	Wetlands	0.04	3.03	16.29	16.84	6.19	0.66
	Croplands	0.01	0.06	0.28	0.34	0.14	0.08
	Settlements	0.02	0.57	2.81	2.85	1.15	0.35
	Water bodies	0.01	0.06	0.18	0.27	0.28	0.93

Discussion

Image Classification and Accuracy Assessment

The overall accuracy assessment values for all the classified images reflect the confusion between some land categories, especially settlements and croplands. This confusion might explain the poor producer's accuracy for both classes. The similar confusions were previously reported by Folega et al. (2014b). The study area is characterized by a cultural landscape marked by traditional agroforestry system wherein farmlands and crops are associated with parklands of multipurpose trees (Wala et al. 2005; Folega et al. 2011; Kebenzikato et al. 2014; Padakale et al. 2015). This cultural landscape is the source of the misclassification of settlements and croplands and even the source of confusion with savannahs (Badjana et al. 2014b). Misclassification in water bodies is due to the low resolution of Landsat imagery limiting the distinction between water bodies with surrounding vegetation.

Land Use and Land Cover Change Analysis

Wetlands are the most important land category found within OKM. This is well in line with the classification of OKM as a Ramsar site (Cheke 2001; Adjonou 2012). It is also the land category that is the most converted, particularly to croplands. There is high pressure on wetlands because they are systematically converted into large paddy fields. Agriculture is then the main driver of change in Landcover and Landuse dynamics (LCLU). It is a shifting cultivation such as elsewhere in Togo and in West Africa. This result is in line with previous studies in tropical regions and particularly in West Africa (Lambin et al. 2003; Houessou et al. 2013; Wood et al. 2004). Other studies, concluded that agriculture, population growth and indirect effects of climate change remain the main factors of land change and the

Table 1.8 Net change in each land category within OKM

	1987–2000			2000–2013			1987–2013		
	Total net change (ha)	Average net change per year (ha)	Annual net change in % of earlier area	Total net change (ha)	Average net change per year (ha)	Annual net change in % of earlier area	Total net change (ha)	Average net change per year (ha)	Annual net change in % of earlier area
Forests	336	25.85	0.16	−12,269	−943.77	−5.79	−11,923	−917.15	−5.74
Savannahs	−20,548	−1580.62	−2.32	−14,321	−1101.62	−2.32	−34,869	−2682.23	−3.94
Wetlands	−12,186	−937.38	−1.21	−8285	−637.31	−0.97	−20,472	−1574.77	−2.03
Croplands	23,190	1783.85	108.13	38,019	2924.54	11.77	61,209	4708.38	285.39
Settlements	9894	761.08	5.45	−5415	−416.54	−1.75	4479	344.54	2.47
Water bodies	−685	−52.69	−1.68	2272	174.77	7.14	1586	122.00	3.89

main threat to biodiversity conservation (Landmann et al. 2010; Heubes et al. 2012). Changes in populations' livelihood through the implementation of indigenous adaptation strategies (Badjana et al. 2011; Diwédiga et al. 2013; Ojoyi and Mwenge Kahinda 2015) could be considered as the indirect effects of climate change. The implementation of recessional agriculture as an adaptive strategy in the study area shows that climate change and LCLU change are tightly linked.

Increase in settlements could be related to the annual rate of population growth in the study area. Actually, OKM is within a region where the population growth rate is the highest in Togo (3.18 %) (RGPH 2011). Moreover, Kpendjal, Oti and Keran districts are the poorest in Togo (DSRP-C 2009). Therefore, there is high pressure on natural resources by the local population. The intrinsic relationship between natural resource degradation and poverty has been shown by many studies (Konaté and Linsenmair 2010; Dimobe et al. 2014). There is a particular problem of natural resource management that increases the pressure on protected areas in Togo after 1990. As described by Folega et al. (2014b), the period from 1990 to 2000 was marked by illegal and anarchic exploitation of protected resources by bordering human populations. This situation resulted from the political, economic and social troubles of 1990 mainly due to uncontrolled democratic opening process and the semi-military and repressive management system implemented from colonial period to 1990. These illegal and anarchic anthropogenic activities led to high land conversion. This could explain the increase of croplands from 1987 to 2000. This increment is higher than the reported agricultural expansion on the national scale for a period of 25 years from 1975 to 2000 by USGS (2013). While croplands increased from 0.91 % in 1987 to 34.81 % in 2013 of the total area of OKM, they have been reported to increase from 12.1 % of the country's land area in 1975 to 21.8 % in 2000.

As shown by transition maps, there is a core area of remaining natural ecosystems within OKM in Keran district. This area has been already mentioned by UICN (2008) as the most conserved area. Periodic visits to this area by savannah elephant coming from bordering countries have been mentioned in several studies (Okoumassou et al. 2004; UICN 2008). This area requires a particular conservation attention. Its remaining natural habitats are still under threats from some anthropogenic activities such as wood cutting (Adjonou et al. 2009) and charcoal production (Kokou et al. 2009). In the centre of Benin, Arouna et al. (2011) found also that charcoal production represented the main activity leading to land cover change. Moreover, there are also threats from transhumance on which no accurate data are currently available. There are in the order of a 1000 heads of cattle pasturing through this area each year damaging crops and invading protected areas. Usually, foraging plants are cut down for cattle and the savannah is burnt without any respect to the fire calendar established for this area.

Considering the net change for each land category (Table 1.8), forests increased by 2.08 % from 1987 to 2000 and decreased by 75.27 % from 2000 to 2013. The increase of forests from 1987 to 2000 could be explained by natural regeneration since forests are located along rivers and in the well protected core area of the former Oti-Keran national park (southern part of our study area). These areas were less pressured when social claims started from 1990. However, the decrease of forests from 2000 to 2013 is the result of the combined effects of increasing anthropogenic activities (wood cutting and charcoal production) and climate change. Recent studies demonstrated that climate change effects in Northern Togo are expressed by inter-annual fluctuations with declining tendency of rainfall and increasing tendency of temperature on the period from 1961 to 2010 (Badjana et al. 2011, 2014a). The deficit in rainfall could weaken plant resilience to fire events. Furthermore, one of the most adaptive strategies to climate change implemented in this are by local population is recessional agriculture. This activity consists of crop cultivation during the dry season on river banks and in wetlands where crop could benefit from flooding and soil moisture. This practice involves the destruction of gallery forest (Diwédiga et al. 2013; Badjana et al. 2014b). Recessional agriculture is categorized as a wetland agriculture and considered as one of the largest overall agriculture adaptations (Menotti and O'Sullivan 2013). It is described as being highly productive in many tropical regions (Whitmore and Turner 2001). The decrease of forests from 2000 to 2013 reflected the ineffectiveness of the management system of this complex of protected areas and the weakness of the current consensual rehabilitation process.

Conclusion

This study provides detailed analysis on the dynamics of Land cover of OKM. There has been important changes in land cover within the protected area from 1987 to 2013. Forests, savannahs and wetlands were converted into human transformed landscapes. Wetlands were the most converted land category. Croplands and settlements have increased with a high magnitude especially from 1987 to 2000. Drivers of all these changes appear to be the ineffectiveness of management system and increasing anthropogenic pressure which is emphasized by climate change effects since adaptive strategy such as recessional agriculture leads to gallery forest degradation and wetland conversion in croplands. These changes threaten biodiversity conservation role of the protected area and even its status not only as Ramsar site but also as priority corridor for the migration of the West African savannah elephant. Results from this study could be used to guide conservation planning in the current process of protected areas requalification for which OKM has been listed as one of the ten top priority protected areas to be requalified. Further investigations will focus on landscape patterns to assess the connectivity of remaining natural land patches since isolation would disrupt the connectivity of the protected areas network for large mammal migration.

Acknowledgement This study was funded by the German Federal Ministry of Education and Research (BMBF) through the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) initiative. We acknowledge all the anonymous reviewers who added a great value to the first version of this manuscript.

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CENTRE D'EXCELLENCE AFRICAIN SUR LE CHANGEMENT CLIMATIQUE, LA BIODIVERSITE ET L'AGRICULTURE DURABLE

Abidjan le 22 Décembre 2016

PERMIS D'IMPRIMER DE LA VERSION CORRIGEE DE LA THESE

Doctorat de l'Université Félix HOUPHOUËT-BOIGNY

Présentée par Aniko POLO-AKPISSO

Theme : Ecological chraracteristics of Elephant (*Loxodonta africana* Blumenbach, 1797) Habitat within Protected Areas Network Oti-Keran-Mandouri in Togo.

Vu et approuvé
Abidjan le 22/12/2016
Le Directeur de WASCAL

Professeur. KONE Daouda
Directeur GRP WASCAL
Coordonnateur CEA-CCBAD

Vu et permis d'imprimer
Abidjan le 22/12/2016

Le Vice-Président de l'Université
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Professeur AFFIAN Kouadio

Abstract

The complex of protected areas Oti-Keran-Mandouri (OKM) is a key biodiversity area in Togo. It is listed as Ramsar site, as International Bird Area and considered as conservation corridor for the African savanna elephant. However, its habitats are under increasing anthropogenic pressure. Therefore, social survey, remote sensing, geographic information system and vegetation sampling were combined to assess the occurrence frequency of elephant from 2010 to 2013, the potential elephant habitat, the dynamics of different land cover within this habitat from 1987 to 2013 and its vulnerability to anthropogenic pressure and climate change. Presence of elephants (one to three or four and even eleven) was reported to occur in villages surrounding OKM with some located more than 10 km away from the borders of OKM. However, the potential elephant habitat is about 30 % the current area of OKM and it is 81.81% fragmented. From 1987 to 2013, natural habitats regressed to the profit of croplands with wetlands being the main contributor. Three main habitat change processes leading to landscape anthropization were identified. These are attrition in forests and savannas, dissection in wetlands and creation in croplands. Two ecological gradients influencing the distribution of plant species and seven plant communities were identified. The analysis of the socio-ecological system revealed that some adaptive strategies to climate change like recessional agriculture are detrimental to biodiversity conservation. Moreover, resident communities expressed no interest in the conservation of this area and suggested its release for them to increase their agricultural land. Population growth, former and current management inadequacy and climate change appeared to be the main drivers of habitat fragmentation and biodiversity loss in this region. The restoration of this complex of protected areas will be only successful if resident communities are put at the heart of the conservation system.

Key words: Biodiversity, Conservation, Habitat suitability, Landscape process, Socio-ecological system.

Résumé

Le complexe d'aires protégées Oti-Kéran-Mandouri (OKM) est un refuge de biodiversité au Togo. Il est classé comme site Ramsar. C'est une aire d'importance internationale pour les oiseaux et considérée comme un corridor de conservation pour l'éléphant de savane en Afrique de l'Ouest. Cependant, ses habitats sont sous l'emprise croissante de la pression anthropique. Aussi, l'évaluation de la présence des éléphants sur cette aire et ses environs de 2010 à 2013, l'habitat potentiel des éléphants, sa dynamique de 1987 à 2013 et sa vulnérabilité au changement climatique et aux pressions antropiques a-t-elle été faite en assossiant les enquêtes sociales, la télédétection, le système d'information géographique et les relevés de végétation. La presence d'éléphants (un à 11) a été rapportée dans les villages environnant OKM avec certains localisés à plus de 10 km des limites de OKM. Toutefois, l'habitat potentiel de l'éléphant est à 81,81% fragmenté et occupe environ 30% de l'aire actuelle de OKM. De 1987 à 2013, les habitats naturels ont regressé au profit de terres cultivées avec les terres humides etant le principal contributeur. Environ 17% des terres humides ont été converties en terres cultivées alors qu'environ 13% et 2% des savanes et des forêts respectivement ont été converties. Trois principaux processus de changement des habitats entrainant l'anthropisation ont été identifiés. Il s'agit de l'attrition au niveau des forêts et dans les savanes, la dissection au niveau des terres humides et la création au niveau des terres cultivées. Deux gradients écologiques influençant la distribution des plantes et sept communautés de plantes ont été identifiées. L'analyse du système socio-écologique a montré que certaines stratégies d'adaptation au changement climatique comme l'agriculture de contre saison, ne sont pas favorables à la conservation de la biodiversité. En plus, les communautés riveraines disent n'avoir aucun intérêt dans la conservation de cette aire et suggèrent sa liberation pour leur permettre d'augmenter la superficie de leur champ. La croissance démographique, l'inadéquate gestion et le changement climatique paraissent être les facteurs principaux de la fragementation des habitats et de la perte de la biodiversité dans cette région. La restoration effective de ce complexe ne pourra être faite qu'en plaçant les populations riveraines au centre du système de conservation.

Mots clés: Biodiversité, Conservation, Habitat potentiel, Processus paysager, système socio-économique.