Interactions between people and forest elephants (*Loxodonta cyclotis*): the case of Campo-Ma’an National Park, southern Cameroon.

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ABSTRACT

Interactions between people and forest elephants (*Loxodonta cyclotis*): the case of Campo-Ma’an National Park, southern Cameroon

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Concordia University, 2022

The aim of this research is to study human-elephant interactions for an integrated management of the landscape that maintains biodiversity while providing better coexisting conditions to human and forest elephants (*Loxodonta cyclotis*) in the Campo-Ma’an Technical Operational Unit. By combining social surveys and field investigations in three subdivisions, I first assessed the extent of wildlife damage to crops and identified the impact of human activities on wildlife. I found that almost all farmers suffered crop damages with considerable crops and economic losses attributed to forest elephants. Forest elephants therefore play a key role in people’s livelihood in the Campo-Ma’an landscape. Then, using camera traps and field investigations, I studied how forest elephants utilize the various land use types (National Park and Forest Management Unit both with various restrictions to human activities, and Community Land where some human activities are allowed) of this human dominated landscape. I found that elephants are attracted to areas with high species richness and increased fruits availability, both patchily distributed over the various land use types. However, forest elephants occurred mostly in community land dominated by human activities. Therefore, given the ongoing increase in human population in this landscape, the threats to forest elephant are expected to increase if no serious actions are taken by wildlife managers and administration. Furthermore, given their elusive nature, I investigated whether we could rely on local ecological knowledge, as compared to field investigation, to assess the diet composition and feeding habits of forest elephants. I showed that local ecological knowledge can be used to assess forest elephants’ most common and important food items. Indeed, the dietary profiles resulting from these approaches were concordant for most plant species. Finally, with the hope that beehive fences can be used to repel elephants from getting into farmlands, I studied the behaviour of local bees (*Apis mellifera adansonii*) in response to physical disturbance. I found a temporal variability in the aggressiveness of bee colonies, with their effect being minimal at night, suggesting beehive fences can only be used in combination with other mitigation measures in this area. Overall, further investigations are needed to suggest reliable measures for peaceful coexistence between forest elephants and humans in this landscape.

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CONTRIBUTION OF AUTHORS

I was the main investigator for all the research work and as first author, responsible for the conception, data analyses, the writing of chapters related to this thesis and the writing of this thesis. The chapters 2, 4 and 5 were co-authored by Dr. Robert Weladji, Mr. Patrick Paré whereas Dr. Robert Weladji, Dr. Alys Granados, Mr. Patrick Paré and Dr. Guillaume Body co-authored the chapter 3. Dr. Robert Weladji advised on the interpretation of the results, reviewed, and corrected all the chapters. Mr. Patrick Paré reviewed and corrected the manuscripts. Dr. Alys Granados, Dr. Guillaume Body both reviewed, contributed to data analysis, interpretations, and corrected chapter 3.

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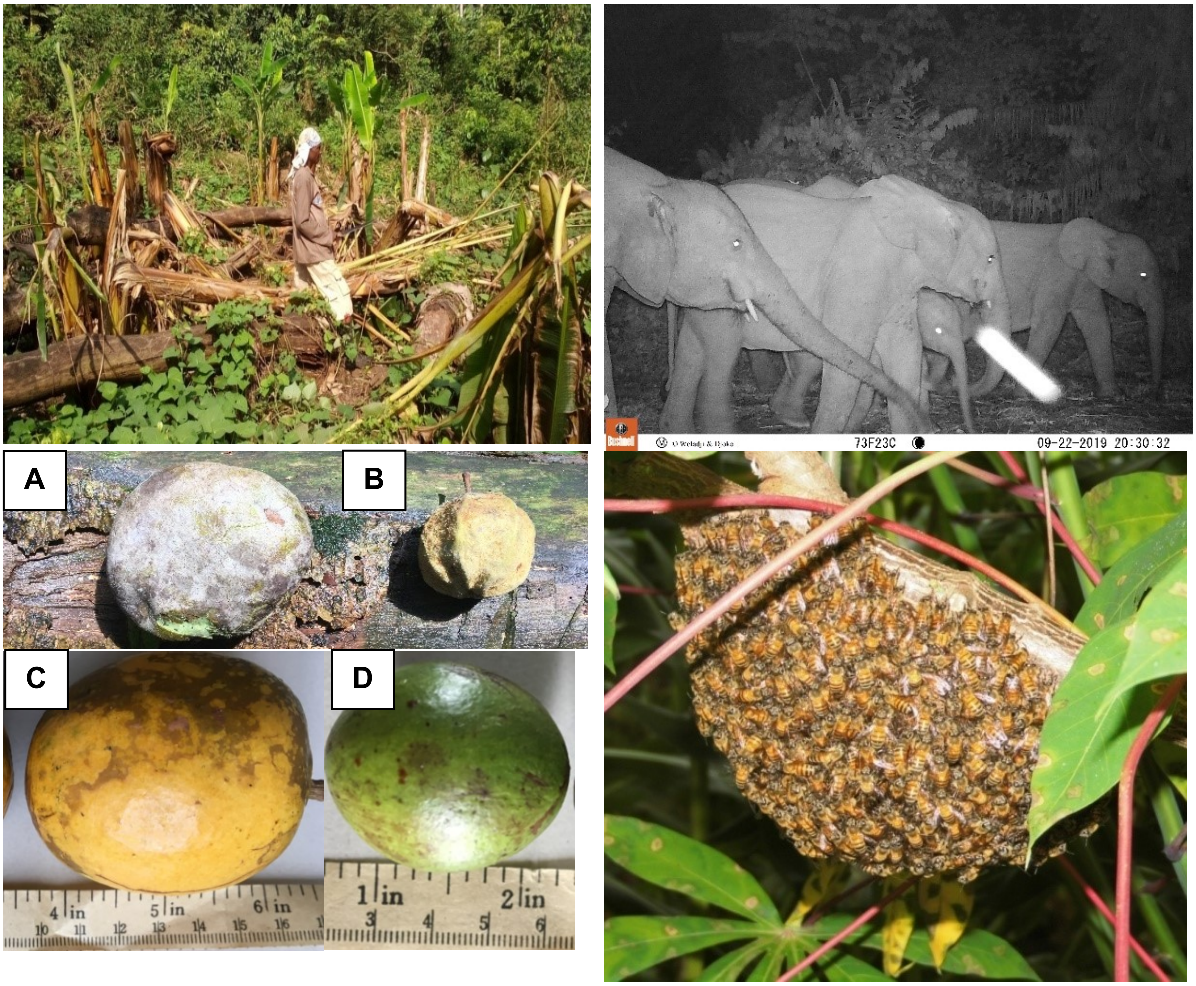
ANOVA:	Analysis of variance
CL:	Community land
CMNP:	Campo-Ma’an national park
CMTOU:	Campo-Ma’an technical operational unit
CT:	Camera trap
FMU:	Forest management unit
GAMM:	Generalized additive mixed model
GLM:	Generalized linear models
GPS:	Global positioning system
HWC:	Human-wildlife conflict
IUCN:	International union for conservation of nature
MINFOF:	Ministère des forêts et de la faune
NP:	National park
PA:	Protected area
PNCM:	Parc national de Campo-Ma’an
QCBS:	Quebec centre for biodiversity science
QGIS :	Quantum Geographic Information System
WWF:	World wildlife fund



Sample capture images of forest elephants entering community land at night (top left), farmer visiting his banana plantation after night damages by a herd of forest elephants (top right). Four sample fruits (bottom left), (A) *Tieghemella africana* (Adjap zok), (B) *Duboscia macrocarpa* (Akak), (C) *Irvingia gabonensis* (Ndo'o) and (D) *Saccoglottis gabonensis* (Bidou) and a colony of African honeybee (bottom right) in the Campo-Ma'an Technical operational Unit, Cameroon © Weladji & Djoko.

Chapter 1 General introduction

1.1 Overview of human wildlife interaction

Conservation through protected areas is an effective management technique that has a broad array of positive and negative social, economic, cultural, and political impacts on local communities (Bennett et al. 2017; Bennett and Dearden 2014; Mariki, Svarstad, and Benjaminsen 2015). In most African countries, protected areas were created by the colonial administrations, without the consent of local people, who lost ownership, as well as access or decision rights on natural resources including wildlife (IUCN 2003; Tchamie 1993). Therefore, the frustrations arising therefrom, in addition to crop damages with subsequent economic losses (Nelson, Bidwell, and Sillero-zubiri 2003; Inogwabini et al. 2013; Mir et al. 2015; Mwakatobe et al. 2014) as well as socio-political and cultural impacts are important sources of conflicts (Bennett and Dearden 2014; Breuer and Ngama 2020; Barua, Bhagwat, and Jadhav 2013). Moreover, human wildlife interactions have hidden aspects that are more complex than they may appear (Barua, Bhagwat, and Jadhav 2013; Dickman 2010; Breuer and Ngama 2020). Psychological impacts such as fear of being killed, increase workload for farmers and fear of loss of food store and starvation often persist after the physical interaction (Breuer and Ngama 2020; Barua, Bhagwat, and Jadhav 2013).

Moreover, land use system with restrictions and habitat use by elephants (*Loxodonta* spp.) evoke feelings of retaliation (Evans and Adams 2018; Mmbaga, Munishi, and Treydte 2017; Mariki, Svarstad, and Benjaminsen 2015). Human wildlife interactions have led to increased poaching, rejection of wildlife policies and social conflicts between locals and conservationists (Shaffer et al. 2019; Tchamba 1996a). Also, interaction between wildlife and human may be a political issue and needs to be resolved politically (Hoare 2015; Evans and Adams 2018). In fact, the land use system results from political decisions some of which lead to wildlife habitat fragmentation (Hoare 2015; Puyravaud et al. 2019; Mmbaga, Munishi, and Treydte 2017).

1.2 Human-elephant interactions

Human population growth and subsequent socioeconomic development facilitate access and use of marginal habitats closer to protected areas, encroaching on elephant habitat (Maisels et al. 2013; Thouless et al. 2016b; Blake et al. 2008). Therefore, elephant human interaction have been increasing in rural areas around protected areas (Weladji and Tchamba 2003; Naughton-Treves 1997). Human-elephant interactions threaten people's livelihood through crop damage (Granados and Weladji 2012; Nelson, Bidwell, and Sillero-zubiri 2003; Hoare 1999). Indeed, crop damage cause huge economic losses to farmers (Mwakatobe et al. 2014; Naughton-Treves 1998; Hoare 1999). Elephants can feed on crops, trample on them and in some cases cause the death of farmers as they live in closer proximity and share spaces and resources (Shaffer et al. 2019; Tchamba 1996b; Karanth and Kudalkar 2017). Different other categories of cost associated with human-elephant interaction could be hidden or visible (Barua, Bhagwat, and Jadhav 2013; Dickman 2010). These include the fear of being killed, destruction of food stores and water sources (see Breuer and Ngama, 2020).

Elephants face habitat fragmentation of their natural habitat through human expansion (Wall et al. 2021). In some cases, interactions are amplified by the socioeconomical activity development (Mir et al. 2015; Breuer and Ngama 2020), lack of appropriate mitigation strategies (Shaffer et al. 2019; Nelson, Bidwell, and Sillero-zubiri 2003; Hoare 1999) or the dynamic of land use change (Bennett et al. 2017; Mmbaga, Munishi, and Treydte 2017). Elephants are often killed in response to damages they cause to crops (Inogwabini et al. 2013; King et al. 2009; Mariki, Svarstad, and Benjaminsen 2015; Ngama et al. 2016). They are also poached for the high economic potential of the ivory (Maisels et al. 2013; Blake et al. 2007; Shaffer et al. 2019; Breuer, Maisels, and Fishlock 2016).

Elephants movement over spatiotemporal scale is shaped mostly by the qualitative and quantitative availability of food and water (Mills et al. 2018; Tchamba 1996b), particularly fruits and minerals (Blake 2002). Their movement has been shown to vary between day and night or between seasons (Shaffer et al. 2019; Tchamba 1996b; Blake 2002; Blake and Inkamba-

Nkulu 2004; Mills et al. 2018; Beirne et al. 2020; Branco, Merkle, Pringle, Pansu, et al. 2019). In some areas, it is observed that elephants seasonally move out of the protected areas and compete with people for space and resources (Weinmann 2018; Naughton-Treves 1998; Granados, Weladji, and Loomis 2012; Mwakatobe et al. 2014). The movement of elephants is through corridors between feeding sites, clearings (bais) or salt flats that need to be protected in order to allow coexistence (Doumenge, Palla, and Itsoua Madzous 2021; Blake and Inkamba-Nkulu 2004).

1.3 Elephant food, habitat, and seasonal movement

Elephant food varies seasonally according to the quality of plant and water availability. It is estimated that elephants may require up to 150 kg of food and 190 l of water daily (Shaffer et al. 2019). They move strategically to optimize the utilization of available food resources over spatiotemporal scale (Tchamba 1996a; Moorcroft 2008; Mills et al. 2018). Indeed, the home range size used by Asian elephants vary between 100–1,000 km^2 (Alfred et al. 2012) whereas in Africa, elephants cover a range size of 11–500 km^2 (Shannon et al. 2006). The range sizes tend to be larger when food or water is limited either during dry or wet season (Tchamba 1996a).

Elephants forage mostly at night to avoid encounters with humans (Ihwagi et al. 2018; Graham et al. 2009). Their diet consists primarily of plant items supplemented by mineral from soil or water (White, Tutin, and Fernandez 1993; Koirala et al. 2016; Biru and Bekele 2012; Mills et al. 2018; Blake and Inkamba-Nkulu 2004). In forest area, fruit production occurs seasonally for different tree species, and elephants tend to wander around tree stands bearing fruits or food resources they feed on (Branco, Merkle, Pringle, Pansu, et al. 2019; Chiyo et al. 2005; Naughton-Treves 1998; White 1994). Those trees, whether edible or not for human, may also occur in or around farmlands, and be a source of conflict between human and elephants, in the form of crop raiding by elephants when visiting those farms or competition between human and elephant over edible fruits.

Variation in resources availability between dry and wet seasons could affect elephant's movement pattern as elephants seek to meet their food needs (Tchamba 1996b; Rode et al. 2006). In dry season, elephants' feeding strategy is constrained by the availability and distribution of water, while in wet season, food and water are available in abundance all over the habitat (De Boer et al. 2005; Tchamba 1996a). In most of their range, water is not a limiting factor for forest elephants and within their habitat, they are familiar with locations of available food and mineral resources (Mills et al. 2018; White, Tutin, and Fernandez 1993).

Management of wildlife populations, whether to conserve threatened species or promote biodiversity generally entails habitat management. Habitat is considered the natural environment in which an animal lives or the collection of resources and conditions necessary for its occupancy. For this thesis, I will be considering elephant habitat as a set of specific environmental features including the plant community and the vegetation association or cover type (Garshelis 2000).

Animal resource selection functions assume that animal's visits to resources are related to animal's preferences (Loarie, van Aarde, and Pimm 2009). Accordingly, animal's preferences can be quantified by comparing the rate of its occurrence in a particular site relative to other sites. In general, elephants tend to avoid habitat with high anthropogenic influence (Blake et al. 2008; Ihwagi et al. 2015). However, depending on their preference for some food items and their location in human dominated landscape, elephants might take some risks. In some cases elephants occur close to human settlements where they feed on fruits (Mills et al. 2018; Ngama et al. 2018). Therefore, the presence of preferred fruit trees in community land may act as attractant for elephants in the Campo-Ma'an landscape.

1.4 Approaches to mitigate human wildlife negative interactions

Many studies have been conducted to find solutions to crop raiding by elephants, but their repellent effects were often temporary, or they had limited effectiveness (Nelson, Bidwell, and Sillero-zubiri 2003; Hoare 2015). These studies highlighted the need of more research on control tests to answer questions involving habituation, long-term effects and possible effects on other wildlife and humans. Among the tests conducted so far by researchers to mitigate crop raiding are olfactory and auditory tools, including chilli-based repellent under different forms, noise makers and elephant pheromones (Nelson, Bidwell, and Sillero-zubiri 2003). Bee's pheromone has also been tested with significant repellent effects (Wright et al. 2018). The oleo-resin capsicum used in aerosol form was found to deter elephants from crops for 20 minutes in up to 75m radius in light winds (Osborn and Rasmussen 1995), while grease on fences showed also a positive action on deterring elephants from crops (Chang'a et al. 2016; Nelson, Bidwell, and Sillero-zubiri 2003). Most of these methods have weaknesses leading to their low rate of success (Mwangi 2015; Weinmann 2018; Nelson, Bidwell, and Sillero-zubiri 2003; Fungo 2011). Because of those weaknesses, including habituation and inappropriateness, some farmers now invest more in guarding their farm (Fungo 2011; Nelson, Bidwell, and Sillero-zubiri 2003). Indeed, repeated exposure of elephants to a mitigation tools might overcome their fears as they soon realize the tools is not a real danger (Nelson, Bidwell, and Sillero-zubiri 2003). In fact, with the ambient poverty in rural areas in sub-Saharan Africa (WorldBank 2017), an elephant intrusion into a farmer's plantation induces huge economic losses (King et al. 2017; Nelson, Bidwell, and Sillero-zubiri 2003), degrade tolerance with wildlife as well as social and cultural coexistence or increase the poaching rate significantly (King 2010; Kansky and Knight 2014; Breuer, Maisels, and Fishlock 2016).

The behaviour of elephants exposed to bee stings in the wild is not just a demonstration of the role honey bees can play in the conflict surrounding agricultural plantations but also the learning behaviour wild elephants might have gathered in their past (King, Douglas-Hamilton, and Vollrath 2007; King et al. 2017). From these perspectives, two approaches can be explored. Either elephants are deterred if they recognise or perceive any evidence of bees' presence through their pheromone (Wright et al. 2018) or bee sound (King, Douglas-Hamilton, and Vollrath 2007), or bees' response to nocturnal aggressions is very active, meaning that bees come out of the hives and fly to sting and repel enemies. Therefore, understanding how

African honeybees react to threat at night could be of greater importance in using them to improve human – elephant coexistence. To the best of my knowledge, this aspect of the mitigation technique has not been subject to rigorous scientific studies. On the one hand, Human and bees have low activity rate at night (Ngama et al. 2016; Gunn et al. 2013). On the other hand, both elephants and honeybees are social species having the potential to be dangerous to humans. Setting up an experiment that bring the two together is difficult as they avoid one another as much as possible (King 2010). Thus, simulation can provide insights on aspects not yet covered to improve the efficiency of mitigation approaches using honeybees as crop guard.

Beekeeping has a strong economic and ecological potential and could ease tensions between humans and wildlife, particularly the elephant (King 2009) in rural areas where precariousness is widespread. Honeybees have the potential to keep elephants away from crops and their socio economic and ecological advantages have led King (2009) to call for more scientific experimentation using honeybees as guardian in a wide range of agricultural settings, to evaluate its effectiveness and feasibility. Although anecdotes exist on elephants avoiding honeybees even at night, they cannot be considered as scientific facts (King 2010). In the Campo-Ma'an Technical Operational Unit (hereafter CMTOU), local people believe that bees are mostly active during the day and elephants generally raid crops at night and are therefore sceptical about the efficiency of bees to deter elephants from crops. Moreover, wild honey is traditionally harvested at night to avoid aggressiveness of wild honey bees (Ngama et al. 2016). This raises questions about the species of bees found in the CMTOU and their behavioural response to nocturnal aggression. These behaviours remain unexplored and need to be investigated.

1.5 Camera trap in ecology

Camera traps are among the most important artificial intelligence technologies used in biodiversity conservation (Green 2022). Camera traps are increasingly being used in ecology to answer a variety of questions related to animal ecology, behaviour, activities pattern

(Bridges and Noss 2011; Caravaggi et al. 2017; Ngama et al. 2016; 2018; Rovero et al. 2013; Burton et al. 2015) and population density (Green 2022; Rowcliffe et al. 2008). This novel approach offers perspectives for long term ecological studies through a non-invasive and cost effective method (Caravaggi et al. 2017; Djekda et al. 2020). Although camera traps are not always completely undetectable by animal, they allow to gather real information on a wide range of wildlife (Rovero et al. 2013; Caravaggi et al. 2017; Burton et al. 2015). Camera trap may also contribute to wildlife protection against poachers by alerting rangers who can respond to illegal activities in time (Green 2022). Although camera traps are able to alert human in the event of an approaching problem animal, it is to be deplored that a human intervention is always necessary to stop or limit the damage which the elephants can cause.

Elephants population distribution can be studied through indirect methods (Nzooh-Dongmo et al. 2015). However, there is a need to relate this distribution to their overall pattern of movement and habitat use. Therefore, different approaches and tools exist including the use of VHF Radio or satellite GPS telemetry, activity sensors and camera traps (Body, Weladji, and Holand 2012; Caravaggi et al. 2017; Ngama et al. 2018; Rovero et al. 2013; Burton et al. 2015). Camera traps are incrinsingly used in ecology to map elephant movement pattern (Cook et al. 2017), study occupancy, activity parttern and diet (Burton et al. 2015), as well as to identify and establish migratory corridors (Douglas-Hamilton et al., 2005). However, camera trap study should account for sampling error such as imperfect detection (Burton et al. 2015).

Proper use of camera traps requires a good knowledge of the functionalities of the devices in relation to the characteristics of the site where the cameras are to be used (Rovero et al. 2013). Site characteristics include the thickness of the under storey, the distance to the target and the height above the ground (Ngama et al. 2016). Setting up camera traps appropriately can allow optimum data collection. Therefore, it is essential to adjust settings to maximize the chances of capturing after judicious choice of installation sites (Burton et al. 2015). Camera traps settings include the triger delay for which various time lags have been used (Ngama et al. 2018; 2016; Tudge et al. 2022; Noack et al. 2019). For this study, a delay of 3-s was chosen to take into account the speed of an animal crossing the field of view of the camera. Cameras were set to take three photos per tigger by an animal (Noack et al. 2019). Good setting can allow rechargeable batteries to cover a month (Rovero et al. 2013; O'Brien, Kinnaird, and Wibisono 2003). Also, there is a need for constant maintenance that include exchanging batteries, verifying damages by wildlife, checking the viewing position of the camera, wiping the lenses and sensors with alcohol (Rovero et al. 2013).

1.6 Elephant and law in Cameroon

Wildlife conservation and management are regulated in Cameroon by the law n° 94/01 of January 20th, 1994, on the forests, the fauna and the fishing regime, and the decree n° 95/466/PM of July 20th, 1995, fixing the modalities of application of the fauna regime. Depending on the weight of their tusk, elephants are classified in two protection classes according to those regulations. They are in class A (totally protected) when their tusks weight "no more than 5 kilograms" each, and in class B (partially protected) when their tusks weight "more than 5 kilograms" each. Class B animals can be hunted legally provided you have a hunting permit. However, they can be killed with no respect to these classifications under the self-defence or crop damages following procedures described by the regulations. Eyebe et al. (2012) described six relevant provisions from the above-mentioned regulations used to protect farmers and their properties from wildlife damages. Although there is no compensation scheme specifically designed for damage caused by wildlife in Cameroon, several methods are applied when the damage is likely to cause a breach of social peace (Eyebe, Dkamela, and Endamana 2012; Tchamba 1996a). These measures have been developed to gain local people confidence and to refute the idea that more importance is given to wildlife they consider as state property than to them (Naughton-Treves 1997; Sitati et al. 2003). There are also provisions in the regulations to ensure part of the income generated by wildlife conservation is redistributed among local people with the objective to gain their trust. Indeed, elephants are sources of touristic attraction and can generate income shared between the government, local council and local population (MINFOF 2014).

1.7 Rationale

The human-elephant interaction over shared natural resources remains a major challenge for conservationists to partially guarantee the survival of elephants (Poulsen, Koerner, et al. 2017; Blake et al. 2008). Indeed, elephant populations have significantly declined in Congo basin due to poaching, and conflicts over space and resources (Maisels et al. 2013; Poulsen, Koerner, et al. 2017). Although protected areas exist, more elephant populations are found living partially or totally outside protected areas where they compete for resources and space with local people (Granados, Weladji, and Loomis 2012). The ongoing human population growth is resulting in increasing encroachment on wild areas, and this could lead to habitat loss or fragmentation, which is not suitable for forest elephants. Removing the constraints that hinder the full satisfaction of expectations for the protection of crops against elephants will benefit conservation. It is therefore urgent to understand the relationship between forest elephants and human living in the conservation area. Also, camera traps images (video and photos) have the potential to raise people awareness through education on environmental or poaching risk (Green 2022; Deith and Brodie 2020; Burton et al. 2015). From there, developing long lasting strategies for coexistence that accommodate elephants to the shared space while improving at local level, the tolerance of people towards conservation is important.

1.8 Objectives

The goal of my research is to assess the status of the dynamics of human-elephant interactions with the aim of promoting an integrated landscape management that maintains biodiversity while providing better coexisting conditions to both human and forest elephants in the CMTOU. To achieve this goal, I will first identify and understand the sources and consequences of the negative interactions between local communities and forest elephants. I will also be proposing mitigation strategies to help promoting the coexistence of different stakeholders involved in the conservation area. Below I will present the four research objectives on which the thesis is built.

Objective 1: Assessing the human wildlife conflict. Although human wildlife interactions are commonly reported around protected areas, the involvement of elephants in these interactions always gives rise to concern for the local populations sharing the living space with this megaherbivore whose food needs are enormous. Thus, the devastating impact of damage elephants can inflict to crops amplifies negative resentments among local communities with varying consequences (Breuer and Ngama 2020). In my study area, I was interested in exploring the nature and extent of the interactions between local communities and wildlife. In Chapter 2 I present an overview of this two-way interactions between human and wildlife with emphasis on forest elephants. Indeed, I assessed human related aspects of the interaction with wildlife in the conservation area and explored the impacts of human resentment on wildlife population as the consequence of negative perception of wildlife conservation across subdivisions in the study area.

Objective 2: Assessing elephant habitat use. Knowing that fruits are of great importance in forest elephants diet (Blake and Inkamba-Nkulu 2004; White 1994), I was interested in knowing how forest elephants use different land types, with different accessibility gradient to local communities, and identifying what drives their movement in this conservation area. In chapter 3, I present the influence of fruit availability on forest elephant relative abundance in the conservation area. Here, I combine the field investigations and camera trap survey to collect data on their occurrence and relative abundance by observing the rate at which forest elephants and human overlap in different land use types. I concentrated this study in the southwestern most tip of the conservation area based on existing elephant distribution map and the number of camera traps available. Indeed, indirect signs of presence were described as decreasing from east to west and from north to southwest of the conservation area (Matthews and Matthews 2006; Nzooh-Dongmo et al. 2015). Moreover, this part of the conservation area has been point out as a stronghold of negative interactions between humans and forest elephants (Eyebe, Dkamela, and Endamana 2012; MINFOF 2014).

Forest elephants are said to be virtually absent in the other parts of the Campo and Ma'an forest due to the major disturbances caused by the construction of the Memve'ele dam in the east, the construction of the Kribi port, the creation of vast agro-industrial plantations in the northwest as well as wood logging and mining in the northwest. The use of dynamite to break up the rocks and the strong pressure exerted by wood logging and poaching around the various construction sites to supply the workers with bushmeat amply justify the choice of the southwestern most tips of the conservation area. Human disturbances may have amplified the decrease in forest elephant density in most of the area in the CMTOU (Matthews and Matthews 2006).

Objective 3: Combining the local ecological knowledge and field survey to determine the feeding habit of forest elephants. In forest area, it is difficult to spot elusive species such as forest elephants (Blake 2002). Therefore, direct observations and data collection are difficult in evergreen forest. In chapter 4, I use indirect observation method and empirical knowledge collected during survey within the local communities (chapter 2), to assess the usefulness of local ecological knowledge in determining the diet and feeding habit of forest elephants (chapter 4). Living and interacting with wildlife in general and forest elephants in particular, allows people living near protected areas to glean useful information that can benefit conservationists in rapidly gathering information for decision-making (Service et al. 2014; Albuquerque et al. 2021). Despite being timely and cost effective, empirical knowledge is not commonly used in forest elephant study. Moreover, one may be interested to know whether beyond crop damage local community have some knowledge about elephant diet.

Objective 4: Pre-evaluating an adaptive and efficient mitigation technique. Much mitigation strategies are being used by farmers to deter elephants from raiding their crops. Although, beehive fence is a promising mitigation method used to deter elephants from raiding crops, site specific test is important to guarantee farmers acceptance, adhesion and consequently the success of the method through integration in their crop defence system (King 2010; Litoroh et al. 2012). Therefore, based on the site-specific principle, I was interested in knowing whether beehive fences can be introduced efficiently in Campo-Ma'an as mitigation tool to reduce crop damage caused by forest elephants. In chapter 5, I present the results of the experimental test conducted on bee colonies. I tested the ability of the sub species of African honeybees (*Apis mellifera adansonii*) found in my study area, thought to be diurnally active, to deter nocturnally active forest elephants from crops. The experiment was also set to draw locals' attention, if successful, to be used as an ecologically and economically rewarding deterrent method before its expansion to the entire conservation area.

Chapter 2 Human-wildlife conflict in the Campo-Ma’an Technical Operational Unit, southern Cameroon

The following chapter is based on the submitted manuscript: Djoko IB, Weladji RB and Paré P. Human-wildlife conflict in the Campo-Ma’an Technical Operational Unit, southern Cameroon. Submitted to *International Journal of Biodiversity and Conservation* on August 04th, 2022.

2.1 Abstract

Human-Wildlife Conflict (HWC) is increasing in the Campo-Ma’an region, threatening human livelihoods and wildlife. Yet the sources and consequences of HWC in this region remain poorly understood. We interviewed 127 households from three subdivisions to investigate the extent of wildlife crop damage and identified humans’ impact on wildlife. Most surveyed households (98%) reported wildlife crop damage, mainly by eighteen species. The severity level’s distribution differed among subdivisions. Out of 23 plants species grown, 14 suffered damages, five being staple foods, suggesting that HWC can threaten food security. Elephants (*Loxodonta cyclotis*) were the second most cited crop raiders, after cane rats (*Thryonomys swinderianus*), causing greatest economic loss. None of the mitigation measures implemented effectively reduced crop raiding. The main human effects on wildlife were poaching and habitat loss, threatening biodiversity. We must monitor crop damage and illegal activities and establish mitigations to reduce human-wildlife interferences. This requires setting up adaptive land-use systems, modifying and empowering wildlife legislation.

Keywords: Forest elephants, wildlife, crop raiding, Campo-Ma’an National Park, Cameroon, mitigation.

2.2 Introduction

Human Wildlife Conflict (HWC) is a situation that occurs when the presence or behaviour of wildlife poses actual or perceived, direct and recurring threat to human interests or needs, leading to disagreements between groups of people and negative impacts on people and/ or wildlife (International Union for Conservation of Nature [IUCN], 2020) The negative consequences on humans may involve wildlife damage to crops (e.g. Granados and Weladji, 2012; Pant et al., 2016), to livestock (e.g. Weladji and Tchamba, 2003; Karanth et al., 2013) or attacks on humans (Karanth, Naughton-Treves, et al. 2013; Karanth and Kudalkar 2017). Conflicts also occur when people, retaliate against the species blamed, or compete with wildlife for resources such as space, water, and food (Hoare 2015; Mariki, Svarstad, and Benjaminsen 2015). Humans have lived alongside and interacted with wild animals throughout evolutionary history and HWC, with its long historical existence, is receiving increasing attention from conservation biologists across the globe (Messmer 2000; Anand and Radhakrishna 2017; Barua, Bhagwat, and Jadhav 2013). Despite these efforts, HWC remains a global phenomenon with nearly 90% of the countries currently afflicted (Anand and Radhakrishna 2017; Messmer 2000).

Most of Africa’s protected areas (PAs) were created by colonial administrators without taking into account the concerns of local communities, and in most cases, people were displaced or deprived of the traditional use of resources, causing them to suffer economic hardship (Gurung 1995; Matseketsa et al. 2019; Weladji and Tchamba 2003). On the other hand, the animals that are to be considered “protected”, mostly abundant in the PAs (Ole 2011), often find themselves roaming outside PAs, creating further damages to crops and livestock (Granados and Weladji 2012). This generates conflicts around PAs, where land has become a scarce resource. Yet, the human population adjacent to wildlife habitats is generally growing, and with it, the demand for more farming lands and more resources from the PAs (Mekonen 2020). Moreover, local communities illegally herd and graze livestock into PAs (Bobo and Weladji 2011; Karanth, Naughton-Treves, et al. 2013), and have engaged into poaching, often also killing species listed as threatened (Mariki, Svarstad, and Benjaminsen 2015; Mwakatobe et al. 2014). For humans living adjacent to PAs, crop raiding is one of the most reported form of HWC (Granados and Weladji 2012; Kaswamila, Russell, and Mcgibbon 2007), and a variety of species groups are the culprits including, but not limited to, elephants

(*Loxodonta spp*), primates, rodents, and birds (IUCN 2020; Mwakatobe et al. 2014). Among the many wildlife species involved in HWC, elephants are the most reported (Anand and Radhakrishna 2017; Granados and Weladji 2012; Naughton-Treves 1998), and generally have bad reputation among local people as they damage a lot in a single raiding event (King 2010; Naughton-Treves 1998; Ngama et al. 2018). Indeed, although being currently listed as Endangered or Critically Endangered in Africa (IUCN 2021) conflict with humans is one of the major causes of the decline of elephant populations, hampering their long-term conservation (Granados and Weladji 2012; Pant et al. 2016).

HWC is widespread, unevenly distributed and complex in nature, making it a central issue in wildlife management (Anand and Radhakrishna 2017; Dickman 2010; Mekonen 2020). Different species are involved, causing different types of damage at different times of the year (Mekonen 2020). Thus, damage by wildlife can disproportionately affect certain crop types over others. This may be because of animal preferences or may be a consequence of the dominant crop types grown in each area (Weladji and Tchamba 2003). Also, crop damages and the resulting retaliations are only visible impacts of HWC, as there are hidden or social impacts poorly documented or not often reported (Barua, Bhagwat, and Jadhav 2013; Dickman 2010; Redpath, Bhatia, and Young 2015). For example, people have given up some of their rights because of their proximity with wild animals or conservation areas (Dickman 2010; Thirgood, Woodroffe, and Rabinowitz 2005) on which they depend for fuelwood, thatch, fish, bushmeat, medicinal plants, and pasture (Weladji and Tchamba 2003; Granados and Weladji 2012). Furthermore, various mitigation strategies developed against wildlife damages are limited with different level of efficiency depending on the target species (Hoare, 2015; King, 2010; Nelson et al., 2003).

HWC is exacerbated in Central Africa, where wildlife is often considered state properties (Naughton-Treves 1998; Ole 2011), with dramatic consequences on both wildlife and local communities (Granados and Weladji 2012; Ngama et al. 2018; Weladji and Tchamba 2003). Despite recent efforts to involve local people and other stakeholders, frustrations remain (Bobo and Weladji 2011). In the Democratic Republic of Congo, elephant damage to crops was reported to decrease farmer's annual revenues by 77% (Inogwabini et al. 2013). In Northern Cameroon, 87% of households complained crop damage with 31% of crop income lost to wildlife around Bénoué Wildlife Conservation Area (Weladji and Tchamba 2003), whereas elephant damages to crops have been estimated between US$40,000 to US$75,000 per year (Tchamba 1996a). On the other hand, between 2002 and 2011, 62% of the forest elephant population of the Congo basin was decimated because of the illegal ivory trade (Maisels et al. 2013). The negative reputation local people have for wildlife could also be present in the Campo-Ma'an region where local people rely heavily on the nearby forest for their livelihood and HWC is reported, mostly from large and medium size mammals including elephants (Eyebe, Dkamela, and Endamana 2012; Ole 2011), and effective mitigation strategies are lacking. Indeed, back in 2004, Eyebe et al. (2012) reported a couple of villages facing damages from elephants in Campo-Ma'an.

The Campo-Ma'an National Park (CMNP) and its peripheral zone known as Campo-Ma'an Technical Operational Unit (hereafter designated CMTOU), in southern Cameroon, has experienced an increase in human population over the years in response to the development and establishment of agro-industrial and logging companies (Tiani, Akwah, and Nguiébouri 2005), and major development projects such as the dam and port constructions (*Ministère des Forêts et de la Faune* [MINFOF], (2014). Moreover, the recent creation of an industrial oil palm plantation and new plans to create forest exploitations in the CMTOU have resulted in the reclassification of about 60,000 ha and the slash of all the trees in the logging concession n°09025. These may increase the frustration by imposing greater restrictions on the use of resources to which local peoples rely on, thereby increasing HWC.

Accordingly, our aim was to identify the main source of conflicts between people and wildlife, as a prerequisite to frame an adaptive management policy through the development of effective mitigation techniques to alleviate potential problems. More specifically, we assessed: 1) the crop damage experience and severity level; 2) the types and stages of growth of crop raided; 3) the wildlife species involved; 4) the factors influencing crop damage occurrence and mitigation strategies used by farmers; 5) the economic impact of crop raiding on farmers' livelihood and, 6) the potential influence of humans on wildlife. Further, 7) we assessed whether there were differences in the effects among subdivisions. We expected households experiencing crop raiding, that occur mostly at mature stage, with more elephant complaints to experience greater economic loss as elephants create more damage to crops (Anand and Radhakrishna 2017; Mwakatobe et al. 2014; Naughton-Treves 1998). Also, we predicted that farms close to the park border will suffer greater damages and economic losses as efforts to conserve wildlife subsequently increase animal population densities, which is followed by further incursion out of the PAs (IUCN 2020; Mwakatobe et al. 2014; Breuer and Ngama 2020). It was also expected that various coping strategies would be used by local population with different level of efficiency in conflict resolution (Hoare 2015; IUCN 2020; Nelson, Bidwell, and Sillero-zubiri 2003).

2.3 Methods

2.3.1 Study area

The CMTOU represents 16% (770 000 ha) of the South region of Cameroon with nine subdivisions, and about 111,000 inhabitants. The CMNP is located between 2°10'N, 9°50'E and 2°25'N, 10°48'E (Figure 2.1) and is surrounded by 162 villages and hamlets along the main road. In addition to the park with 264,064 ha, the CMTOU includes three others land use systems, the Forest Management Units (FMU) for logging (235,485 ha), a state maritime estate (320 ha) and a multipurpose area (275,033 ha) devoted to community forests and human activities (Tiani, Akwah, and Nguiébouri 2005). Our research included three subdivisions: Campo, Niete and Ma'an with different socio-cultural backgrounds (MINFOF 2014). The mean annual precipitation is about 2500 mm (Tchouto 2004). The mean annual temperature is 25°C and the climatic conditions are favorable for agriculture all year round. There are about 80 species of mammals, including a critically endangered forest elephant (*Loxodonta cyclotis*) population of about 544 individuals and 2200 great apes (Nzooh-Dongmo et al. 2015). Table 2.1 includes most crops grown in the region (Tiani, Akwah, and Nguiébouri 2005).

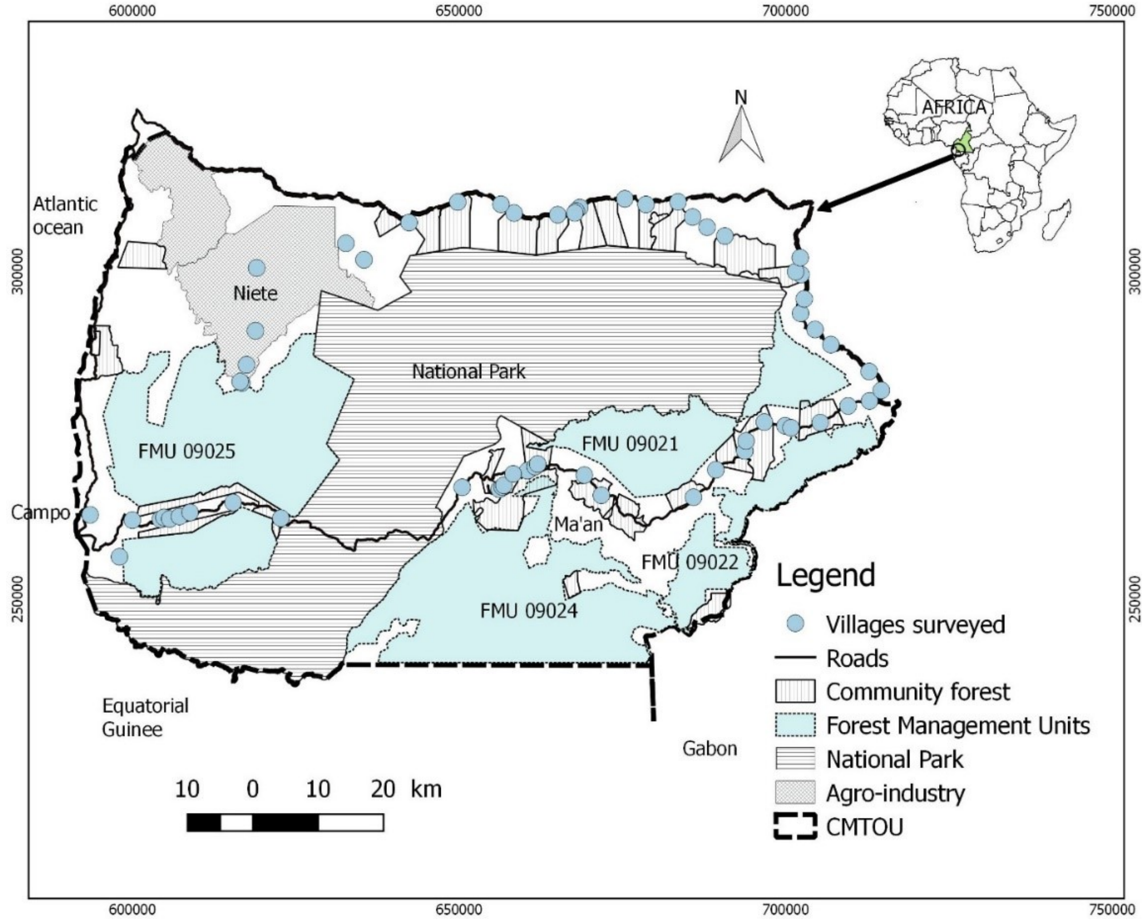


Figure 2.1 Location of study site and different land use types in the Campo-Ma'an Technical Operational Unit (CMTOU), southern Cameroon.

2.3.2 Data collection

Data for the human impacts on wildlife were obtained from the park's annual reports (2014-2017) and images from 19 camera traps collected between May and December 2019 in the CMTOU. No human image from the camera traps would be shared with park staff or be published as they may be used for prosecution against them. In fact, community members were informed about the purpose of our work, and that their privacy would be respected (i.e. no image would be shared with park authorities), and they helped identify the locations of cameras (see Sandbrook et al., 2018; Sharma et al., 2020). From the images, we extracted those with human presence, and subsequently identified and classified them as hunters (e.g.

with a hunting device or animal carcasses), forest loggers (e.g. with a logging device or with wood products), or others when known (e.g. park staff or researchers with their crew) (Deith and Brodie 2020).

Data on wildlife influence on local communities were collected from May through August 2018 in the CMTOU. We visited 54 communities within the CMTOU based on the availability of their leaders and informed them about the purpose of the research. Among them, 23 (42%) villages, from the above mentioned three administrative subdivisions (12 villages in Campo, 4 in Ma'an and 7 in Niete), were selected opportunistically for interviews. Within a village, households were also selected opportunistically based on their presence at the time we were present for actual interview and willingness to take part to the research, which they confirmed by reading and signing the consent form (Supplementary material S2.1) (Mouafo et al. 2021; Ngama et al. 2019). We interviewed households' heads, their wives, or any adults male or female (≥18 years old) present because adulthood start at 18 years old in Cameroon (Patrice 2019). See also Hariohay et al. (2020), Mouafo et al. (2021) and Mwakatobe et al. (2014). Overall, 127 households were interviewed, 25% being females. Interviews were conducted in French wherever possible, as most people were fluent in French (Granados and Weladji 2012; Fopa et al. 2020). In one instance, the respondent, from a *Bagyeli* household, did not speak French, and we used a local interpreter. Following Granados and Weladji (2012) and Weladji and Tchamba (2003) method, the interview consisted of semi-structured questionnaire during which the respondent had to answer several crop damages related questions (Supplementary material S2.2).

The extent of crop damage was obtained using the respondents' declarations on the estimated area reported damaged by wildlife (see Hariohay et al., 2020; Neupane et al., 2017). We intended to visit all farms where crop damages were reported, but due to logistical reasons, and the difficulty to estimate the extent of damage for most animals (since most damages had occurred several months prior to our visit), we decided to only visit farms that experienced elephant's crop raiding recently (< 4 months) knowing that elephants signs may last about three months (see Nzooh-Dongmo et al., 2015). Accordingly, we visited twelve farms and used data on some previously reported crop raiding events, assessed and compiled by the conservation office, to validate the responses received, thereby minimizing the risk of exaggeration from the responses received. Cassava and bananas are staple foods commonly grown in a slash-and-burn agriculture system in our study area (MINFOF 2014). Growing these plants require farmers to use the same piece of land about two years before the allow it to lie fallow for many years (Breuer and Ngama 2020). Therefore, respondents were asked whether they were victims of crop raiding during the last three years, and if yes, to identify the stage of growth of the crop damaged (Supplementary material S2.2), to provide an estimate of the distance of their farm from the village and from the park border (Mwakatobe et al. 2014; Breuer and Ngama 2020). Most of the respondents were aware of the distance of their villages to the entry of the CMNP by road but ignored the distance to the closest border of the CMNP or FMU. CMNP and FMU are considered wildlife habitats and the presence of wildlife in these two land use types is ideal for coexistence with farmers. Because farmers ignored the distance from their location to the park border, we used QGIS software (QGIS Development Team 2020) to estimate the linear distances from the closest park border or FMU to each village. We considered the raiding events within the last three years in term of estimated percentage of crops damaged by wildlife (Karidozo and Osborn 2005). Crops losses caused by different animal species were assessed for each cropping season. These percentages were grouped into four categories (Supplementary material S2.2): Moderate (0% - 25%), severe (25% - 50%), more severe (50% - 75%) and extremely severe (> 75%). Other household members were present during the interview and could confirm or refute the information they provided, to account for possible loss of information. Multi-cropping system is used for agricultural production in our study area. Therefore, several crops could be damaged simultaneously. In addition, a crop could be subject to multiple raiding events by different wildlife species. To assess the level of involvement of each animal in crop damage, we counted the number of incidents involving each crop type and attributed to each animal species.

The economical assessment of crop damages on people's livelihood was determined by estimating the actual total annual harvest by type of crops for each farmer, the proportion sold as well as the price per unit for each type of crop. This helped to overcome the problem of different units used to measure different types of crops. For example, cocoas are sold in bags of 100kg while cassavas are sold in baskets. Knowing the annual income from agriculture for each farmer, we deducted the monetary loss by dividing the current sale by the average percentage of losses in fields. For this purpose, we considered the mid values of the interval used to classify extent of damage (12.5 for moderate, 37.5 for severe, 67.5 for more severe and 87.5 for extremely severe) for all the calculations.

Equation 1 : Economic losses = $\sum (H_i \times P_i)/\%\text{loss}$.

Where H_i represents the total annual harvest of crop type i and P_i the price of unit sale for crop type i on the local market.

We performed this research in accordance with the Certification of Ethical Acceptability for Research Involving Human Subjects # 30009480 delivered by the Concordia University Human Research Ethics Committee. Locally, the research protocol was reviewed and approved by CMNP manager, and the research was approved by the regional administrative authority (authorization n°025/AR/L/SG/DAAJ/SDAT issued on June 19th, 2018, by the South Region Governor).

2.3.3 Statistical analysis

Questionnaire responses were summarized and cross tabulated for statistical analysis. We used a Generalized Linear Models (GLMs) with a binomial distribution and logit link to test the occurrence of crop raiding experienced by households across the three subdivisions and by severity level. Our response variable in this model had two levels (whether the respondent experienced crop damage or not) and therefore binomial. In our second model, we assessed the impact of crop raiding on individual crop type, the response variable being the total count of raiding events on each crop species grown by the farmers. GLM with a Poisson distribution and a log link function were used to identify whether crop specie and the severity level predicted the frequency of reported damage experienced by a given crop type across the subdivisions. We used a quasi-Poisson distribution instead to account for over-dispersion, and only included data for known crop species in the analysis. For our third model, we used GLM with Poisson distribution to identify whether the wildlife species and the level of severity in crop damage across subdivisions could explain variation in the frequency of reported event caused by a given wildlife species. The total count of wildlife involvement in crop raiding incidents was used as response variable whereas the severity level of farm damaged, the wildlife species and subdivisions were used as predictors. A quasi-Poisson distribution was also used here to account for over-dispersion. For all GLM, the log-transformed number of respondents per subdivision was used as offset to account for differences in the statistical population difference between subdivisions (Agresti 1996).

We also ran separate ANOVA models to compare the mean size of reported land area affected by crop loss caused by wildlife, mean distance to FMU or National Park, average economic loss within each subdivision. Pairwise comparisons were performed using Tukey-Kramer corrections for the difference between the means. We used Pearson chi-squares to compute the difference between the subdivisions in the distribution of the severity level and stages of growth of the crops damaged. Pearson chi-squares were also used to assess the difference between mitigation methods, the differences in elephant’s involvement in crop raiding incidents between subdivisions, the distribution of human presence (total number of independent observations of poachers and loggers from photos) across three land use types (the National Park, the FMU and the community land) and the stage of growth of damaged crops. Unless otherwise specified, we reported means with their standard deviations, and estimated difference with their 95% confidence intervals. Statistical analyses were performed using R statistical software (R Core Team 2020) with significance level set at 0.05.

2.4 Results

2.4.1 Crop raiding experience

From the 12 farms visited, nine (75%) were consistently in accord with the questionnaire responses, while the rest had lower actual damage than reported during interview. Of the respondents, 98 % (n = 127) reported crop damage by wildlife with no significant differences between subdivisions (GLM test, $\chi^2_2 = 1.61$, $p = 0.450$). All respondents from Campo (n = 68) representing 54% of the total and Ma'an (n = 14) with 11% suffered crop damages whereas the only two respondents that did not suffer crop damages were from Niete (2% of total). Across subdivisions, there was no difference among the levels of severity (GLM test, $\chi^2_3 = 6.07$, $p = 0.110$). Overall, 29% (n=36) of the respondents experienced extremely severe crop damages, 22% (n = 27) was more severe, 26% (n = 32), severe and 23% moderately severe. Between subdivisions however the distribution of the severity level differed significantly (Chi square test, $\chi^2_6 = 14.85$, $p = 0.021$; Figure 2.2). For households experiencing extremely severe damages, significant differences were observed between Campo with 35% and Ma'an with 14% (Chi square test, $\chi^2_1 = 8.89$, $p = 0.003$), while Campo and Niete (with 24%) as well as Ma'an and Niete were comparable (all $p > 0.1$).

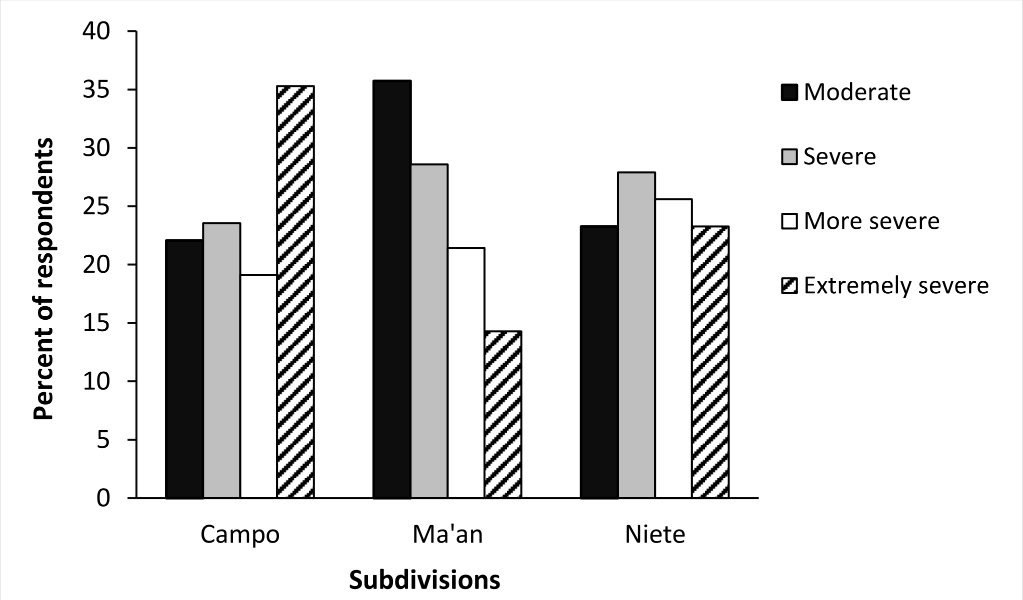


Figure 2.2 Relative distribution of damages to crops by severity level in three subdivisions of the Campo-Ma'an region, southern Cameroon.

2.4.2 Types of crops damaged, and wildlife involved

Overall, of the 23 types of crops grown by the respondents, 14 (Table 2.1) were reported damaged by wildlife. The distribution of incidents reported varied significantly with respect to crop types (GLM test, $\chi^2_{13} = 115.93$, $p < 0.001$) and subdivisions (GLM test, $\chi^2_2 = 134.23$, $p < 0.001$), with a model $R^2 = 0.23$. The five most damaged crops reported (79% of raiding events) were also staple crops, namely cassava, maize, banana, groundnut, and cocoyam. Forty respondents (31%) reported the damage of all their crops in farms with 21 in Campo and 19 in Niete. The level of severity did not differ with respect to crop type (GLM test, $\chi^2_3 = 4.76$, $p = 0.314$). The distribution of the stages of growth at which incidents generally occur did not differ between the subdivisions (Chi square test, $\chi^2_4 = 7.07$, $p = 0.132$). Within subdivisions however, mature crops were more affected than both intermediate (Chi square test, $\chi^2_1 = 35.64$, $p < 0.001$) and young (Chi square test, $\chi^2_1 = 40.95$, $p < 0.001$) stages (Figure 2.3). Overall, 71% of damages reported happened at mature stage, 16% at intermediate stage and 13% at young stage of crops within subdivisions.

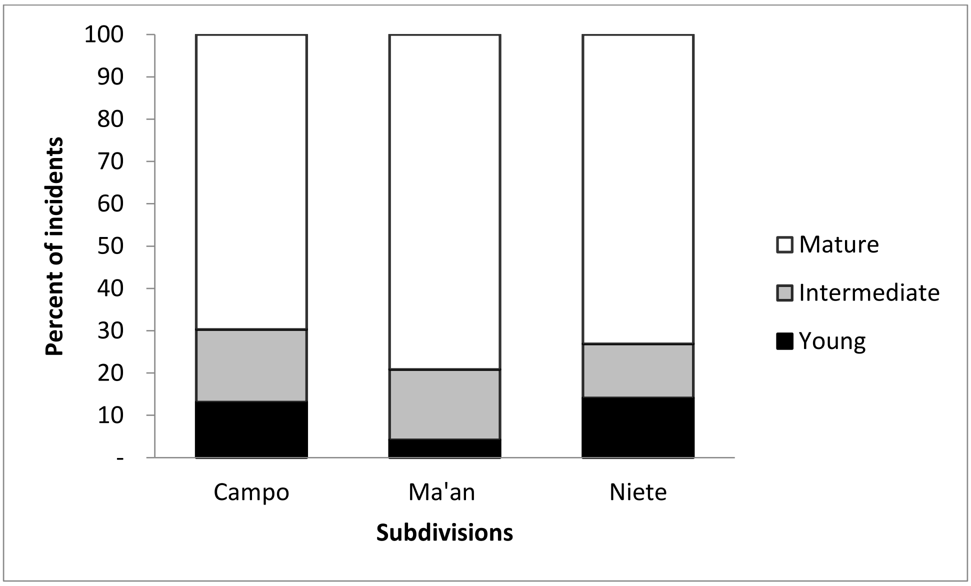


Figure 2.3 Percent distribution of crop raiding incidents by growth stages of the crops in three subdivisions of the Campo Ma’an region, southern Cameroon.

Table 2.1 The distribution of the percentage of reported wildlife incident by crops type.

Types of crops	Overall N = 125	Campo n = 68	Ma'an n = 14	Niete n = 43
Cassava: *Manihot esculenta*	89	91	100	81
Maize : *Zea mays*	61	54	71	67
Banana: *Musa paradisiaca*	50	60	64	30
Groundnuts : *Arachis hypogaea*	48	44	86	42
Cocoyam : *Colocasia esculenta*	38	26	50	51
Sweet potatoes : *Ipomea batatas*	19	22	7	19
Squash : *Cucurbita* spp	16	13	43	12
Yam : *Dioscorea* spp	12	12	0	16
Cocoa: *Theobroma cacao*	9	6	36	5
Sugar cane: *Saccharum* spp	10	6	21	12
Palm tree: *Alaeis guineensis*	4	3	0	7
Pepper : *Capsicum frutescens*	1	2	0	0
Okra: *Abelmoschus esculentus*	1	2	0	0
African pear: *Dacryodes edulis*	1	0	0	2

Table 2.2 displays the distribution of the crop raiders by subdivision, from which, five were reported more often reported [Cane rat (28%), elephant (19%), talapoin (14%), porcupine (11%) and rat (9%)]. Overall, although the model fit was not high (R^2=0.13), the distribution of crop raiding incidents was significantly different with respect to wildlife species (GLM test, $\chi^2_{17} = 58.44$, $p = 0.021$) and the involvement of various species in crop damage differed among subdivisions (GLM test, $\chi^2_2 = 131.13$, $p < 0.001$). Elephants were more destructive to crops in Niete (28%) and Campo (20%) as compared to Ma'an with only 1% (Chi square test, $\chi^2_2 = 23.99$, $p < 0.001$).

Table 2.2 Distribution of crop raiding incidents reported per animal taxon in Campo (N = 450), Ma’an (N = 131) and Niete (N = 219). *Birds refer to Grey Parrot (*Psitacus eritacus*) and Village Weaver (*Ploceus cucullatus*).

Animal species		**Campo**		**Ma'an**		**Niete**	
	Total	**n**	**%**	**n**	**%**	**n**	**%**
Cane rat: *Thryonomys swinderianus*	225	120	27	33	25	72	33
Elephant: *Loxodonta cyclotis*	151	89	20	1	1	61	28
Talapoin: *Miopithecus talapoin*	113	71	16	14	11	28	13
Porcupine: *Atherurus africanus*	86	37	8	27	21	22	10
Rat: *Cricetomys gambianus*	75	24	5	27	21	24	11
Bush pig: *Potamochoerus porcus*	41	36	8	5	4	0	0
Sitatunga: *Tragelaphus spekei*	22	19	4	3	2	0	0
Gorilla: *Gorilla gorilla*	24	17	4	7	5	0	0
African buffalo: *Syncerus caffer*	18	13	3	2	2	3	1
Mandrill: *Mandrillus sphinx*	11	11	2	0	0	0	0
Snakes	7	3	1	2	2	2	1
African small-grain lizard: *Varanus* spp	4	3	1	1	1	0	0
Chimpanzee: *Pan troglodytes*	5	3	1	2	2	0	0
Squirrel: *Xerus erythopus*	9		0	6	5	3	1
Pangolin: *Uromanis tetradactyla*	2	2	0	0	0	0	0
Birds*	4	1	0	0	0	3	1
African civet: *Vivera civetta*	2	1	0	0	0	1	1
Daman tree: *Dendrohyrax arboreus*	1	0	0	1	1	0	0

2.4.3 Factors influencing crop damage occurrence and mitigation measures used

The severity of crop damage did not vary according to the average distance of households from the park border (ANOVA test, $F_{3, 119} = 0.62$, $p = 0.603$). Although not significant (ANOVA test, $F_{2, 119} = 2.17$, $p = 0.119$), households in Ma’an seemed on average closer to the park (Mean ± SD = 4.5 ± 3.6 km) than those in Campo (7.25 ± 4.2 km) and Niete (6.3 ± 4.5 km). Most respondents (97%, n = 123) were settled on national domain and only 3% (n = 4) owned their land. Most farm plots (72%, n = 74) were at least 5 km from the nearest border of the National Park, but still were victims of wildlife damages regardless of subdivisions. The average distance of households from FMU did not vary with the severity of crop damage ($p = 0.321$) but was significantly different between subdivisions (ANOVA test, $F_{2, 119} = 21.35$, $p < 0.001$), with model $R^2 = 0.28$. On average farms from Ma'an (3.3 ± 2.1 km) were farther to FMU border than those from Campo (2.2 ± 0.8 km; Estimated difference 1.17, [0.17, 2.18]); while farms from Ma’an were on average farther than those from Niete (3.95 ± 1.9 km; Estimated difference 1.79, [1.12, 2.45]).

Sixteen methods were identified as commonly used by locals to protect their crops from wildlife damages (Table 2.3). Overall, mitigation techniques used by respondents differed significantly in proportion for the five most used methods (Table 2.3) regardless of the subdivisions (Chi square test, $\chi^2_4 = 39.81$, $p < 0.001$). While noise making was equally used among subdivisions (Chi square test, $\chi^2_2 = 2.77$, $p = 0.251$), use of traps (16%, Chi square test, $\chi^2_2 = 23.23$, $p < 0.001$) and fencing (24%, Chi square test, $\chi^2_2 = 13.77$, $p = 0.001$) were less used in Niete as compared to Campo and Ma’an (Table 2.3).

Table 2.3 Frequency and percentage distribution of mitigation techniques per subdivision.

Methods	**Total**	**Campo**		**Ma'an**		**Niete**	
	N	**n**	**%**	**n**	**%**	**n**	**%**
Fencing	54	35	52	8	57	11	24
Trapping	45	30	44	8	57	7	16
Noise making	22	15	22	2	14	5	11
Fire around the farm	20	15	22	1	7	4	9
Camping in the farm	13	12	18	0	0	1	2
Abandon the plot	6	2	3	0	0	4	9
Killing problem animal	4	2	3	1	7	1	2
Lighting farm at night	1	1	2	0	0	0	0
Raising bees	1	1	2	0	0	0	0
Scarecrows	4	1	2	1	7	2	4
Pepper crops	1	1	2	0	0	0	0
Clearing farms' edge	4	0	0	1	7	3	7
Shifting land	2	0	0	0	0	2	4
Growing sweet potatoes	1	0	0	0	0	1	2
Early harvest	1	0	0	0	0	1	2
Selecting crop	1	0	0	0	0	1	2
None	14	5	7	1	7	8	18

2.4.4 Economic impact of human wildlife conflict

Average agricultural income losses did not vary between the subdivisions (ANOVA test, $F_{2, 90} = .05$, $p = 0.950$), but varied significantly with severity level (ANOVA test, $F_{3, 90} = 3.39$, $p = 0.021$), with model $R^2 = 0.10$). The average losses were 68% of agricultural income in Campo (Mean ± SD = 644,480 ± 1,003,630 FCFA or US $1,075 ± 1672.7), 23% in Ma'an (420,265 ± 267,200 FCFA or US $700.5 ± 445.3) and 74% in Niete (1,075,800 ± 2,801,530 FCFA or US $1,793 ± 4,667). The average loss of income for households experiencing moderate losses (189,080 ± 248,615 FCFA or US$ 315 ± 415, n = 14) were lower (Estimated difference with 95% CI = -1174180.2, [-2,266,542.61, -81,817.84]) compared to the average income loss of those with extremely severe crop losses (1,462,763 ± 2,686,825 FCFA or US $2,437 ± 4,478, n = 25). Households with more severe income losses (522,840 ± 870 FCFA or US $ 871 ±

1,096, n = 21) and those with severe losses (376,910 ± 390,015 FCFA or US $ 628 ± 650, n = 19) were comparable (All $p > 0.05$). The average agricultural income was estimated at (945,235 ± 1 196,515, (US $1,575.5 ± 1,994), 1,794,135 ± 2,153,780 (US $2,990 ± 3,590), 1,327,660 ± 3,051,700 FCFA (US$ 2,212 ± 5,086) respectively for Campo, Ma'an and Niete. All calculations are done at a rate of US $ 1 = 600 FCFA.

2.4.5 Human influence on wildlife

We present data from the anti-poaching unit for the period 2014-2017 from the CMTOU in Table 2.4. It appears that a variety of evidence exists confirming the real impact of humans on wildlife including actual gun seized to poachers. Between May and December 2019, 19 cameras deployed in the conservation area took 20,325 photos. From these images, 10,681 humans were seen on 4,376 photos (22%) and included 428 (4%) hunters, 9,531 (89%) loggers, 28 (1%) antipoaching patrols staff and 694 (6%) research assistants.

Table 2.4 Summary of the results from the antipoaching unit between 2014 and 2017 in the Campo-Ma'an Technical Operational Unit. Gun seized, traps destroyed, firearms cartridges, ammunition seized, camps destroyed, animal remains seized, ivory seized, and elephant carcasses are all related to illegal actions of human against wildlife. Hearing reports refer to human suspected to having conducted illegal activity in relation to wildlife and transferred to the court for prosecution. Complaints against wildlife refer to a limited number of farmers who reported their crop damages to the conservation office.

Poaching indices	**2014**	**2015**	**2016**	**2017**
Gun seized	19	11	15	23
Firearm cartridges	159	282	177	230
Traps destroyed	578	319	819	607
Ammunition seized	243	101	138	119
Camps destroyed	35	52	57	66
Animal remains	466	211	135	149
Hearing report	6	7	20	14
Ivory seized	0	2	0	2
Elephant carcasses	0	1	3	4
Complaints against wildlife (elephants, gorilla, mandrill)	16	2	3	3

Human occurrence differed between land use types (n= 9,959, Chi square test, χ^2_2 = 18,64, p < 0.001; Figure 2.4). The majority were filmed in the community area as compared to the park (Chi square test, χ^2_1 = 9721, p < 0.001) and the FMU (Chi square test, χ^2_1 = 9,129.70, p < 0.001). In addition, more persons were filmed in the FMU compared to the park (Chi square test, χ^2_1 = 189.90, p < 0.001). The distribution of the hunters differed significantly between land use types (Chi square test, χ^2_2 = 403.88, p < 0.001; Figure 2.4). Overall, more hunters (78%, n = 333) were observed in the community area as compared to the park (2%, n = 7, Chi square test, χ^2_1 = 312.58, p < 0.001 and FMU (21%, n = 88, Chi square test, χ^2_1 = 142.58, p < 0.001). There were also more hunters in the FMU than in the park (Chi square test, χ^2_1 = 69.06, p < 0.001). Of the 9,531 images of loggers, the majority (99%, n = 9,409) were filmed in community area as compared to the FMU (1%, n = 122, Chi square test, χ^2_1 = 9,049.20, p < 0.001; Figure 2.4). No tree logging activity was observed in the park.

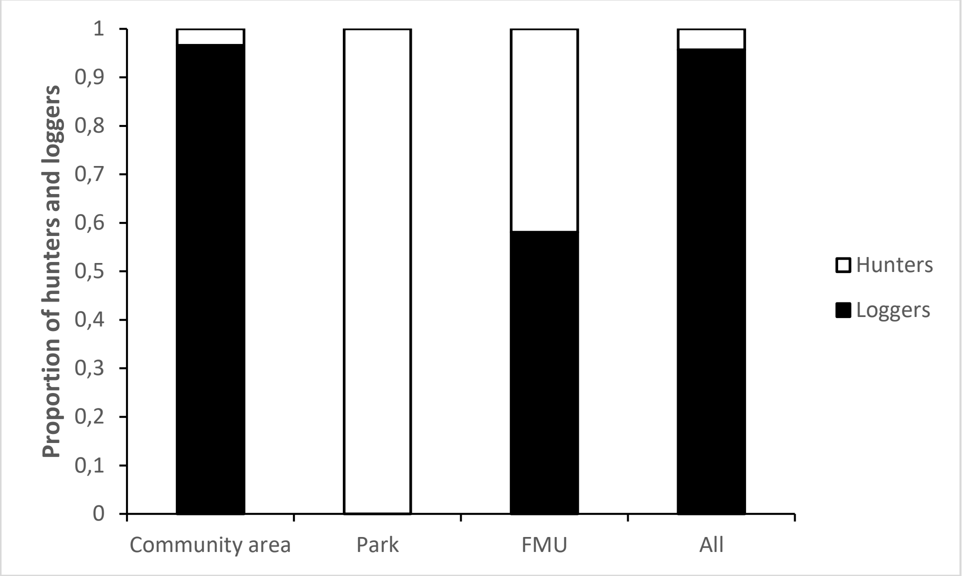


Figure 2.4 Proportion distribution of the number of images of hunters and loggers across Community Land, National Park, and Forest Management Unit (FMU). When present in the National Park or FMU, hunters are considered as poachers.

2.5 Discussion

Our findings confirm the reportedly increasing HWC worldwide, with evidence of wildlife damaging crops and humans poaching and destroying wildlife habitat. We also show that level of conflict varies among subdivisions and therefore can be site specific, causing the abandonment of farms and the dependence of the populations of Campo on the food crops that are no longer cultivated locally. Finally, we provide evidence of humans' influence on wildlife using human photos from 19 camera traps.

That 98% of the respondents reported being victim of damages by wildlife is symptomatic of people living close to PAs and may be the result of the increase in population in this area; from 60,338 inhabitant in 2002 to 111,000 in 2011 (MINFOF 2014). This result is consistent with several studies with more than 80% of households experiencing wildlife crop raiding (Gontse, Mbaiwa, and Thakadu 2018; Karanth, Naughton-Treves, et al. 2013; Weladji and Tchamba 2003). As it is generally the case, a variety of wildlife species from various taxa were identified as responsible of damages to crops, including elephants and rodents (King 2010; Mekonen 2020; Ole 2011). We found the level of damage to differ between the subdivisions, being less severe in Ma'an where elephant density is lowest (Nzooh-Dongmo et al. 2015; Matthews and Matthews 2006). The observed pattern matched elephant's distribution in the CMTOU, as we found Ma'an to be the less affected by elephant damages whereas Niete, previously problem-free (MINFOF 2014; Eyebe, Dkamela, and Endamana 2012), became a new elephant conflict area since the start or major project in the conservation area. Elephants were the animals causing the most losses in Campo and Niete with their single raiding event surpassing the cumulative raiding of all other crop raiders. This result is consistent with the broad idea of extreme severity associated with elephant damages (Anand and Radhakrishna 2017; Kaswamila, Russell, and Mcgibbon 2007; Ngama et al. 2018; Gontse, Mbaiwa, and Thakadu 2018).

Selective damages to staple food crops by wildlife lower the yield of their victims (Eyebe, Dkamela, and Endamana 2012; Kaswamila, Russell, and Mcgibbon 2007; Nyirenda et al. 2018; Breuer and Ngama 2020). Although crop damage occurs at all stages of plant growth, it gets worse when crops mature and are ready for harvest by farmers. This result is consistent with other findings (Granados and Weladji 2012; Mwakatobe et al. 2014; Pant et al. 2016; Breuer and Ngama 2020). Forest elephants might consider farms with mature crops as part of their seasonal food. Indeed, mature crops are of high nutritional values providing important calories needed by wild animals while reducing their movement and feeding time. We observed in the field that the creation of plantations opens the canopy and creates attractive spots, surrounded by fruit trees consumed by wildlife, including elephants. Such disturbed areas create secondary forest that have been shown to be attractive to wildlife because it concentrates good quality food in a small area (Mwakatobe et al. 2014; Breuer and Ngama 2020).

Distance to the PA is an important predictor of the severity level of damages to crops (Naughton-Treves 1997; Mwakatobe et al. 2014). It appeared that most damages occurred within 500 m of villages, very far from the park border but unfortunately often close to the logging concessions considered PAs, and therefore part of wildlife habitat (Nzooh-Dongmo et al. 2015; MINFOF 2014). Contrary to observations elsewhere (Mwakatobe et al. 2014; Pant et al. 2016; Naughton-Treves 1997), we found that proximity to park border did not explain the level of damages. Wildlife in the conservation area takes advantage of the contiguous forest cover despite a variety of land use systems being applied. Indeed, the 2015 inventory of wildlife shown that elephants as many other wildlife reside permanently in the FMU to which villages are closer than to the park (Nzooh-Dongmo et al. 2015; MINFOF 2014).

Farmers mostly make cash income from the sale of their crops. Crop destructions by wildlife influenced household economic stability as elsewhere (Hoare 1999; Weladji and Tchamba 2003; Kaswamila, Russell, and Mcgibbon 2007; Gontse, Mbaiwa, and Thakadu 2018; Mwakatobe et al. 2014). The average agricultural income lost per year per household were lower in Ma'an (23%) than in Campo (68%) and Niete (74%), and this corroborates the distribution of the elephant populations likely to raid farms unfortunately with no direct aid from the conservation authorities. This indicates that despite the diversity of crop raiders, the imprint of the forest elephants on people's income is particularly noticeable (Breuer and Ngama 2020; Compaore et al. 2020; Nyirenda et al. 2018).

Several studies have documented evidence of detrimental effects of human activities on wildlife (Fa et al. 2015; Kouassi et al. 2017; Lata, Misra, and Shukla 2018), which may well also be occurring in the CMTOU where we found evidence of poaching and logging attributed to local communities. Bushmeat is a staple food for people living in the vicinity of PAs (Fa et al. 2015; Kouassi et al. 2017; Martin et al. 2020). Because of the restrictions on hunting, poaching is often the only way people can have access to the much-needed bushmeat, although one can hunt in the community area as per the domestic use right. In fact, the hunting and consumption of species with high growth rate is tolerated to improve cohabitation between forest wardens and farmers, and to minimize risk of human–human conflict (*sensu* Dickman, 2010; Breuer and Ngama, 2020; Martin et al., 2020). That local communities do not have access to the species causing them the more losses can trigger negative attitudes toward wildlife and conservation (Granados and Weladji 2012; Weladji and Tchamba 2003). Based on this, one may consider some of their actions as retaliations, justifying to some extent their resentment towards wildlife as seen by the many proofs reported by the law enforcement unit (amount of poachers' camps and traps destroyed, ammunitions collected, firearms and ivories seized, poachers arrested, etc. (Table 2.4, Tiani et al., 2005). Local communities were also involved in "illegal" logging in the CMTOU. These activities impose the opening of roads and removal of trees some of which provide fruit food to forest elephants. Consistent to other findings, this will lead to the fragmentation and loss of wildlife habitat, the movement of animals to other sites where they may become vulnerable and ease the access to the park for poachers (Lata, Misra, and Shukla 2018; Breuer and Ngama 2020). Although our images displayed illegal hunters and loggers, we did not denunciate them to park authorities, thereby fulfilling our obligation of respecting their privacy, a guarantee for the acceptance by the populations of the introduction of camera traps for research (Sandbrook, Luque-lora, and Adams 2018; Sharma et al. 2020). Disturbances in the eastern side of the park with the construction of the dam (2012–2017) might have forced large mammals, including elephants, to move away (Nzooh-Dongmo et al. 2015; MINFOF 2014).

Severe damages to different crop species threaten the food security of the populations and may build in them anger as no alternative food source exist, which makes it difficult to resolve HWC (Barua, Bhagwat, and Jadhav 2013; Dickman 2010). Local resentment is often intensified by conservation regulations that impede local communities' capacity to cope with losses to wildlife (Dickman 2010). Consequently, they turn to illegal activities in the conservation area, which put pressure on wildlife habitat and threaten biodiversity. This call for an urgent need for a solution that is broad enough to accommodate both parties and this is not easy to achieve. Indeed, although several mitigation strategies have been proposed and even tested in several places; most of them have limitations suggesting that conflict requires original and comprehensive approaches for long-term resolution (Anand and Radhakrishna 2017; Dickman 2010; Karanth and Kudalkar 2017). Because of the many factors involved, HWC is complex (Dickman 2010; Anand and Radhakrishna 2017). Conflict situations in the

CMTOU are all about crop damages by wildlife in search of nutritious and palatable foods, but also poaching, making coexistence difficult for communities and conservationists (Breuer and Ngama 2020; Sitati et al. 2003). This situation induced direct costs for farmers in terms of time and money (Barua, Bhagwat, and Jadhav 2013; Nyirenda et al. 2018). There are also indirect costs, such as the psychological effects associated with the risk of starvation, injury or even being killed which may affect their wellbeing (Barua, Bhagwat, and Jadhav 2013; Hoare 2015; Breuer and Ngama 2020). In fact, HWC is shaped by actual and past interactions with wildlife. Considering such hidden aspects that shape some conflict situations can be a significant step toward lasting solution (Barua, Bhagwat, and Jadhav 2013; Dickman 2010; Hoare 2015; IUCN 2020).

The construction of fences and traps around fields was used against small fauna, while the production of noise by any means possible was used to repel problem animals such as elephants, great apes and other animals considered dangerous, as reported previously (Ole 2011; MINFOF 2014). Fencing is often associated with camping in the forest near the farms around large fires, producing smoke that may keep animals away. These methods, taken individually or in combination, unfortunately, require a physical presence which has repercussions on the organization of the family, their livelihood, and the education of the children, especially during the harvest period (King 2010; Mwakatobe et al. 2014). Sometimes, farmers use scarecrows or call for culling from the wildlife authorities, which do not occur often. A compensation scheme existed in early period of the creation of the CMNP including setting up revolving funds with women's associations, and micro-credit system to help local people develop economic activities but has since disappeared because of the insolvency of the first beneficiaries (MINFOF, 2014). Other specific less-widely used techniques have also been implemented such as night lighting of fields with flares and cultivation of chili at the edge of the field, but as we know, smart elephants get habituated when repeatedly exposed to new methods (King, 2010; Nelson et al., 2003). Compensation schemes have been also proposed elsewhere and used as mitigation strategies, but results are not always conclusive (Nelson, Bidwell, and Sillero-zubiri 2003; Karanth, Gopalaswamy, et al. 2013).

Economic losses in agriculture could justify the intensity of alternative activities such as hunting, fishing, gathering or picking of non-wood forest products that provide financial support to households (Tiani, Akwah, and Nguiébouri 2005). In addition, we noticed the lack of enthusiasm for the creation of new agricultural plots by some respondents in Campo, arguing that the presence of the elephant in their vicinity is forcing them to switch their feeding habits favoring imported products, to be purchased and for which they are not used to. At the subdivision level, the direct impacts of the conflict in the western side of the park (Campo and Niete) could be the lack of locally produced foodstuffs, which would have helped to lower the cost of living. Unfortunately, almost all the products consumed are imported from areas less exposed to HWC including Ma'an. Such impacts have been describe in northern Congo leading to an increased price of staple food products (Breuer and Ngama 2020).

Before concluding on this research, although we validated crop raiding data with those compiled at the conservation for large and medium size mammals, we acknowledge several limitations to the study. We used recall type questionnaires whereby the data is obtained based mainly on the declarations of farmers. Therefore, they present the risk that people may differ in their ability to recall and may not be accurate in their answer because of poor memory. Also, they may have overestimated the loss hoping to receive some sorts of compensation at one point. The interview took place in private for some households whereas some respondents were interviewed in presence of their relatives who could have influenced their answers to questions, depending on how information was being shared within a household. Despite our efforts to validate the extent of damages reported by the respondents, we were only able to visit 12 farms from which recent elephant damages could still be visible in the field. Although signs maybe less visible, we could have visited other farms damaged by other wildlife species as well.

2.6 Conclusion

We reported evidence of HWC in the CMTOU, with the subdivisions with higher elephant density suffering higher economic losses. As agriculture is the main source of food and income for these populations, we need to understand elephant movement patterns better to inform on the development of appropriate mitigation measures. It is imperative that we rethink conservation policies for large mammals in this densely populated area. This will imply revisiting land use planning and the choice of sites allocated for the creation of large-scale plantations in this landscape. We acknowledge that HWC is complex in nature and that mitigation strategies do not always work. Accordingly, we recommend using holistic and adaptive solutions, that consider direct and indirect costs while satisfying wildlife and human needs. This will require setting up adaptive land use systems, modifying and empowering wildlife legislation. For example, the creation of a community hunting area on the FMU as proposed by the management plan of the CMNP (MINFOF 2014), and the facilitation of the use rights by allowing locals more access to natural resources from the CMTOU to favor tolerance and coexistence of both protagonists. Also, it may be important to set up a permanent crop damage monitoring process in different villages, close to farmer, to estimate the real level of loss.

2.7 Supplementary materials

Supplementary material S2.1: Consent form

Human-wildlife conflict in the Campo-Ma'an Technical Operational Unit, southern Cameroon

By:_______________, PhD student,____________ University. Contact:___________

Preamble:

This questionnaire is designed for research on "the human-wildlife conflicts" in your community, carried out by me, _________________________. The research aims are to: (1) assess the socio-economic impact of the human-wildlife interactions around CMNP; (2) study the relationship between different stakeholders i.e. park staff, local people, the private organizations as well as the non governmental organizations operating in the area; (3) Assess people's attitudes and perceptions towards wildlife, the park and the wildlife legislation; (4) Study some ecological aspects of the elephants including testing some mitigation measures; and finally (5) Propose plans to mitigate conflicts and promote ecosystem-based management for the park.

If you accept to participate, you will be asked several questions (see questionnaire), and eventually we will visit your farm to assess the level of damage caused by elephants to your crops. The answers that you will provide us on the following questionnaire, which lasts approximately 45 minutes, will remain confidential and will be used exclusively by the researchers for the study.

There is no risk in participating in this study. However, by providing your name, we may use this information in the events of a compensation program that is retroactive. There is no guaranty for this, however. You are free to decline or accept that your name be disclosed for this purpose.

It remains at your discretion to determine whether you wish to answer the questionnaire in whole or in part, or if you do not wish to participate at all. If this study is published, the anonymity and confidentiality of this questionnaire will always apply. You must also be at least 18 years old to participate.

If you have any questions, please do not hesitate to ask me during the interview or later by email at "______________________" or by phone at"________________________".

Do you agree to participate in the study under the conditions described above?

If yes, say YES

If no, say NO

Thank you!"

Supplementary material S2.2: Subset of the household questionnaire

Name: ___________________________ Age ________________ Sex_____________

Education level:

Primary:	Lower secondary:	Upper secondary:	Higher education:

(1) Did you experience crop damage by wildlife anytime the last 3 years? Y___ N___

(2) If yes, list crop types by area cultivated and the expected income/sale from each.

	Area	Crop types	Total output (tons/bags)	Sale (in Franc CFA)
1 2 3 4 …				

(3) How far is your farm from the village?

01 : 0-500 m	02 : 0.5-1 km	03 : more than 1 km	04: Estimate (from the village)

(4) How far is your farm from the CMNP?

01: 0-2 km	02: 2-5 km	03: > 5 km (give an estimate)

(5) What proportion of your field was damaged?

01: a little bit (0 - 25%) moderate	03: more than half (50% - 75%) more severe
02: just under half (25% - 50%) Severe	04: the whole field (75% - 100%) extremely severe

(6) What animals are responsible for the damage (by crop type and by crop stage of growth)

		Stage of growth		
Species	Type of crop damaged	Young	Intermediate	Mature
1				
2				
3				
4				
5				
…				

(7) What are the methods you have used to deter wildlife from causing crop damage? Name and describe each, including to what extent it was effective.

1:_______________________________________

2: _______________________________________

3:_______________________________________

4:…

Chapter 3 Fruit availability influences forest elephant habitat use in a human dominated landscape, Campo-Ma’an, southern Cameroon

The following chapter is based on the online published manuscript: Isaac B. Djoko, Robert B. Weladji, Alys Granados, Patrick Paré, Guillaume Body (2022). Fruit availability influences forest elephant habitat use in a human dominated landscape, Campo-Ma’an, southern Cameroon. *Tropical Conservation Science.* https://doi.org/10.1177%2F19400829221117053.

3.1 Abstract

African forest elephants (*Loxodonta cyclotis*) are Critically Endangered yet research on factors influencing their resource use is limited in Central Africa. We assessed the influence of fruit availability, land use types and anthropogenic activity on forest elephant presence and relative abundance in the southwest part of the Campo-Ma’an Technical Operational Unit (CMTOU) to better understand elephant habitat use in human-dominated systems and inform elephant management strategies. We used 17 camera trap stations and surveyed 17 line transects to monitor forest elephant presence and relative abundance as a function of fruit availability, tree species richness and land use types. Our study area spanned a gradient of human disturbance and included a National Park (NP), Forest Management Unit (FMU), and Community Land (CL). Forest elephants were more likely to occur in areas with increased fruit availability and tree species richness. Also, the likelihood of their presence was higher in CL than in FMU and NP. Elephant relative abundance was negatively affected by human activities such as hunting and logging. The relationship between elephant relative abundance and fruit availability was stronger in CL and NP as compared to the FMU. Elephant relative abundance was higher during the rainy season. Forest elephant habitat use was positively affected by fruit availability across land use types, and negatively affected by human activities in the southwest part of the CMTOU. Continued monitoring of elephant responses to food availability in CMTOU is warranted to track changes in elephant habitat use. Knowledge of the distribution of fruiting trees consumed by forest elephants may allow managers to predict hotspots of habitat use, and to therefore develop effective management strategies.

Keywords: Camera trap, Central Africa, Cameroon, conservation, elephant, endangered species, mammal.

3.2 Introduction

Human disturbance can affect food resources available to forest elephants (Loxodonta cyclotis) (Poulsen, Clark, and Bolker 2011; Mills et al. 2018). The removal of trees for logging or the creation of roads for example, may lead to the loss of fruiting trees that are an important food resources for elephants (Blake et al. 2008). Although forest elephants are generalist herbivores, they show a preference for fruits (Blake and Inkamba-Nkulu 2004; Campos-Arceiz and Blake 2011; White, Tutin, and Fernandez 1993; Ndi, Fonkwo, and Kinge 2022) which can provide important minerals and influence their habitat use (Rode et al. 2006; Sach et al. 2019). Human disturbance that influences fruit availability could therefore have important implications for elephant behaviour (White, Tutin, and Fernandez 1993; Bush et al. 2020) and can lead to a decrease in body condition (Bush et al. 2020; Sach et al. 2019). For example, because there are fewer fruit trees, people and forest elephants have to share trees more frequently and aggressive interactions may occur (Breuer and Ngama 2020). Also, human activity near fruiting trees may affect elephant movement and food selection if elephants are displaced from or avoid those areas (Puyravaud et al. 2019; Breuer, Maisels, and Fishlock 2016). Fruit availability may vary seasonally and affect elephants' behaviour and movement pattern (Mills et al. 2018; Mmbaga, Munishi, and Treydte 2017; Branco, Merkle, Pringle, Pansu, et al. 2019; Breuer and Ngama 2020).

The Critically Endangered forest elephant *(Loxodonta cyclotis*) has declined at an accelerated rate in recent decades (IUCN 2021). Declines are largely due to habitat loss, and illegal hunting (Maisels et al. 2013; Poulsen, Koerner, et al. 2017). Protected areas (PAs) are often created as part of conservation strategies where such activities are prohibited but increasing human presence from various projects such as mining, agricultural expansion, urban development and logging around PAs, can still negatively influence wildlife behaviour, including elephants (Farfán et al. 2019; Breuer, Maisels, and Fishlock 2016). Elephants frequently roam outside PAs and may become habituated to human presence to varying degrees (Brittain et al. 2020; Granados, Weladji, and Loomis 2012). In some cases, their proximity to human settlements may lead to conflicts with people, driven by competition for space and resources (Thouless et al. 2016a; Blanc 2008; Mariki, Svarstad, and Benjaminsen 2015). The consequences of such conflict can be serious, often affecting local livelihoods through crop raiding, or the killing of people and/or elephants (Mariki, Svarstad, and Benjaminsen 2015; Tchamba 1996a). Alternatively, elephants may avoid areas used by humans because they may perceive increased risk of mortality, leading to more cryptic behaviour (Ihwagi et al. 2015; 2018; Breuer, Maisels, and Fishlock 2016; Wall et al. 2021).

Although human population density is relatively low (~ 1 inhabitant/km², WWF 2021), throughout the Congo Basin, the expansion of their activities have been shown to threaten biodiversity (Poulsen, Koerner, et al. 2017; Thouless et al. 2016a; Blake et al. 2007; Wall et al. 2021; Blake et al. 2008; Breuer, Maisels, and Fishlock 2016). However, few studies have investigated the consequences of anthropogenic disturbances on forest elephants in Cameroon (see Ole, 2011; Amin et al., 2020; Brittain et al., 2020).

The use of camera traps as a wildlife monitoring tool has increased over the last decade in the Congo Basin (Djekda et al. 2020; Bruce et al. 2018; Farfán et al. 2019). Studies seeking to monitor large bodied mammals have largely used interviews or transects and recce to assess species status and population distribution (Amin et al. 2020; Nzooh-Dongmo et al. 2015; Brittain et al. 2020). However, transects and recces are expensive to carry out in large areas and the effectiveness in detecting elusive species may be limited (Burton et al. 2015; Djekda et al. 2020) whilst camera traps have been shown to be a cost-effective and reliable method for monitoring wildlife communities (Djekda et al. 2020; Bruce et al. 2018), including forest elephant activity pattern and behaviour (Ngama et al. 2016; 2018). Camera Traps have been used by researchers to monitor large bodied mammal including forest elephants in the Dja Faunal Reserve, southeast Cameroon (Bruce et al. 2018; Farfán et al. 2019), also part of

Congo Basin, like Campo-Ma’an National Park . Understanding how forest elephant use habitat in Campo-Ma’an, particularly in areas where camera trap surveys have not been done and where human wildlife conflict is growing, can inform management decisions to set up strategies for coexistence.

Here, we quantified the influence of fruit availability, land use types and human activity on forest elephants in Campo-Ma’an Technical Operational Unit (CMTOU), Cameroon. Our study area spanned a gradient in human accessibility and disturbance (a National Park (NP), Forest Management Unit (FMU) and Community Land (CL)). The FMU is a forest concession run by a certified timber company for wood extraction primarily but where some wildlife conservation measures were implemented, a requirement for maintaining their certification. These conservation measures included anti-poaching activities carried out by the company and park rangers. Specifically, we explored whether the forest elephant habitat use varied between land use types in the CMTOU. We expected human activities to negatively affect forest elephants’ relative abundance, which should be highest in the park, where human activity is restricted (Supplementary Table S3.1). Elephant habitat use can be negatively associated with intensive logging which causes forest fragmentation and facilitate access to poachers by creating roads in previously inaccessible areas of the forest (Blake et al. 2008; Amin et al. 2020; Breuer, Maisels, and Fishlock 2016). Further, elephants may avoid areas of high poaching intensity (Breuer and Ngama 2020), and may increase their walking speed when passing through such areas (Ihwagi et al. 2018). Human - elephant conflict may result in elephant range contraction or range shift if they are extirpated from areas where conflict occurs (Wall et al. 2021; Breuer and Ngama 2020; Breuer, Maisels, and Fishlock 2016).

Elephants make movement choices based on nutritional needs (Sach et al. 2019). Accordingly, larger fruits may better attract forest elephants as they contain more nutrients. However, whether forest elephant habitat use is influenced by fruit size needs to be explored further. Because forest elephants feed on fruits (Ndi, Fonkwo, and Kinge 2022; Blake and Inkamba-Nkulu 2004) and their movement is driven by their nutritional needs, habitat use could be influenced by fruit size (Sach et al. 2019). Indeed, the uneven distribution of fruit trees as well as the difference in nutritional values may favor the choice for large fruits. Therefore, we determined fruit size from existing literature in order to assess whether they affected forest elephant presence and abundance. Finally, we tested the influence of tree species richness and fruit availability on elephant presence and relative abundance, expecting a positive relationship because greater species richness may offer more feeding options (Neupane et al. 2019; Mills et al. 2018). Moreover, high tree species richness in a limited space may provide elephants with a greater diversity of minerals they require for their metabolism (Sach et al. 2019; Rode et al. 2006).

3.3 Methods

3.3.1 Study area

This study took place in the southwest part (~ 75 000 ha) of the Campo-Ma'an Technical Operational Unit (CMTOU, 770 000 ha), Cameroon (2°10' N / 9°50' E and 2°25' N / 10°48' E, Figure 1). The CMTOU is a mosaic of three land use types, including Campo Ma'an National Park (CMNP, 264 000 ha), a forest management unit (FMU) where timber extraction has been ongoing since 2000, and a multipurpose community land area (CL) where farming, use rights for domestic purposes (hunting, fishing, artisanal logging of wood, gathering), housing, and infrastructures are permitted (MINFOF, 2014). CMNP is a state-managed strict protected area where access for purposes other than research and tourism are prohibited, except for the *Bagyeli* (an indigenous community) in well-defined areas to allow the perpetuation of their cultural heritage. Within the past two decades, the FMU (n°09025) was selectively logged for commercial tree species, estimated at about 0.23 to 0.28 tree/ha (Tchiofo-Lontsi et al. 2019) (e.g., *Lophira alata, Erythrophleum ivorense*) before being partially declassified in 2019 for conversion to palm oil plantation. Existing roads and bridges were abandoned in the FMU because logging companies were no longer active. Most are now used by Camvert-SA, an industrial palm oil plantation company covering 60 000ha of the declassified part of the FMU.

The CMTOU is rich in biodiversity with many threatened species (e.g. leopard *Panthera pardus*, western lowland gorilla *Gorilla gorilla*, forest elephant, chimpanzee *Pan troglodytes*, giant pangolin *Smutsia gigantea*, African forest buffalo *Syncerus caffer nanus*). This area is also subject to wood logging, dam and port constructions, and agro-industrial plantations. Small scale farms also occur in and around the conservation area, making the CMTOU a hotspot of Human-Elephant Conflict due to the high concentration of forest elephants in some parts of the CMTOU (MINFOF 2014; Nzooh-Dongmo et al. 2015).

There are 2297 vascular plant species here, of which 29 species are endemic to CMTOU (Tchouto 2004). There are two dry seasons (June to August and December to February) and two rainy seasons (March to May and August to November). Mean annual precipitation ranges between 1700 and 2800 mm, while the altitude goes from 0-500 in the west lowland to 400-1100 m towards east side. Although the area has been described as water rich with many rivers and swamps (MINFOF 2014; Tchouto 2004), some of them may be seasonal, with elephants relying on these temporary water sources at various times of the year (Beirne et al. 2020; Mills et al. 2018). In the CMNP, four forest clearings (bais) and a salt lick, reported as places that forest elephants like to visit (Blake and Inkamba-Nkulu 2004; Breuer and Ngama 2020), have been monitored for ecotourism in CMNP (MINFOF 2014; Forje, Tchamba, and Eno-Nku 2020).

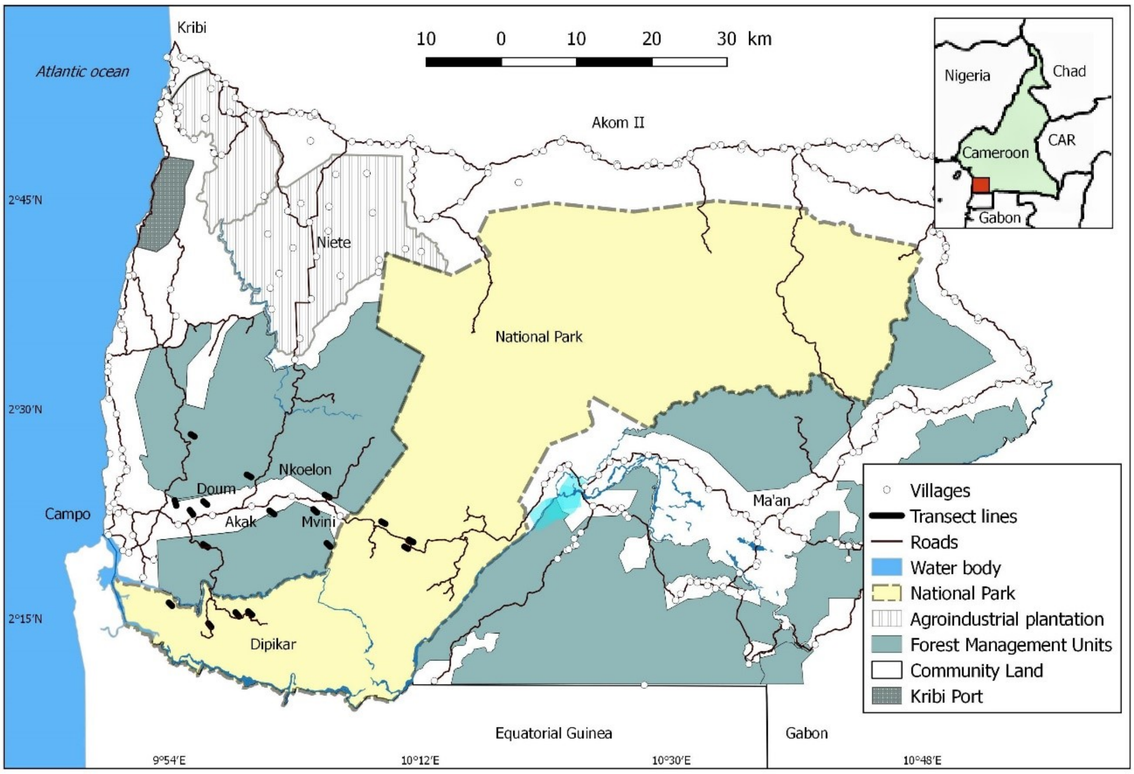


Figure 3.1 Campo-Ma'an Technical Operational Unit, Cameroon, displaying the main land use types (Forest Management Units, Community Land, National Park, Agroindustry) as well as the transect lines (along which the camera traps were located).

3.3.2 Data collection

3.3.2.1 Camera trapping

We deployed 19 Bushnell camera traps (Trophy Cam HD Essential E3 Trail Brown 16 MP 119837C Model, Bushnell, Kansas) in southwestern Campo-Ma'an. Deployment was stratified between land use types (6 cameras stations in the FMU, 4 in the CL and 7 in the NP). Four stations were located on inactive timber skidding trails originally created for wood logging about 22 years ago, five were on paths created and maintained by forest elephants and eight were under or near fruiting trees. Camera placement was chosen based on expert knowledge of a team of field assistants (hunters, wood logging workers) with the goal of maximizing detection of forest elephants when present at camera trap location. Distance between adjacent camera traps ranged between 1.2 km and 8.8 km. Camera traps were active 24 hours/day between June 2019 and May 2020. Because two sites hosted two camera traps each, we dropped data from two camera traps and report only data from 17 camera traps stations and corresponding transects (transect methods detailed below). Camera stations were visited approximately every 30 days to replace SD cards and batteries. Camera traps were not rotated within strata and seven camera traps had been stolen, three of which were replaced. Another camera trap was moved from its initial location because of problems with humidity. Cameras were set at 80 to 150 cm height, angled horizontal and approximately 5 to 15 m away from target features (e.g. roads, fruiting trees). The quiet period (i.e. the trigger delay between consecutive photos) was set to three seconds. Camera trap photos were date and time stamped. We used an independence interval of 30 min for species at the same camera trap station (Deith and Brodie 2020; O'Brien, Kinnaird, and Wibisono 2003; Tudge et al. 2022; Chakraborty et al. 2021). Photos with multiple individuals of the same species at the same camera trap station on the same time frame was considered a single detection event (Chakraborty et al. 2021).

3.3.2.2 Line transects

From each camera trap station, a transect was established (Appendix S1) for a total of 17 transects (each 500 m x 50 m, covering 2.5 ha). Along each line transect, tree species richness (number of species of trees/ha) was surveyed once, and fruit availability was surveyed monthly. Transects were delimited with markers and all woody tree species, whether bearing fruits or not, with diameter at breast height (1.3 m above ground) ≥ 20 cm, were identified. Local, common and/or scientific names were used to identify specimens to at least the genus level by local botanists. Where specimens could not be identified in the field, they were collected and later identified at the Cameroon National Herbarium.

Fruit availability was measured monthly, as the number of trees bearing ripe fruits (hereafter fruiting trees). In all, 42.5 ha were covered monthly. For most of the tree species, fruiting period last about a month (Chapman, Wrangham, and Chapman 1994). In Congo Basin, most trees are tall enough for their fruits to be out of reach to forest elephants. For example *Saccoglottis gabonensis* may fruit at 45 m height (White 1994) so forest elephants mostly access the fruits that fall on the ground. The total number of trees with ripe fruits in each line transect during each monthly visit was used to estimate fruit availability (trees/ha) (Chapman, Wrangham, and Chapman 1994). For each line transect, fruit availability was estimated by dividing the total number of trees with ripe fruits counted during each monthly survey by transect area (i.e. 2.5 ha). The average sizes of fruits from identified fruit trees were later obtained from the Plant Resources of Tropical Africa website (https://www.prota4u.org/database/). Signs of human activity on transects were measured directly and indirectly. Direct signs of human activities were identified as humans from camera trap images and included research team or park staff.

To account for imperfect detection of human activity at camera trap stations (humans present but not detected by the camera trap), indirect signs of human activity were measured from line transects as frequency in which firearm cartridges, traps, signs of machetes cuts on vegetation, evidence of hunting camps, wood skidding trails, and tree stumps resulting from logging were detected each month.

3.3.2.3 Ethics

Village meetings were organized during which we presented our authorization letter to the village chief and any community member upon request. Human images from camera traps were processed according to ethical guidelines suggested by Sharma et al. (2020). For example, community members were informed about our work and were involved with camera trap location selection and set up. They were also informed that their privacy would be respected and none of their images would be transferred to park staff for prosecution nor would they be published. Field assistants were contacted directly by our research team and were paid daily for their work.

3.3.3 Data analysis

We were interested in testing the effects of several anthropogenic and habitat covariates on two response variables: 1) elephant presence and 2) elephant relative abundance at each station. Elephant presence was modeled per month as a binary response (presence or absence) at each camera station. Independent detections of elephants were used as an index of elephant abundance, determined as:

Equation 2 : $N \times 100/A$

where N is the number of independent detection events at a station during a month, and A is the total number of camera trap days (Chakraborty et al. 2021; O'Brien, Kinnaird, and Wibisono 2003). We also used this equation to determine relative abundance of humans. Camera trap images were processed using Timelapse 2.0 v 2.2.3.5 (Greenberg 2020). We used indirect signs of human activity to assess the monthly density of human activities in different land use types. Density was calculated as the total number of indirect signs of human activity, divided by transect area (2.5 ha) each month. All types of human activity signs were weighted equally in the analyses.

Analyses were performed separately for elephant presence and for elephant relative abundance. As there are no strong knowledge on the form of the relation between the response variables and our explanatory variables, we allowed non-linear relations to be considered, which we combined with a mixed modelling approach to overcome pseudo replication within sites, by using generalized additive mixed model (GAMM). Accordingly, we tested the effects of anthropogenic variables (direct human activity, indirect human activity, land use types), habitat covariates (seasonality, fruit availability, tree species richness, distance to nearest water source, average size of fruits (cm)) on elephant presence and relative abundance using GAMM. Seasonality was modeled as categorical variable with four levels: rainy season, short rainy season, short dry season, or dry season. We also sought to test for the interacting effects between covariates to better understand whether, for example, elephant responses to fruit availability was influenced by land use types or season (Mills et al.

2018). Camera trap station ID was modeled as a random intercept in each model to account for repeated sampling within individual stations.

We used backward variable selection for both models, by sequentially dropping the single term with the highest non-significant p-value from the models and re-fitting, until all terms were significant (https://rdrr.io/cran/mgcv/man/gam.selection.html). Terms present in interaction terms could not be removed until the interaction term was removed (Supplementary Tables S3.2 & S3.3).

Continuous covariates were standardized to have a mean of 0 and standard deviation of 1, to facilitate comparison of their effects on elephant presence or relative abundance. The smoothing parameter of the model was set to be k = 4 for all variables. The elephant presence model was run with a logistic link function. Elephant relative abundance was fit using the Tweedie family with log link function. Covariates were tested for multicollinearity using Variance Inflated Factor (VIF) using car package (Fox and Weisberg 2019). GAMMs were run using MGCV package version 1.8-38 (Wood 2021) using the maximum likelihood method. When significant differences were found among different levels of a variable, we changed the reference level to be able to compare all pairs. All statistical analyses were performed using R v. 4.0.2 (R Core Team, 2020), with a 95% level of significance.

3.4 Results

Our camera trap survey included a total of 4510 camera trap days with elephants being detected on 159 of those days (see Supplementary Table S3.4). In all, 375 ha were surveyed for fruit availability and for tree species richness in line transects.

3.4.1 Forest elephant presence

As compared to Community Land (CL), forest elephant presence was significantly lower in Forest Management Unit (FMU) (p = 0.037; Table 1, Figure 2a) and National Park (NP) (p = 0.004; Table 1, Figure 2a), whereas they occurred similarly in FMU and NP (p = 0.088, Figure 2a). Forest elephant presence was positively associated with tree species richness (p

< 0.001, Table 2, Figure 2b) and distance to the nearest permanent river (*p* = 0.004, Table 2, Figure 2c). There was a significant interaction between fruit availability and land use types (*p* < 0.001, Figure 2d-f). Indeed, elephant presence in FMU was significantly and positively associated to fruit availability (*p* = 0.005, Table 2, Figure 2e) while fruit availability had no effect on elephant presence in CL or NP (all *p* > 0.05, Table 2, Figure 2d, Figure 2f).

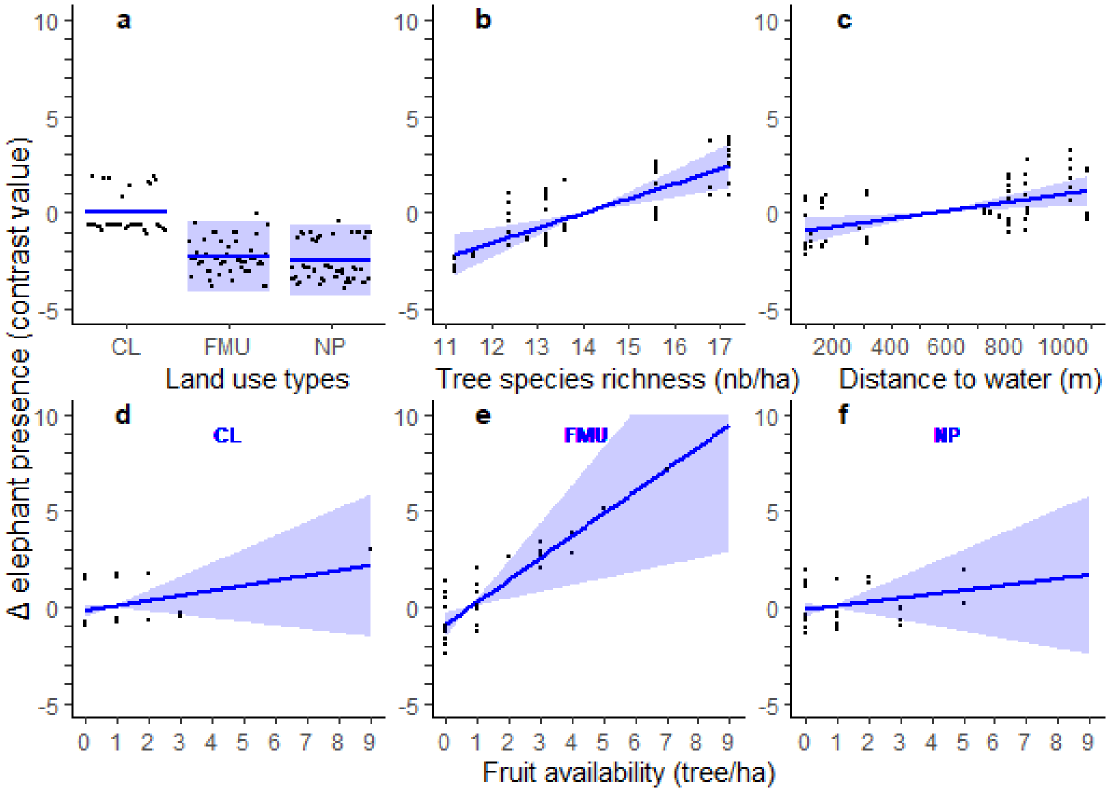


Figure 3.2 Relationship between forest elephant presence (contrast values of partial residuals) and land use types (a), tree species richness (number of species/ha) (b), distance to the nearest permanent river (m) (c) and the interaction between land use types and fruit availability (tree/ha) (d-f), Model estimates are based on generalized additive mixed effect model regression model. The parametric variable was land use types (CL, FMU, NP) and the non-linear variables were distance to the nearest permanent river (m), tree species richness (tree/ha) and the interaction between land use types and fruit availability. Camera trap station was modeled as the random effect and the contrast method was used to scale the response, hence the negative values in the Y-axis.

Table 3.1 Coefficient estimates of the results from generalized additive mixed model (GAMM) of elephant presence (response variable). R^2(adj) = 0.223, deviance explained = 25.3%, binomial family and logit link function, maximum likelihood (ML) = 68.485, Scale estimation = 1, n = 150. The reference level is CL. Significant coefficient estimates are noted in bold.

Explanatory variables	**Estimate**	**SE**	**Z value**	***p*-value**
Intercept	0.500	0.539	0.759	0.448
Land use type FMU	-1.643	0.788	-2.086	**0.037**
Land use type NP	-2.55	0.888	-2.878	**0.004**

Table 3.2 Approximate significance of smooth terms of the results of generalized additive mixed model (GAMM) of elephant presence (response variable). edf = effective degree of freedom for the model terms, Ref. df = estimated residual degree of freedom. (R^2(adj) = 0.223, deviance explained = 25.3%, binomial family and logit link function, maximum likelihood (ML) = 68.485, n = 150). Significant coefficient estimates are noted in bold.

Explanatory variable	**χ^2 test**	**Ref. df**	**edf**	***p*-value**
Species richness	16.485	1	1	**< 0.001**
Distance to perennial water	8.419	1	1	**0.004**
Fruit availability: Land use type CL	1.299	1	1	0.254
Fruit availability: Land use type FMU	7.872	1	1	**0.005**
Fruit availability: Land use type NP	0.619	1	1	0.431

3.4.2 Forest elephant relative abundance

Forest elephant abundance was lower in the FMU than in the CL and NP (both $p < 0.001$) but similar between CL and NP ($p = 0.136$, Table 3, Figure 3a). Seasonality influenced forest elephant relative abundance, ($p < 0.001$). Indeed, elephant relative abundance was higher during rainy season than in the short dry season ($p = 0.009$, Table 3, Figure 3b) but was similar for all other seasons (all $p > 0.05$, Figure 3b). Also, elephants were less abundant at camera trap stations where direct human activity was high ($p = 0.017$, Table 4, Figure 3c). There was a significant interaction between fruit availability and season ($p < 0.001$; Table 4, Figures 3d-f) as well as between fruit availability and land use types ($p < 0.001$; Table 4, Figures 3g-j).

Elephant relative abundance increased with fruit availability in CL (*p* < 0.001, Table 4, Figure 3d) and NP (*p* < 0.001, Table 4, Figure 3f) but not significantly in FMU (*p* = 0.252, Table 4, Figure 3e). The relationship between fruit availability and elephant relative abundance changed according to seasons (Table 4, Figure 3g-j), with the relationship being negative in the rainy season (*p* = 0.027, Table 4, Figure 3i).

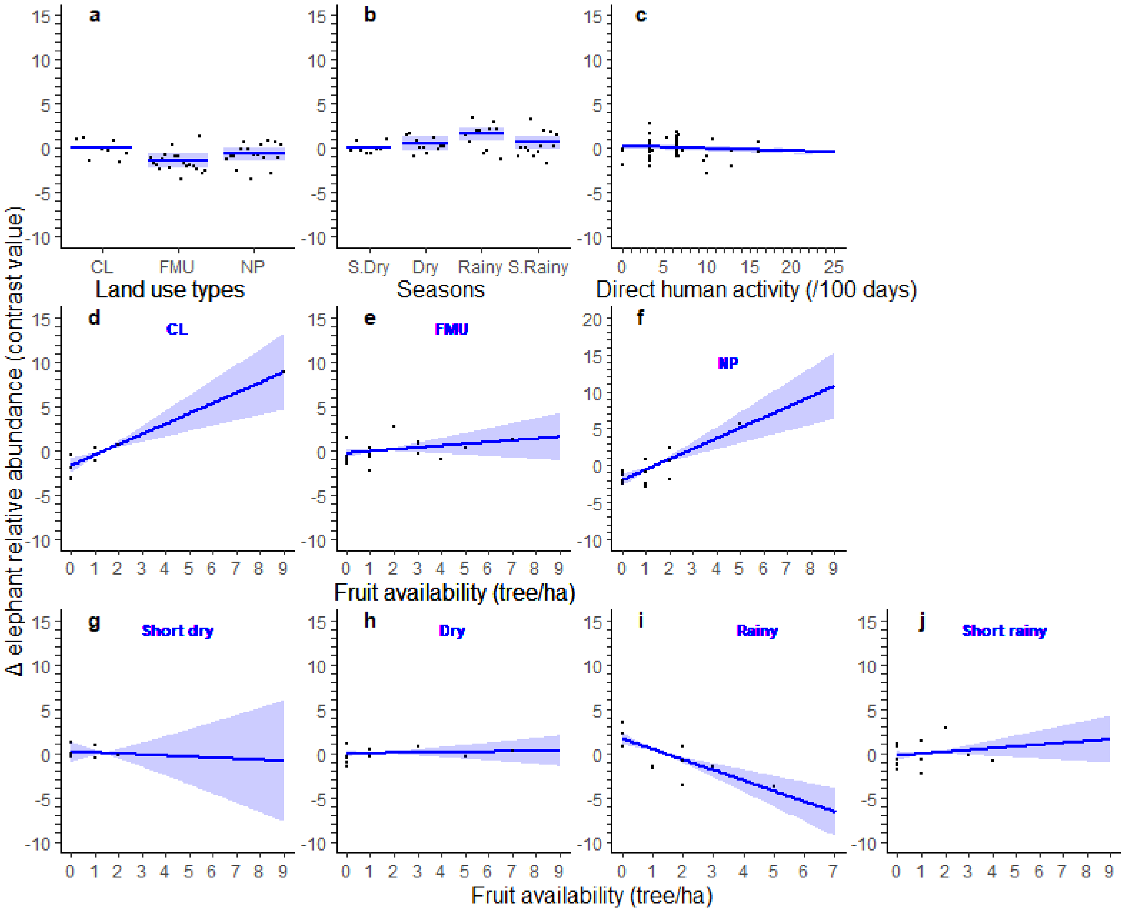


Figure 3.3 Relationship between forest elephant relative abundance (contrast value of partial residuals) and land use types (a), seasons (b), human activity rate (/100 days) (c), and interactions between fruit availability(tree/ha) and land use types (d-f), fruit availability and seasons (g-j). Model estimates are based on generalized additive mixed model regression model. Parametric terms were Land use types (CL, FMU, NP) and seasons (dry, short rainy and short dry and rainy) and non-linear terms were human camera trapping rate, the interactions between seasons and fruit availability and between fruit availability and land use types.

Table 3.3 Coefficient estimates from generalized additive mixed model (GAMM) of elephant relative abundance (response variable). R^2(adj) = 0.468, deviance explained = 54.1%, Tweedie family (power parameter p = 1.583) with log link function, maximum likelihood (ML) = 138.61, scale estimation = 2.093, n = 45, (see method for model). The reference levels are CL and short dry season. Significant estimates are noted in bold.

Explanatory variables	**Estimate**	**SE**	**t value**	***p*-value**
Intercept	3.189	0.485	6.576	**< 0.001**
Land use type FMU	-1.750	0.463	-3.777	**< 0.001**
Land use type NP	-0.548	0.359	-1.528	0.136
Dry season	0.541	0.512	1.057	0.298
Rainy season	1.196	0.427	2.799	**0.008**
Short rainy season	0.730	0.486	1.504	0.142

Table 3.4 Approximate significance of smoothing terms of the results of generalized additive mixed model (GAMM) of elephant relative abundance (response variable). edf = effective degree of freedom for the model terms, Ref. df = estimated residual degree of freedom. (R^2(adj) = 0.468, deviance explained = 54.1%, Tweedie family (power parameter P = 1.583) with log link function, maximum likelihood (ML) = 152.01, scale estimation = 2.093, n = 45, (see method for the model). Significant coefficient estimates are noted in bold.

Smoothing terms	**edf**	**Ref. df**	**F test**	***p*-value**
Fruit availability: short dry season	1.001	1.001	0.500	0.484
Fruit availability: short rainy season	0.002	0.004	0.045	0.989
Fruit availability: dry season	1.015	1.030	0.734	0.400
Fruit availability: rainy season	1.007	1.013	23.036	**< 0.001**
Fruit availability: Land use type CL	1.003	1.005	16.486	**< 0.001**
Fruit availability: Land use type FMU	1.009	1.018	1.327	0.252
Fruit availability: Land use type NP	1.013	1.025	22.114	**< 0.001**
Direct human activity	1.053	1.103	6.361	**0.017**

3.5 Discussion

Both elephant presence and relative abundance were positively influenced by fruit availability, suggesting that the pattern of habitat use by forest elephants is driven, in part, by the availability of the fruits they consume. However, elephant local abundance decreased in long rainy season when they are more scattered due to the diversity and the spread of food resources. In our study area, fruits availability is seasonal, and habitat use is influenced by tree species richness which is patchily distributed in all land use types. Direct human activity was negatively related to elephant relative abundance, suggesting that human and forest elephants may avoid each other although they spatially overlap in the southwest part of the CMTOU. Our results highlight the importance of fruits for forest elephants, similar to other findings that fruit availability is an important driver of habitat use by forest elephants (White 1994; Blake and Inkamba-Nkulu 2004; Blake 2002; Mills et al. 2018; Poulsen, Rosin, et al. 2017; Bush et al. 2020).

Contrary to our expectations, the likelihood of elephant presence was higher in the CL than the FMU and the NP whereas their relative abundance was negatively related to direct human activities dominated by wood logging and hunting. During periods of logging, human disturbances (noise from machinery, felling of trees, creation of tracks, etc.) are particularly high, and forest elephants may avoid overlapping with those areas, especially if human are present. This suggests that, if intensified, certain types of human activity may have a strong influence on elephant habitat use in our study area as has been already reported elsewhere (Poulsen et al., 2011; Puyravaud et al., 2019). This presence of forest elephants in CL may suggest a trade-off between risk of mortality associated with human presence and access to food resources in secondary forest (CL and FMU). Indeed, areas subject to human-induced habitat disturbances, such as cropping lands in the CL and wood logging in FMU provide feeding opportunities for forest elephants (Breuer and Ngama, 2020; Grantham et al., 2020; Poulsen et al., 2011). Elephants frequently occurred in the FMU and in the CL where they feed along the dead-end skidding trails in logging concession and human food crops as also shown in Gabon (Mills et al. 2018; Breuer and Ngama 2020; Ngama et al. 2018). However, our results are contrary to the study by Tudge et al. (2022), that did not detect forest elephants, reported to be rare (Brittain et al. 2022), in some community forests around Dja Biosphere Reserve in southeast Cameroon where human activity is greater (Amin et al. 2020; Poulsen, Koerner, et al. 2017). In our study area, the risk of elephants being killed by farmers in CL might be reduced because rangers frequently patrol this southwest area of the CMTOU which is where the conservation head office is located. In contrast, the east side of the park is not patrolled to the same extent and may be perceived by elephants as less safe. Previous studies have noted a low density of large mammals in this part of the CMTOU as a result of human disturbances (Matthews and Matthews 2006; Eyebe, Dkamela, and Endamana 2012). Also, signs of human presence (hunting, machete cut, trail, gathering) have been on the rise in the FMU and to a lower extent the NP (Nzooh-Dongmo et al. 2015). Indeed, in NP and FMU, images of poachers with hunting tools were frequently detected and the theft of five of our camera traps occurred inside the NP. The removal of our camera traps by some people was presumably to cover up illegal activities. As mentioned earlier, human activities are permitted in the CL (MINFOF 2014). In southeast Cameroon, Dancer (2019) found that parks are targeted by poachers; the lack of funding usually does not allow for permanent surveillance by rangers compared to FMU. Therefore, the lack of detection of forest elephants in community forests which is part of the CL in the southeast of Cameroon as reported by Tudge et al. (2022), suggest that, compared to our study area, the pressure on forest elephants might be low enough to allow them to occur in all land use types. Also, forest elephants were detected at least once every month in each land use types. This continued presence suggests that forest elephants are year-round residents, with enough food resources to sustain themselves, contrary to elephants elsewhere for which seasonal migration may be driven by fruit availability (White 1994). Forest elephant habitat use is tied to fruiting phenology (Blake 2002; White, Tutin, and Fernandez 1993) and elephant presence was more tightly related to fruiting in FMU where, on average, fruit availability was higher. Fruit availability peaked in the long rainy season. The effect of the variation in fruit availability between long and short rainy seasons on elephant relative abundance was marked between September and October, which is also the period when logging activity peaked and reports of crop raiding by elephants were highest (Ole 2011).

The distance to nearest permanent water sources correlated positively with the presence of forest elephants (Figure 2c) ranging from 100 to 1090 m. This result contradicts our prediction that distance to perennial rivers had no effect on elephant presence as the area has been reported water rich. However, it corroborates the pattern reported in Gabon where elephants move farther from perennial water sources during wet seasons in response to the reduced limitation of water supply (Mills et al. 2018).

Our findings illustrate the ability of elephants to adapt to some level of human disturbance, yet also highlight the need to monitor forest elephants in CL and FMU because their presence could lead to conflicts with humans (Breuer and Ngama, 2020, Puyravaud et al., 2019). Repeated crop raiding has been previously documented in this area and led to retaliatory killing of elephants (PNCM 2017).

3.6 Implications for conservation

Tree species richness and fruit availability affected forest elephant presence and relative abundance. Indeed, forest elephant (Figure 4) presence was associated with fruit availability, some of which fruit trees are present in all land use types (e.g. Sacoglottis gabonensis) with spatial and seasonal variations in fruit production. Such variability represents a significant change in fruit availability for forest elephants who rely on them for food. We found forest elephants occurring mostly in CL, especially during harvesting period which corresponds to the period when farmers also reported incidence of crops raiding. During that period, farmers are afraid of encountering forest elephants, and may make fewer visits to the forest where they normally go to gather fruits and other non-timber forest products (Ole 2011; MINFOF 2014). This indicates that forest elephants might have adapted to using the multipurpose land in our study area as feeding site.

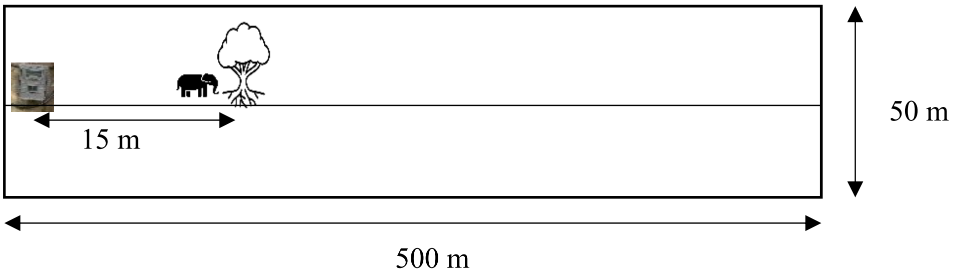
Figure 3.4 Sample camera trap images of forest elephants from the Campo-Ma’an Technical Operational Unit, Cameroon.

Even though people are prohibited from entering the NP, we noted frequent human presence, highlighting the need to strengthen the enforcement of laws forbidding their entry. Increased presence of park rangers in NP and FMU will be critical for the persistence of forest elephants in the study area as this can help to reduce the illegal killing of wildlife in the area. Besides increased patrolling, there is also a need to simultaneously increase engagement with local people and developing income-generating activities (e.g. beekeeping and chili farming) for them, other than hunting, and to create mechanisms that allow them to benefit from the park. For example, law enforcement can be accompanied with a push-pull like strategy, typically used to control unwanted animal in agricultural lands (Cook et al. 2017), which over time, create attractive feeding conditions for forest elephants in the NP and FMU where they could be more secure (Neupane, Johnson, and Risch 2017). This push-pull strategy may consist of planting fruiting trees known to be preferred by elephants in order to favor their movement in the NP and FMU, away from edges (pulling strategy), while progressively cutting some fruiting trees (not those commonly consumed by human) in or close to CL around farms following an approved and well-tested method. A similar approach has been proposed to mitigate human – elephant conflict in Nepal (Neupane, Johnson, and Risch 2017).

Our study also highlights the value of using camera traps for monitoring wildlife and the need to establish long-term research in the whole CMTOU. Palm oil plantations are predicted to overtake logging as one of the main forms of landscape disturbance in the study area. Therefore, predicting the potential impacts of large scale agro-industrial farms on forest elephants is crucial for the development of effective management and conservation strategies.

3.7 Supplementary materials

Appendix S3.1 Diagram of camera trap placement in relation to band transects surveyed for plant species richness. Transect bands were 50m wide and 500m long. Transects length ran in 120° or 300° directions from each camera placed at 15m from target trees or road.



Supplementary Table S3.1. Land use types, level and type of disturbances, human accessibility, predictions, and reference to literatures sustaining the prediction.

Land use types	**Level and type of human disturbances**	**Human Accessibility**	**Abundance and presence predictions. References**
CL	**Higher:** Gathering of non-timber forest products, hunting, agriculture, housing, development projects, logging.	All communities Extractive companies; rangers	**Absent – low :** Tudge et al., 2022 ; Brittain et al., 2022, Eyebe et al., 2012; Matthews and Matthews, 2006; MINFOF, 2014
FMU	**Medium:** research, tourism, cultural activities, gathering of non-timber forest products in identified and limited area for authorized community, logging.	Logging company workers; rangers; researchers; Bagyeli (Vulnerable communities) and authorized communities	**Medium - high** Brittain et al., 2020 Eyebe et al., 2012; Matthews and Matthews, 2006; Nzooh-Dongmo et al., 2015; MINFOF, 2014
NP	**Lower:** research, tourism, cultural activities, gathering of non-timber forest products in identified and limited area for authorized community	Only the *Bagyeli* community Researchers, tourists, rangers	**High :** Amin et al., 2020 Bruce et al., 2020 Nzooh-Dongmo et al., 2015; Eyebe et al., 2012; Matthews and Matthews, 2006; MINFOF, 2014

Supplementary Table S3.2. Model selection to predict the occurrence of forest elephants Campo-Ma'an conservation area. Each removed factor is followed by the associated *p*-value. k = number of knots (smoothing parameter) and ML = maximum likelihood. EP = Elephant presence, LT = Land use types, S = Season, FA = Fruit availability, IHS = Indirect human signs, HTR = Human trapping rate, DW = Distance to water, MFS = Mean fruit size and SR = Specie richness.

Model	**Removed factors and *p*-values**
Full model: gam1_0<-gam(EP ~ LT + S + s(s_FA, by = S, k = 4) + s(s_FA, by = LT, k = 4) + s(s_IHS, k = 4) + s(s_HTR, k = 4) + s(s_SR, k = 4) + s(s_DW, k = 4) + s(s_MFS, k = 4), random = ~ (1|Sites), data = data, family = binomial, method = "ML")	
gam1_1<-gam(EP ~ LT + S + s(s_FA, by = S, k = 4) + s(s_FA, by = LT, k = 4) + s(s_IHS, k = 4) + s(s_HTR, k = 4) + s(s_SR, k = 4) + s(s_DW, k = 4), random=~(1|Sites), data=data, family=binomial, method="ML")	s(s_MFS, k = 4) ***p*** = 0.844
gam1_2<- gam(EP ~ LT + S + s(s_FA, by = S, k = 4) + s(s_FA, by = LT, k = 4) + s(s_HTR, k = 4) + s(s_SR, k = 4) + s(s_DW, k = 4), random=~(1|Sites), data=data,family=binomial, method="ML")	s(s_IHS, k = 4) ***p*** = 0.586
gam1_3<- gam(EP ~ LT + S + s(s_FA, by = S, k = 4) + s(s_FA, by = LT, k = 4) + s(s_SR, k = 4) + s(s_DW, k = 4), random=~(1|Sites), data=data,family=binomial, method="ML")	s(s_ HTR, k = 4) ***p*** = 0.279
gam1_4<- gam(EP ~ LT + S + s(s_FA, by = LT, k = 4) + s(s_SR, k = 4) + s(s_DW, k = 4), random=~(1|Sites), data=data,family=binomial,method="ML")	s(s_FA, by = S, k = 4) : All ***p*** > 0.05
Reduced model: gam1_5<- gam(EP ~ LT + s(s_FA, by = LT, k = 4) + s(s_SR, k = 4) + s(s_DW, k = 4), random=~(1|Sites), data=data, family=binomial, method="ML")	S All ***p*** > 0.05

Supplementary Table S3.3. Model selection for predicting forest elephants use of habitat in Campo-Ma'an conservation area. Each removed factor is followed by the associated *p*-value. tw = Tweedie family, k = smoothing parameter and ML = maximum likelihood. ETR = Elephant trapping rate, LT = Land use types, S = Season, FA = Fruit availability, IHS = Indirect human signs, HTR = Human trapping rate, DW = Distance to water, MFS = Mean fruit size and SR = Specie richness.

Models	**Removed factors** ***P*-values**
Full model: gam2_0<-gam (ETR~ LT + S + s(s_FA, k=4) + s(s_FA, by = S, k=4)+ s(s_FA, by = LT , k=4) + s(s_IHS, k=4)+ s(s_HTR, k=4)+s(s_SR, k=4) + s(s_DW, k=4) + s(s_MFS, k=4), random=~(1|Sites), data=data%>%filter (Presence==1), family =tw(), method="ML")	
gam2_1<-gam (ETR~ LT + S + s(s_FA, k=4) + s(s_FA, by = S, k=4)+ s(s_FA, by = LT , k=4) + s(s_IHS, k=4)+ s(s_HTR, k=4)+s(s_SR, k=4) + s(s_MFS, k=4), random= ~(1|Sites), data=data%>%filter (Presence==1), family =tw(), method="ML")	s(s_DW, k=4) *p* = 0.761
gam2_2<-gam (ETR~ LT + S + s(s_FA, k=4) + s(s_FA, by = S, k=4)+ s(s_FA, by = LT , k=4) + s(s_IHS, k=4)+ s(s_HTR, k=4)+s(s_SR, k=4), random=~(1|Sites), data=data%>%filter(Presence==1), family=tw(),method="ML")	s(s_MFS, k=4) *p* = 0.594
gam2_3<-gam (ETR~ LT + S + s(s_FA, by = S, k=4)+ s(s_FA, by = LT , k=4) + s(s_IHS, k=4)+ s(s_HTR, k=4)+s(s_SR, k=4), random=~(1|Sites), data=data%>%filter(Presence==1), family= tw(),method="ML")	s(s_FA) ***p*** = 0.695
gam2_4<-gam (ETR~ LT + S + s(s_FA, by = S, k=4)+ s(s_FA, by = LT , k=4) + s(s_IHS, k=4)+ s(s_HTR, k=4)+s(s_SR, k=4), random=~(1|Sites), data=data%>%filter(Presence==1), family= tw(),method="ML")	s(s_SR) ***p*** = 0.087
Reduced model: gam2_5<- gam (ETR~ LT + S + s(s_FA, by = S, k=4)+ s(s_FA, by = LT , k=4) + s(s_HTR, k=4)+s(s_SR, k=4), random=~(1|Sites), data=data%>%filter(Presence==1), family= tw(),method="ML")	s(s_IHS) ***p*** = 0.411

Supplementary Table S3.4. Summary of camera traps (CT) effort across different land use types. [.] represents the number of camera traps set to video mode for which data were excluded from analysis. (.) represents the number of additional camera traps bought to replace some of the stolen camera traps.

Land types	**Community Land (CL)**	**Forest Management Unit (FMU)**	**National Park (NP)**	**Overall**
Number of CT stations [CT set to videos]	4 [1]	6	7 [1]	19
Number of CT stolen (replacement)	1	1	5(3)	7 (3)
Expected number of CT days	1460	2190	2555	6205
Realized number of CT days	1022	1793	1695	4510
Percent realized (%)	70	81.87	66.34	72.68
Overall number of month expected	48	72	84	204
Overall number of month realized	34	59	57	150
Overall number of elephant photographs	554	2378	1902	4834
Overall number of elephant independent events	29	99	100	228
Mean capture rate (Mean ± SD) per 100 CT days	3.1 ± 6.2	5.5. ± 19.8	5.7 ± 15.6	5.04 ± 15.9

Chapter 4 Combining local ecological knowledge and field investigations to assess diet composition and feeding habit of forest elephants in Campo-Ma'an National Park, southern Cameroon.

The following chapter is based on the published manuscript: Djoko, IB, Weladji, RB and Paré P (2022). Combining local ecological knowledge and field investigations to assess diet composition and feeding habit of forest elephants in Campo- Ma'an National Park, southern Cameroon. *International Journal of Biodiversity and Conservation*, *14*(3), 103–114. https://doi.org/10.5897/IJBC2022.1549.

4.1 Abstract

Forest elephants are nocturnal and elusive animals, making it difficult to perform direct observations on them. Data on elephants' diet and feeding habit are lacking despite most forest elephants' habitats being lost to anthropogenic activities; yet such knowledge may be important for their conservation, particularly in a human dominated landscape. Local ecological knowledge and field investigations were combined to assess diet composition and feeding habit of forest elephants in Campo-Ma'an landscape. The study also aimed to evaluate the level of concordance between the two approaches. The study reports that forest elephants in Campo-Ma'an feed on 87 plants species, including crops. Twenty-two of these plant species were reported by both methods, most of them being potential drivers of human-elephant conflict as they are simultaneously used by humans and elephants. Also, field investigations revealed that, to satisfy their energy requirements, forest elephants relied mostly on leaves and fruits during the wet seasons and mostly on barks from trees during the dry seasons. Overall, the two methods appeared to be complementary, despite field investigations yielding fewer species, as we only covered the park partially. We suggest that combining both methods could be a cost-efficient way to address forest elephants ecological and management questions.

Keywords: Indigenous knowledge, *Loxodonta cyclotis*, plants species consumed, traditional knowledge.

4.2 Introduction

Forest elephants (*Loxodonta cyclotis*) are now classified as critically endangered (IUCN 2021) and up to 57.4% of their potential range is found outside protected areas (Wall et al. 2021). Indeed, landscape modification can be critical for wide-ranging elephants whose existence depend on habitat conditions (Koirala et al. 2016; Mmbaga, Munishi, and Treydte 2017; Doumenge, Palla, and Itsoua Madzous 2021). Elephants are generalist feeders (Choudhury et al. 2008) with large body mass, and therefore need large range to collect their food (Biru and Bekele 2012) and can spend up to 18h per day searching for food (Campos-Arceiz and Blake 2011; Jin et al. 2006; Leggett 2009; Sach et al. 2019). It may be a challenge to satisfy their needs in an environment where habitat is increasingly being lost, resulting in reduced food availability for elephants (Koirala et al. 2016). Accordingly, they feed on different biological types of plants ranging from roots/tubers and grasses to trees of different species, depending on the seasons and the ecosystems (Kouamé et al. 2011; Koirala et al. 2016; Biru and Bekele 2012; De Boer et al. 2000). The bulk of elephant's diet come from leaves (Short 1981; Kabigumila 1993) and fruits (White 1994; Campos-Arceiz and Blake 2011; Blake and Inkamba-Nkulu 2004). However, various proportions of roots, barks, stems, branches, twigs and flowers are also consumed by elephants (Short 1981; Biru and Bekele 2012; Koirala et al. 2016; White, Tutin, and Fernandez 1993; Kabigumila 1993). Forest elephants have been reported feeding on more than 500 plant items in Ndoki National Park, Congo (Blake 2002), 307 food items in the Lopé Reserve, Gabon (White, Tutin, and Fernandez 1993), and on at least 33 fruiting tree species in Odzala National Park, Republic of Congo (Maurois, Chamberlan, and Maréchal 1997). Moreover, preferences for some key tree species such as *Sacoglottis gabonensis* (White 1994; Ngama et al. 2019), *Irvingia gabonensis*, *Pseudospondias macrocarpa*, *Ballonella toxisperma, Dusboscia macrocarpa, Parinari excelsa* (Blake 2002; Maurois, Chamberlan, and Maréchal 1997; Ngama et al. 2019; Campos-Arceiz and Blake 2011) have been reported. In Cameroon, studies on diet and feeding habit of elephant are very limited and mostly described for savanna elephants with Tchamba (1996) and Foguekem et al. (2011) reporting respectively 45 and 20 plant species consumed by savanna elephants in the Waza Logone area. As for forest elephants, Tchamba and Seme (1993) reported 22 fruiting tree species as part of their diet in the Santchou Reserve. Primary data on diet and feeding habit of forest elephants from direct observation can be challenging to obtain due to their low population density, nocturnal lifestyle, and their elusive nature (Kambissi 2010; Service et al. 2014). However, local people might have knowledge from their long-time interactions with nature (Service et al. 2014). This has prompted the use of alternative and less invasive methods, such as Local Ecological Knowledge (LEK) in elephant ecology (Biru and Bekele 2012; Buchholtz et al. 2020). LEK provide reliable, timely and cost-effective data from communities living nearby and interacting with nature (Albuquerque et al. 2021; Pan et al. 2016; Allendorf et al. 2020; Brittain et al. 2020; Service et al. 2014; Buchholtz et al. 2020). LEK surveys can reduce the risk of research equipment such as camera traps being stolen (such as, Caravaggi et al., 2017).

LEK surveys can facilitate the rapid understanding of threats to wildlife, resulting in faster decision-making (Albuquerque et al. 2021; Haenn et al. 2014; Buchholtz et al. 2020). For example, LEK has been used for rapid assessment of the status and threats to pangolin (*Manis pentadactyla*) (Nash, Wong, and Turvey 2016) and to study range shift of grizzly bear (*Ursus arctos horribilis*) (Service et al. 2014), wildlife presence and abundance, and identification of areas where conservation actions are needed (Allendorf et al. 2020), occupancy and distribution of wildlife (Service et al. 2014; Haenn et al. 2014), and even to study elephant diet in Ethiopia (Biru and Bekele 2012) and to predict landscape use by elephants in Botswana (Buchholtz et al. 2020). Nevertheless, LEK remains an undervalued source of information for diet and feeding habit of forest elephants. While it has been used in Botswana to model the land use pattern by savanna elephants (Buchholtz et al. 2020), in the entire Congo Basin, study on elephant diet and feeding habit using LEK is limited. In

Cameroon, interviews and field investigations were recently used in Nki National Park to study forest elephants feeding pattern (Ndi, Fonkwo, and Kinge 2022). LEK has been combined with occupancy analyses to study the reliability and suitability of LEK in rapid assessments of forest elephants occupancy in timber logging concessions (Brittain et al. 2020) and LEK studies focused mainly on pangolins. Indeed, Fopa et al. (2020) assessed local ecological and traditional medicine knowledge of pangolins, (*Smutsia gigantea, Phataginus tricuspis, Phataginus tetradactyla*) as well as the level of conservation awareness amongst local people around Deng-Deng and Mpem et Djim National Parks, whereas Simo et al. (2020) used LEK to tailor camera traps surveys to improve the detectability of pangolin. Similarly, Mouafo et al. (2021) investigated local peoples' knowledge of pangolin presence, perceptions of population trends, cultural importance, consumptive, and non-consumptive uses, as well as hunting of pangolins. In the CMTOU, studies referring to food for elephants focused on food crop damaged by wildlife including forest elephants using indirect observation methods such as interviews and field visits (Eyebe et al., 2012; Ole, 2011). Much is known about savanna elephant diet, particularly with respect to plant species consumed, their diversity and distribution, their feeding habit, and more importantly the impacts of seasons on their ranging behavior (Blake 2002). Indeed, forest ecosystem are more diverse, and therefore offer more fruits and other plant items that make up the diet of forest elephants. Moreover, forest habitats are generally not subject to water and mineral shortage as it is the case in savanna (Blake 2002). To know the elephants' diet and feeding habit in the perspective of sustainable food supply is an important conservation goal especially in areas where land-use change can cause loss of key resources (Puyravaud et al. 2019). Campo-Ma'an conservation area is plagued by increasing degradation of wildlife habitat, which would be better known to communities living nearby but less understood by scientists and decision makers. To fill this gap, this study combines LEK and field surveys to assess elephant's diet composition and feeding habit in Campo-Ma'an conservation area. Specifically, we will (1) assess which plant species and parts are reported by local population as being consumed by elephants, (2) determine through field investigations which plant species and plant parts have signs of browsing by elephants, (3) assess the level of co-occurrence in terms of plant species between the two methods as well as their relevance and, (4) identify the influence of the seasons on field surveys of feeding habit. LEK is powerful at the local scale in understanding the resources used by elephants as people interact or share resources with them (Puyravaud et al. 2019). Therefore, the most reported plant species by LEK method are expected to be confirmed or validated by field surveys, or vice versa.

4.3 Method

4.3.1 Study area

The Campo-Ma’an National Park (CMNP), 264,064 ha, and its peripheral zone covers about 770,000 ha. There are about 111,000 inhabitants from six main native ethic groups and 17 other ethnic groups. This area is located between 2°10’N, 9°50’E and 2°25’N, 10°48’E, in the Southern Region of Cameroon (Figure 4.1).

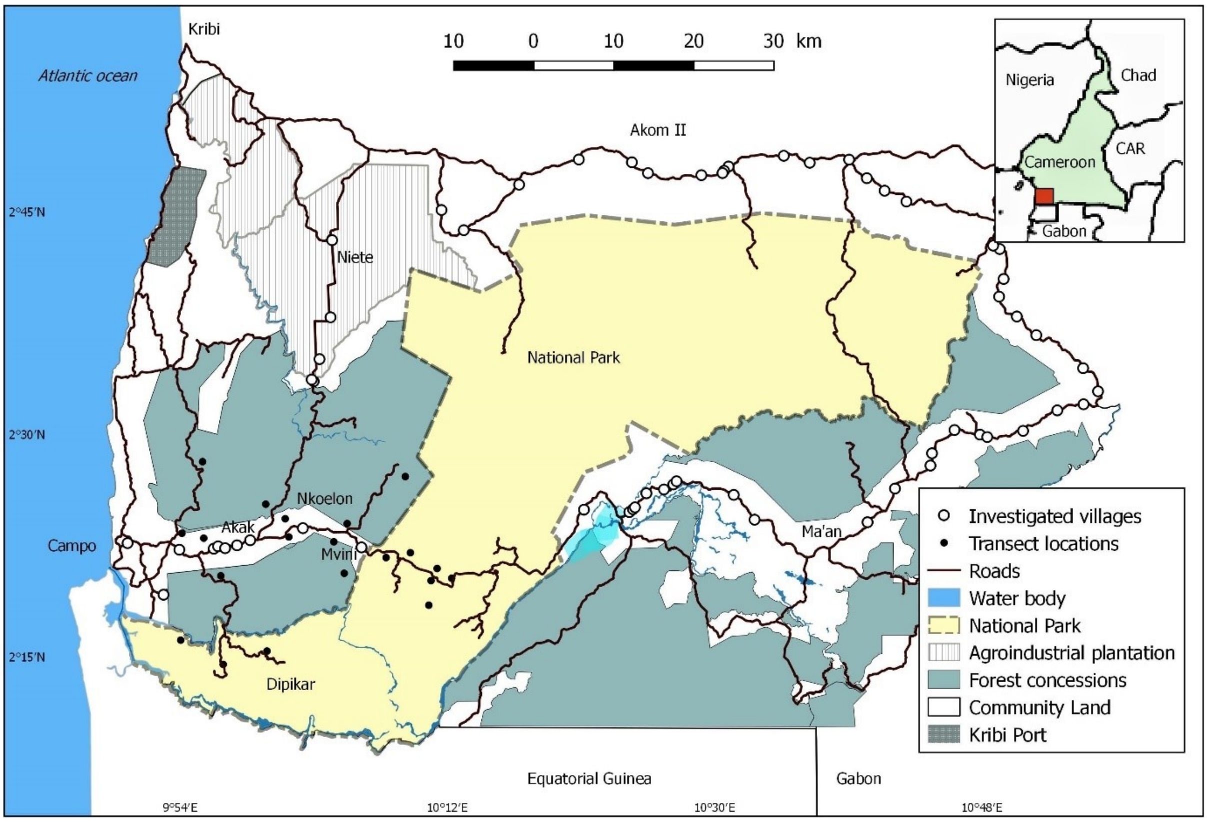


Figure 4.1 Location of study site and different human land use types in the Campo-Ma'an Technical Operational Unit that encompass the park and its multipurpose use peripheral area. Investigated villages, camera positions and transect lines.

The climate is coastal equatorial characterized by two dry seasons and two rainy seasons. The mean annual precipitation is about 2,500 mm and the mean temperature is 25°C. Many streams, river branches and swampy areas make the study area water rich (MINFOF 2014; Tchouto 2004). The vegetation consists mainly of old secondary forest, but patches of primary forest of the dense humid evergreen type still occur and the area has a high level of endemism and plant species diversity. There are about 2,297 vascular plant species and ferns of which 29 species are endemic to the conservation area (MINFOF 2014; Tchouto 2004). About 249 plant species are Non-Timber Forest Products and 112 trees species are commercially logged (such as *Lophira alata, Erythrophleum ivorense, Guibourtia ehie, Pterocarpus soyauxii, Piptadeniastrum africanum, Dalium bipindensis, Lovoa trichilioides*). Logging opens the forest, giving way to the growth of pioneer tree species such as *Alchornea cordifolia, Anthocleista* *shweinfurthii, Bridelia micrantha, Harungana madagascariensis, Musanga cecropioides, Trema occidentalis and Macaranga* spp.*,* species on which herbivores rely for food (Tchouto et al. 2009; Bekhuis, De Jong, and Prins 2008). In degraded areas, herbaceous species such as *Chromolaena odorata, Lycopodiella cernua, Nephrolepis bisserata, Selaginella myosurus* are generally found surrounding woody trees left standing in secondary vegetation. Maranthaceae, Costaceae and Zingiberaceae families are mostly found along the abandoned logging paths and swamps (Tchouto 2004). The area harbors threatened wildlife species, among which the forest elephant population, estimated at 544 [425-695] individuals (Nzooh-Dongmo et al. 2015).

4.3.2 Data collection

Open field with high visibility favor direct observation in diet studies (Biru and Bekele, 2012; Sach et al., 2019; Tchamba et al., 2014; Weladji and Tchamba, 2003). In forest area, visibility is limited by the dense vegetation and thick foliage, making it difficult to spot elusive and low-density species such as forest elephant (White, Tutin, and Fernandez 1993; Blake 2002). Here we use (1) semi structured interviews for LEK and (2) field investigations to assess diet composition and feeding habit.

4.3.2.1 Local Ecological Knowledge surveys

LEK data were collected from June through August 2018 using key informant interviews (village chiefs) and questionnaires to villagers. From the 162 villages surrounding the park, 54 village chiefs authorized us to carry out the research in their hamlet. When we later came back to administer the questionnaires, we only found people in 23 villages, from which 98 households were interviewed based on their willingness to take part to the research, which they confirmed by reading and signing the consent form (Supplementary material S4.1). Efforts were made to interview heads of households, their wives or any adult male and female (>18 years old, the adulthood age in Cameroon (Patrice 2019)) due to their high likelihood of encountering elephants during wood logging, farming, hunting and gathering activities (Tiani, Akwah, and Nguiébouri 2005; Buchholtz et al. 2020) or their ability to learn from their seniors or parents (Gilchrist et al. 2005). Also, women (27%) were interviewed because of their participation in game hunting and gathering activities (Tiani, Akwah, and Nguiébouri 2005; Martin et al. 2020). Interviews were conducted in French wherever possible, as most people were fluent in French. In one instance, the respondent, a Bagyeli household, did not speak French, and we used a local interpreter. The interview consisted of semi-structured questionnaire similar to Granados and Weladji (2012) during which the respondent answered questions about elephant food habit, local or commercial names of plant species and/or parts consumed (foliage, root/tubers, stems, barks and fruits), and the corresponding season (wet or dry) (Biru and Bekele 2012; Koirala et al. 2016). Because the scope of the study was broader, involving human-elephant interactions, each interview lasted about 45 min.

4.3.2.2 Field surveys

Twenty transects of 2.5 ha each (500 x 50 m) were surveyed for a total coverage of 50 ha/month during 12 consecutive months from June 2019 to May 2020. Transects were delimited with discrete markers and all woody plant species examined for bark-stripping. Following Koirala et al. (2016), opportunistic surveys on food plants were also carried out each month along the tracks leading to the transect locations. Elephant feeding sites can be identified by tracks or food scraps. Conspicuous feeding such as uprooting or breaking plants stems and branches, pulling down climbing plants or stripping leaves are some characteristics of elephants feeding sites (Campos-Arceiz and Blake 2011; Short 1981; Biru and Bekele 2012; Koirala et al. 2016; White, Tutin, and Fernandez 1993). However, it was not always easy to disentangle elephant browsing signs from those of other herbivores. Therefore, additional steps were taken, such as assessing the presence of elephants' footprints, identifying fresh elephants' dung piles near leaves, stems and fruits with signs of consumption, or by visually assessing and characterizing the impact on the damaged plant (Koirala et al. 2016). Visual and physical investigations of dung piles using a stick were also performed whenever possible to identify undigested seeds (Biru and Bekele 2012). Caution was taken to avoid reconsideration of debarking signs during consecutive monitoring of transects whereas all other observations were considered independent from the previous visits. Plant parts were identified with local, commercial and/or scientific names to at least the genus level with the help of field assistants when necessary and recorded along with parts eaten, the day and month of the observation. Where specimens could not be identified in the field, they were collected and later identified at the Cameroon National Herbarium.

4.3.2.3 Validation of some consumed plants

In addition to transects, 9 camera traps were placed under identified fruiting trees (such as, 5 *Saccoglottis gabonensis, 2 Tieghemella africana* and *2 D. macrocarpa*) reported as preferred fruit trees during LEK surveys and were active from May 2019 to July 2020, 24 hours/day. Stations were chosen based on prior knowledge of the area by a team of four field assistants (3 local trackers/hunters, and 1 forest warden) able to identify trees and areas potentially or known to be used by elephants. Herbivores in forest are likely to use road verges to browse (Bekhuis, De Jong, and Prins 2008), or fruiting trees as feeding sites (Blake and Inkamba-Nkulu 2004). Accordingly, camera traps were set 80 to 150 cm in height, angled horizontal and approximately 5 to 15 m away from target features (such as, roads, fruiting trees). The quiet period was set to three seconds for photos (that is the trigger delay between consecutive photos) and a maximum of 60 seconds for videos. Camera trap photos and videos were date and time stamped.

4.3.3 Data analysis

Data from LEK surveys and field investigations were verified for spelling of local names and cross tabulated with one plant part per row. Botanists were consulted to identify unknown species. The local or commercial names of the plants reported eaten by elephants were searched for scientific names using Vivien and Faure (2011) or the Plant Resources of Tropical Africa database (https://www.prota4u.org/database/) mostly for non-commercial species. Scientific names were reported following Angiosperm Phylogeny Group classification system (The Angiosperm Phylogeny Group 2009). For species that were still unidentified, we consulted the National Herbarium using dried plant samples or images. After this stage, any remaining unidentified species was removed from the list. Data were grouped into taxonomic family, scientific names, local name and parts consumed (Biru and Bekele 2012), and biological types. For field investigations, plant parts with signs of elephant browsing during each monthly field visit were considered independent observations. In this study, while elephants' diet refers to the plant species known as consumed by elephants, feeding habit refers to the variety of plant parts and proportions, on which elephants rely for food on a seasonal basis. Diet composition, which refers to different plant species providing food for elephants were identified and grouped by taxa, biological types and feeding habit, which is the distribution of different plant parts eaten over time (stems, leaves, barks, fruits, tubers). Data were grouped into a contingency table and relative frequency of feeding signs were calculated for each plant part, and subject to chi-square analysis. When a cell in the contingency table had only a small number of counts, Fisher exact tests were used instead. We also assessed co-occurrence between the LEK and the field survey approaches by comparing the diet and the pattern of feeding habit obtained from each method. Images or videos of elephants feeding on plant species were examined for identification and validation of plant species and parts eaten (such as, barks or fruits), or sampled during the next field trip for further identification or validation. All statistical analysis were performed using R v. 3.6.3 (R Core Team, 2020), with a 95% level of significance.

4.4 Results

4.4.1 Plant species and plant parts consumed reported by Local Ecological Knowledge

LEK data revealed that 62 plant species from 36 taxonomic families were part of the Campo-Ma'an elephants' diet, of which 10 were cultivated food crops (Table 4.1). The plants parts most reported included fruits, leaves, stems, roots, and barks, with a significant difference in frequencies of the parts reported (Chi spare test, $\chi^2 = 104.200$, df = 4, $p < 0.001$; Figure 4.2A). According to local knowledge, elephants consumed significantly more fruits as compared to leaves ($\chi^2 = 10.714$, df = 1, p = 0.001), stems ($\chi^2 = 34.909$, df = 1, $p < 0.001$), roots ($\chi^2 = 46.049$, df = 1, $p < 0.001$), and tree barks ($\chi^2 = 48.600$, df = 1, $p < 0.001$). Also, leaves were significantly more reported being consumed than stems ($\chi^2 = 9$, df = 1, p = 0.003), roots ($\chi^2 = 17.065$, df = 1, $p < 0.001$), and tree barks ($\chi^2 = 19.200$, df = 1, $p < 0.001$). No significant difference in reported consumption was observed between barks, stems, and roots ($\chi^2 = 3.875$, df = 2, p = 0.144).

4.4.2 Plant species and plant parts consumed reported by field surveys

Field investigations showed that 47 plant species from 29 taxonomic families, of which 4 are food crops, were consumed by elephants (Table 1). Elephants' diet included 8 herbs, 6 shrubs and 33 trees. Plant parts eaten included fruits, leaves, barks, stems, and roots with a significant difference in their distribution (Chi square test, $\chi^2 = 35.500$, df = 4, $p < 0.001$; Figure 2B). Fruits were more consumed than stems ($\chi^2 = 7.043$, df = 1, p = 0.008) and roots ($\chi^2 = 29.121$, df = 1, $p < 0.001$). Similarly, more leaves were consumed than roots ($\chi^2 = 30.118$, df = 1, $p < 0.001$) and stems ($\chi^2 = 7.680$, df = 1, $p < 0.001$). Signs of consumption from stems and barks were comparable ($\chi^2 = 1.060$, df = 1, p = 0.303). No significant difference was observed between bark, leaf, and fruit consumption signs ($\chi^2 = 3.694$, df = 2, p = 0.157). As compared to signs of roots consumption, there were significantly more stems ($\chi^2 = 11.267$, df = 1, $p < 0.001$) and barks ($\chi^2 = 17.190$, df = 1, $p < 0.001$) consumption signs.

4.4.3 Degree of co-occurrence in plant species between the LEK and field surveys

Overall, 47% (n = 47) species seen with signs of feeding in the field were reported during LEK surveys. There were significant differences between the feeding habit patterns reported from LEK and field surveys (Fisher exact test, two-sided, $p < 0.001$). The proportion of barks consumed were significantly greater than reported by local communities ($\chi^2 = 12.565$, df = 1, $p < 0.001$). More fruits were reported than observed in the field ($\chi^2 = 12.565$, df = 1, $p < 0.001$), whereas the contribution of leaves ($\chi^2 = 0.600$, df =1, $p = 0.439$) and stems ($\chi^2 = 1.087$, df = 1, $p = 0.297$) in feeding habit were comparable for both methods. The pattern of root consumption also appeared to be similar for LEK and field surveys ($\chi^2 = 1.800$, df = 1, $p = 0.180$). Of the nine targeted trees (from three different species), camera trap confirmed that forest elephants fed on their fruits, barks, and leaves. In addition, 5 other plant species were seen being consumed through videos and photos (Table 4.1).

4.4.4 Influence of seasons on field surveys feeding habit

Field surveys' feeding habit patterns differed between dry and wet seasons (Fisher exact test, two-sided, $p < 0.001$, Figure 4.3 A and B). More barks were seen stripped by elephant during dry as compared to wet seasons (Chi square test, $\chi^2 = 15.680$, df = 1, $p < 0.001$) whereas more leaves ($\chi^2 = 9.931$, df = 1, $p < 0.001$) and more stems ($\chi^2 = 4.840$, df = 1, $p < 0.001$) were browsed during wet as compared to dry seasons. Fruit and root consumption was comparable between wet and dry seasons (all $p > 0.05$) and no sign of root consumption by elephant was observed during the dry season.

4.3 Discussion

Knowledge of diet and feeding habit of elephant is important for developing human elephant conflict mitigation strategies (Koirala et al. 2016). We found a total of 87 plant species which forest elephants relied on for food. The LEK surveys reported 62 plant species, while the field surveys found 47 plant species as part of the forest elephant diet, with 22 co-occurring plant species and eight plant species (fruit tree, herbs, and shrubs trees) validated for a total of 44 families (Table 1). Their food items came from trees, shrubs, herbs, and climbers. Elephants relied on a variety of plant parts such as roots, stems, barks, leaves, and fruits, consumed at varying proportions and seasons (Figures 2 and 3). These results are higher than the 43 species of plants from 24 families reported by Ndi et al., (2022) in Nki National Park but close to the 95 plant species found by De Boer et al. (2000) in a mosaic of forest and savanna in Mozambique, and 106 plant species consumed by Asian elephants in Shangyong

National Natural Reserve in China (Jin et al. 2006). The total number of plants potentially consumed by elephants appeared to be lower than the 351 plant species found in Congo within the Ndoki National Park (Blake 2002) and 230 species reported in Gabon within the Lopé Reserve (White, Tutin, and Fernandez 1993). However, these researchers obtained those results using different approaches by combining direct observations, dungs, and food scraps resulting from long-term studies.

Table 4.1 Distribution of plant species reported by local people as being consumed by elephants per family, scientific names, local names, biological types, and parts eaten and the source of information.

Family	**Scientific names**	**Local names**	**Biological types**	**Parts eaten**	**Source**
Anacardiaceae	*Annickia chlorantha*	Mfo'o	Tree	Barks	Field
	Anthrocaryon klaineanum	Onzabili	Tree	Barks, fruits	LEK
	Pseudopondias spp.	Ofos	Tree	Fruits	LEK
	Pseudospondias mombin	Kassemanga	Tree	Fruits	LEK
	Trichoscypha arborea	Ekong	Tree	Fruits	LEK
Anisophylleaceae	*Poga oleosa*	Angale	Tree	Fruits	LEK
Annonaceae	*Cleistopholis patens*	Avom	Tree	Leaves	LEK
	Greenwayodendron suaveolens	Otouan	Tree	Leaves	Field
	Hexalobus crispiflorus	Owe	Tree	Fruits	Field, LEK
	Xilopia quintasii	Mvoma	Tree	Fruits	Field
Apocynaceae	*Alstonia boonei*	Ekouk/ Emien	Tree	Leaves, barks	Field, LEK
	Funtumia africana	Mutondo	Tree	Barks, fruits, leaves	Field, LEK

	Tabernaemontana crassa	Etuen	Tree	Leaves	Field
Arecaceae	*Cocos nucifera*	Coconut	Herbs	Leaves, stems	LEK
	Elaeis guineensis	Alen	Herbs	Leaves, stems, fruits	LEK
	Eremospatha macrocarpa	N'kan	Climbers	Barks, stems, leaves	LEK
Bignoniaceae	*Spathodea campanulata*	Tulipier du gabon	Tree	Barks	Field
Bombacaceae	*Ceiba pentandra*	Doum	Tree	Barks	LEK
Boraginaceae	*Cordia* spp.	Cordia	Shrubs	Leaves	Field
Bromeliaceae	*Ananas comosus*	Ananas	Herbs	Fruits	LEK
Burseraceae	*Dacryodes igaganga*	Sahgoun	Tree	Fruits	LEK
Caricaceae	*Carica papaya*	Foforo	Shrubs	Fruits	LEK
Clusiaceae	*Allanblackia floribunda*	Abanka	Tree	Leaves, fruits	LEK
	Garcinia kola	Bitakola/onye	Tree	Fruits	LEK
Commelinaceae	*Palisota* spp.	Palisota	Herbs	Leaves, stems	Field
Costaceae	*Costus* spp. *	Costus	Herbs	Leaves, stems	Field
Cucurbitaceae	*Cucumeropsis manii*	Squash	Herbs	Fruits	Field, LEK
	Luffa spp. *	Luffa	Herbs	Fruits, stems	Field
Dioscoreaceae	*Dioscorea elephantipes*	wild yam	Herbs	Tubers	LEK
Ebenaceae	*Dyospiros* spp.	Mevini	Shrubs	Leaves	Field
Euphorbiaceae	*Anthonotha macrophylla*	Enack	Tree	Barks	Field
	Macaranga spp. *	Assas	Shrubs	Barks, leaves	Field, LEK
	Manihot esculenta	Cassava	Herbs	Roots, leaves	Field, LEK
Fabaceae	*Albizia adianthifolia*	Senesack	Tree	Barks	Field
	Calpocalyx cauliflorus	Etuen	Tree	Leaves	Field
	Calpocalyx heitzii	Miama	Tree	Barks, leaves	Field
	Cylicodiscus gabonensis	Okan	Tree	Barks	Field

	Detarium macrocarpum	Aboroso	Tree	Fruits	LEK
	Distemonanthus benthamianus	Movingui	Tree	Leaves	LEK
	Erythropleum ivorense	Tali	Tree	Bark	LEK
	Pentaclethra macrophylla	Ebai	Tree	Fruits	LEK
	Piptadeniastrum africanum	Atui	Tree	Fruits	LEK
	Scorodophloeus zenkeri	Elelom	Tree	Leaves	LEK
	Tetrapleura tetraptera	Akpwah	Tree	Fruits	Field, LEK
Flacourtiaceae	*Oncoba glauca*	Miamegomo	Tree	Leaves	Field, LEK
Humiriaceae	*Sacoglottis gabonensis* *	Bidou	Tree	Fruits, leaves	Field, LEK
Hypericaceae	*Harungana madagascarensis*	Atondo	Shrubs	Leaves, stems	Field, LEK
Irvingiaceae	*Irvingia gabonensis*	Ndo'o	Tree	Bark, fruits	Field, LEK
	Klainedoxa gabonensis	Ntee/ngon	Tree	Leaves, fruits	LEK
Lamiaceae	*Vitex grandifolia*	Bivoua	Tree	Fruits	LEK
Lauraceae	*Persea americana*	Avocatier	Tree	Fruits	LEK
Leeaceae	*Leea guineensis*	Otebissong	Shrubs	Leaves	Field
Malvaceae	*Cola griseiflora* *	Cola	Shrubs	Leaves	Field
	Desplatsia dewevrei	Mfeneg	Tree	Fruits, roots	LEK
	Duboscia macrocarpa *	Akak	Tree	Barks, fruits, leaves	Field, LEK
	Eribroma oblongum	Eyong	Tree	Barks, fruits	Field
Marantaceae	*Haumania denckelmanniana*	See	Herbs	Root	LEK
Meliaceae	*Entandrophragma utile*	Sipo	Tree	Bark	LEK
	Trichilia rubescens	Nkieme	Tree	Barks	Field

Moraceae	*Antiaris africana*	Ako'o	Tree	Leaves	LEK
Musaceae	*Musa* spp.	Banana	Herbs	Leaves, stems, fruits	Field, LEK
Myristicaceae	*Coelocaryon preussii*	Bidou eteng	Tree	Fruits	LEK
	Pycnanthus angolensis	Eteng/Ilomba	Tree	Leaves, stems, barks	Field, LEK
	Staudtia kamerunensis	Niové	Tree	Leaves	Field, LEK
Olacaceae	*Coula edulis*	Ewomen	Tree	Fruits	LEK
	Ongokea gore	Nguek	Tree	Fruits	Field, LEK
	Strombosia pustulata	Edip	Tree	Barks	Field
	Strombosia scheffleri	Mbazoa	Tree	Leaves	Field
Pandaceae	*Microdesmis puberula*	Evindi afan	Tree	Barks, leaves	Field
	Panda oleosa	Afan	Tree	Fruits, leaves, roots	Field, LEK
Phyllanthaceae	*Margaritaria discoidea*	Ebebang	Tree	Leaves	LEK
	Uapaca guineensis	Assam/Oyang	Tree	Barks, fruits, leaves	Field, LEK
Poaceae	*Zea mays*	Maize	Herbs	Stems, fruits, leaves	Field
	Oxytenanthera abyssinica	Bambou	Herbs	Leaves	LEK
	Saccharum spp.	Canne	Herbs	Leaves, stems	LEK
Rutaceae	*Fagara heitzii*	Bongo H/Olon	Tree	Barks	Field
Sapotaceae	*Baillonnella toxisperma*	Moabi	Tree	Fruits	LEK
	Chrysophyllum africanum	Abam	Tree	Leaves	LEK
	Chrysophyllum lacourtianum	Berema	Tree	Fruits, leaves, barks	Field, LEK
	Tieghemella africana *	Adjap zock	Tree	Barks, fruits	Field, LEK

Simaroubaceae	*Odyendyea gabonensis*	Oseng	Tree	Fruits	LEK
Sterculiaceae	*Theobroma cacao*	Keuka	Shrubs	Fruits	LEK
Strychnaceae	*Strychnos aculeata*	Babe	Tree	Fruits	LEK
Tiliaceae	*Grewia coriacea*	Grewia	Tree	Fruits	Field
Urticaceae	*Musanga cecropioïdes*	Asseng	Tree	Stems, leaves	Field, LEK
	Myrianthus arboreus	Bikango	Tree	Fruits	LEK
Zingiberaceae	*Afromomum* spp. *	Adjom	Herbs	Leaves, fruits	Field, LEK

Local names are given in Bulu, Ewondo, Bagyeli or French language. "*" refers to species observed being eaten by elephants in videos and photos from camera traps. LEK stands for Local Ecological Knowledge.

The forest elephants of Campo ate mostly leaves, especially during wet seasons. Although the vegetation is described as evergreen, the wet period corresponds with the emergence of buds and the production of new leaves which are less lignified and more tender. Herbaceous plants (*Costus* spp., *Palisota* spp., *Luffa* spp.) or shrubs (*Leea guineensis, Harungana madagascarensis, Macaranga* spp.) and crops were reported by field investigations during the wet seasons. Also, signs of browsing on leaves, twigs, or young stems of *Musanga cecropioïdes, Macaranga* spp. and *Harungana madasgarensis* saplings were generally observed in disturbed areas such as logging trails, logging decks, edges of farms, and felling gaps. Leaves have been reported as an important part of elephant's diet in Lopé Reserve in Gabon (White, Tutin, and Fernandez 1993). We found that fruits play an important role in elephant diet in both dry and wet seasons in Campo-Ma'an. This can be explained by the fact that the area is dominated by a variety of tree species with different phenology schedules, thereby securing the availability of fruits on a continuous basis, although patchily distributed.

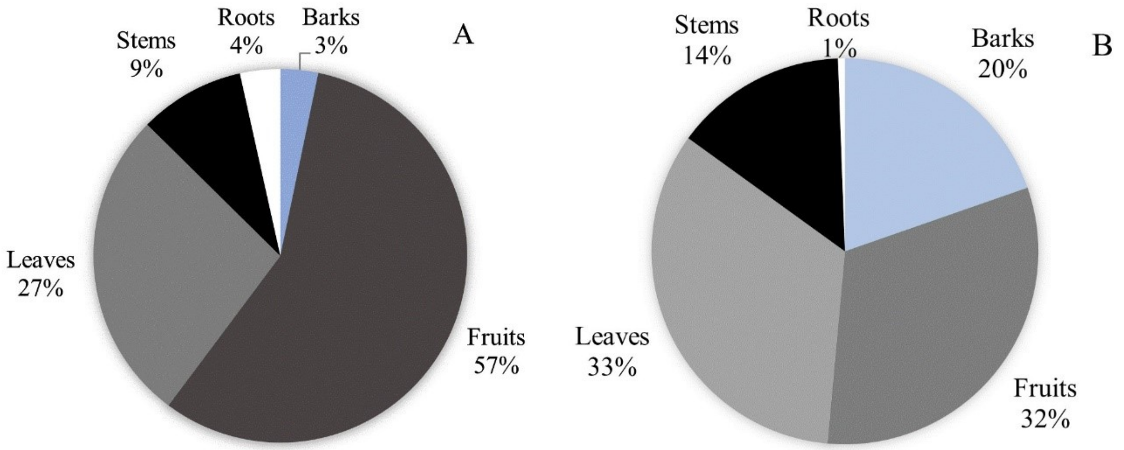


Figure 4.2 Percent distribution of the plants parts eaten as reported by LEK (A) and field investigations (B).

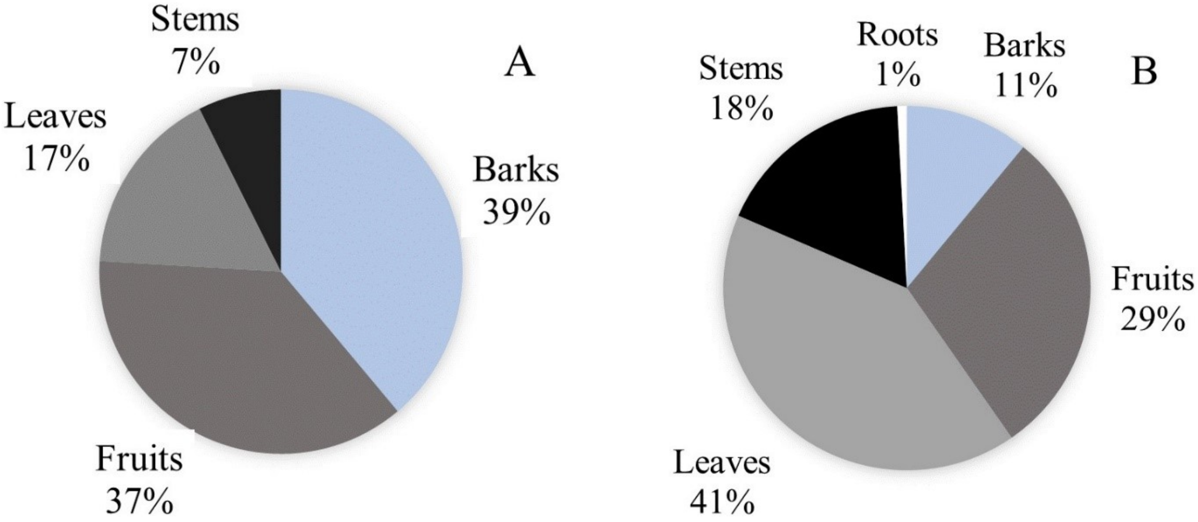


Figure 4.3 Distribution of plant parts eaten (%) as observed from field investigations for dry (A) and wet (B) seasons.

Also, fruits have high concentrations of minerals, proteins and sugars needed for metabolism. Indeed, we saw the following trees producing fruits during both dry and wet seasons *Sacoglottis gabonensis, Duboscia macrocarpa, Irvingia gabonensis, Tieghemella africana, Uapaca guineensis*, and all were reported by both the LEK and field survey methods. Seasonal movement of elephants has been related to such fruits in Ndoki National Park in Congo (Blake 2002) and Lopé reserve in Gabon (White 1994; Beirne et al. 2020; Mills et al.

2018). Consumption of barks by forest elephants increased during dry seasons whereas the proportion of leaves eaten decreased. This variation in proportions may suggest that key minerals needed by elephants during the dry season might be greater in concentration in the barks of trees as compared to the leaves. Key minerals (calcium, iodine, iron and zinc) have been documented for savanna and Asian elephants (Sach et al. 2019) but they remain unknown for forest elephants. Although debarking is not generally severe for trees, their contribution, with roots and stems in providing minerals to elephants has been reported in Tanzania (Kabigumila 1993) and Gabon (White, Tutin, and Fernandez 1993). The low concentration of food resources in minerals over seasons (Rode et al. 2006; Sach et al. 2019) is often compensated by water and soil from bais. In the CMNP, four potential bais and a lick have been monitored for ecotourism by WWF (MINFOF 2014) but none of them was consistently used by forest elephants. Therefore, the feeding strategy of forest elephants is based on their ability to select foods that best meet their nutritional needs among the available resources (Sach et al. 2019). Root/tubers and stems appeared to be consumed at varying proportions over seasons. Roots have been seen hollowed out during the rainy season when soil is moist in area other than swampy areas.

The results showed both similarities and dissimilarities between LEK and field surveys in reported plant species and parts eaten by forest elephants. Twenty-five species were reported exclusively by field investigations and 40 exclusively by LEK surveys. Moreover, among species reported by the two methods, differences were still observed for parts eaten. Thirty-two percent of parts reported by LEK surveys were consistent with field investigations whereas 68% were found to be partially consistent to field observations. For example, LEK reported fruits from *Duboscia macrocarpa* were the only part eaten by elephants, whereas field investigations showed evidence of barks and leaves with forest elephant feeding signs. Also, for *Sacoglottis gabonensis*, the most reported specie for fruits consumption (about 13% of reports), we did not obtain evidence of leaves consumption during field investigations as reported by LEK surveys. Therefore, we argue that discordance between the two methods may be due to the influence of food selection related to seasonal availability (Jin et al. 2006). As such, the two methods might be seen as complementary, and not mutually exclusive, if we are to gather timely and inexpensive information on wildlife (Gilchrist et al. 2005; Service et al. 2014). Elephants' feeding habit may generate conflict with humans, as *Irvingia gabonensis, Hexalobus crispiflorus, Coula edulis*, reported by both methods, are also food items used by local communities. The understories of some tree species are used as hunting sites since fruit from those trees attract several wildlife species, thereby exposing them to hunters. For example, we have noticed that *Ongokea gore* fruits are used as bait on traps for small sized mammals. Those plants have been reported by both methods as part of the forest elephant diet, suggesting that local populations have important and reliable knowledge about the diet of forest elephants in their surroundings. Field investigations were limited to the southwestern tip of the conservation area. Therefore, as compared to data from the LEK, we may have only covered a limited number of species available in the conservation area Tchouto (2004) reported 15 different types of vegetation in Campo-Ma'an conservation area with most fruitful plant species being distributed in limited spaces. Given that direct observation of forest elephants is difficult and costly due to forest elephants being elusive and mostly nocturnal (Kambissi 2010), relying on LEK could be beneficial for providing information on some aspects of elephant ecology, including their diet, and feeding habits. For example, LEK surveys have been recommended as a tool to be used when doing research on elusive and threaten species such as pangolins (Fopa et al. 2020; Nash, Wong, and Turvey 2016). Local communities are likely to know a great deal about their local environment and the species with which they have interacted over time, either in competition for shared resources or when dealing with crop damage from wildlife.

4.4 Conclusion

This study has shown considerable overlap in plant species consumed by forest elephants as reported by LEK and field surveys. LEK approach provided valuable information that was confirmed by field surveys of elephant diet composition as well as their feeding habits. Some differences were nevertheless observed between the two methods used, and we believe further investigations are needed before one can better understand what can explain the observed disparities. The findings suggest therefore that LEK can effectively give information on species that can provide important food items to forest elephants. Furthermore, this study gives an overview of the level of interactions that LEK surveys participants have with forest elephants. The combination of LEK and field surveys could be a cost-effective way to collect relevant information on species, while helping to improve the awareness of populations on the potential impacts or threats their activities could pose to forest elephants. Moreover, knowledge of elephants' diet composition can be useful for habitat restoration in a human induced habitat losses and habitat fragmentation.

4.5 Supplementary material

Supplementary material S4.1: Consent form

HUMAN-WILDLIFE CONFLICT IN THE CAMPO-MA'AN TECHNICAL OPERATIONAL UNIT, SOUTHERN CAMEROON

By: ______________, PhD student, ___________ University. Contact: __________

Preamble:

This questionnaire is designed for research on "the human-wildlife conflicts" in your community, carried out by me, _________________________.

The research aims are to: (1) assess the socio-economic impact of the human-wildlife interactions around CMNP; (2) study the relationship between different stakeholders i.e. park staff, local people, the private organizations as well as the non governmental organizations operating in the area; (3) Assess people's attitudes and perceptions towards wildlife, the park and the wildlife legislation; (4) Study some ecological aspects of the elephants including testing some mitigation measures; and finally (5) Propose plans to mitigate conflicts and promote ecosystem-based management for the park.

If you accept to participate, you will be asked several questions (see questionnaire), and eventually we will visit your farm to assess the level of damage caused by elephants to your crops. The answers that you will provide us on the following questionnaire, which lasts approximately 45 minutes, will remain confidential and will be used exclusively by the researchers for the study.

There is no risk in participating in this study. However, by providing your name, we may use this information in the events of a compensation program that is retroactive. There is no guaranty for this, however. You are free to decline or accept that your name be disclosed for this purpose.

It remains at your discretion to determine whether you wish to answer the questionnaire in whole or in part, or if you do not wish to participate at all. If this study is published, the anonymity and confidentiality of this questionnaire will always apply. You must also be at least 18 years old to participate.

If you have any questions, please do not hesitate to ask me during the interview or later by email at "   " or by phone at"   ".

Do you agree to participate in the study under the conditions described above?

If yes, say YES

If no, say NO   Thank you!"

Chapter 5 Diurnality in the defensive behaviour of African honeybees *Apis mellifera adansonii* and implications for their potential efficacy in beehive fences.

The following chapter is based on the online published manuscript: Djoko IB, Weladji RB and Paré P (2022). Diurnality in the defensive behaviour of African honeybees *Apis mellifera adansonii* and implications for their potential efficacy for beehive fences. *Oryx*, 1–7. https://doi.org/10.1017/S0030605321001721.

5.1 Abstract

Across the range of the African elephant *Loxodonta* sp., negative interactions with people are prevalent, and the impact of the resulting economic losses on farmers calls for solutions. The use of beehive fences, a mitigation method with ecological and socio-economic benefits, is gaining momentum in African savannah landscapes. We assessed the diurnal and nocturnal defensive behaviours of African honeybees *Apis mellifera adansonii* in response to visual and physical disturbances in the Campo–Ma'an conservation area, Cameroon. We examined six bee colonies, assessing their activity level, aggressive behaviour and ability to defend themselves when disturbed at different times of day. We found that activity levels varied between colonies and that colonies were more active during the day and inactive at night. The defensive perimeter around the hives also varied between the colonies and was generally greater during morning and evening periods. Bee colonies did not defend their hives around midday and at night. In response to a threat, bees were more likely to fly out from the hive during daytime than at night, with variation amongst colonies. Overall, as elephant intrusions occur mostly at night, beehive fences alone may not be an adequate mitigation method against crop damage caused by forest elephants *Loxodonta cyclotis.* We suggest combining beehive fences with other mitigation methods to improve crop protection.

Keywords: Aggressive behaviour, *Apis mellifera adansonii*, defensive perimeter, forest elephant, mitigation, simulation.

5.2 Introduction

Crop farming can be challenging within the range of elephants *Loxodonta* sp., and ongoing land-use change exacerbates encroachment of agriculture into elephant habitats (Puyravaud et al. 2019; Mmbaga, Munishi, and Treydte 2017). Elephants enter farmlands and feed on crops mostly at night (Gunn et al. 2013; Ngama et al. 2016), often leading to negative human–elephant interactions. Several strategies have been developed to promote coexistence, including biological methods (Vollrath and Douglas-Hamilton 2002; Nelson, Bidwell, and Sillero-zubiri 2003; King 2010; King et al. 2017). However, often these strategies are only effective temporarily or do not meet people's expectations in terms of their ability to prevent crop damage by elephants (Dror et al. 2020; Nelson, Bidwell, and Sillero-zubiri 2003; King et al. 2017).

Honeybees *Apis mellifera* are increasingly being used to protect crops from elephants (King et al. 2017; Vollrath and Douglas-Hamilton 2002; Cook et al. 2017; Ngama et al. 2016; Soltis et al. 2014). *Apis mellifera adansonii* in West and Central Africa and *Apis mellifera scutellata* in East and Southern Africa (Fletcher 1978; Engel 1999) have a reputation of particularly aggressive behaviour and are able to kill animals by stinging (e.g humans (Fletcher 1978; Soumana et al. 2016), waterbuck cow *Kobus ellipsiprymnus* (Barnes, Diego, and Danquah 2005), goats *Capra* spp. (Karidozo and Osborn 2005). They repel intruders crossing their defensive perimeters (Lecomte 1961) by spreading pheromones (Wright et al. 2018), buzzing or stinging (King and Raja 2016; King et al. 2018; Soltis et al. 2014). The effect of pheromone release on savannah elephants *Loxodonta africana* has been demonstrated in Greater Kruger National Park (South Africa; Wright et al., 2018). In Kenya, farms protected by beehive fences were more productive than unprotected farms as elephants succeeded only in 20% of their attempts at breaking such fences (King et al. 2017). Similarly, in Gabon empty hives and hives with low bee activity (< 40 bee movements per minute; a bee movement being defined as a bee exiting or entering the hive) did not deter elephants, whereas active hives (40–60 bee movements per minute) did (Ngama et al. 2016).

Bees are predominantly diurnal insects and only a few species fly at night (Theobald et al. 2006). For example, *A. m. adansonii* can take advantage of moonlight to forage at night (Fletcher 1978; Theobald et al. 2006), and when disturbed, *A. m. scutellata* have been observed to swarm from beehives to repel elephants during the night as well as during the day (King 2013). Farmers are often reluctant to adopt honeybees as elephant deterrents (Noga et al. 2015; King 2010; King et al. 2017), and in Thailand it was reported that *A. mellifera* and *Apis cerana* were not aggressive towards Asian elephants *Elephas maximus* when disturbed during the day or at night (Dror et al. 2020). These geographical and temporal variations in the behaviour of bees call for site-specific research to validate the efficacy of honeybees as potential elephant deterrents. This should be done before investment in beehives fences is promoted.

Encroachment of agricultural areas into elephant habitat around Campo–Ma'an National Park (Cameroon) has intensified in recent years, increasing competition over space and resources (MINFOF 2014). We experimentally assessed the aggressiveness of disturbed *A. m. adansonii* at different times of day to determine whether they could be used to deter intruding elephants. In the first study of this kind in this area, we artificially disturbed and recorded the behavioural responses of *A. m. adansonii* during daytime and night-time periods to assess their potential efficacy for use in beehive fences to protect crops. We evaluated three indicators of honeybee efficacy in protecting crops from simulated elephant visits: (1) the activity level of colonies (measured as the frequency of bee movements at the hive entrance), (2) the level of aggressive behaviour of the colonies (measured as the mean distance from hives at which honeybees showed defensive behaviour), and (3) the bees' response in the form of a defensive flight when disrupted by an intruder.

5.3 Study area

We conducted our field experiments in Mabiogo (Figure 5.1), one of 162 villages in the Campo–Ma'an conservation area in southern Cameroon, which includes Campo–Ma'an

National Park (264,064 ha). Approximately 111,000 people of various socio-cultural backgrounds live in the conservation area, all of which rely on agriculture and forest products, including wild honey, for their livelihoods (Tiani, Akwah, and Nguiébouri 2005; MINFOF 2014). Staple food crops are grown during short and long rainy seasons and farmers experience interactions with wildlife from the Park, including an estimated population of 544 (range: 425–695) free-ranging forest elephants (MINFOF 2014). The Park is unfenced, and beekeeping is unusual in the area. However, interactions between elephants and wild honeybee colonies are expected to occur in the forest. The mean annual precipitation is c. 2,500 mm, the mean annual temperature is 22–28 °C, and the area maintains high humidity throughout the year. Many rivers and swamps are present in the area and the vegetation consists of trees and herbaceous flowering plants (Tchouto 2004).

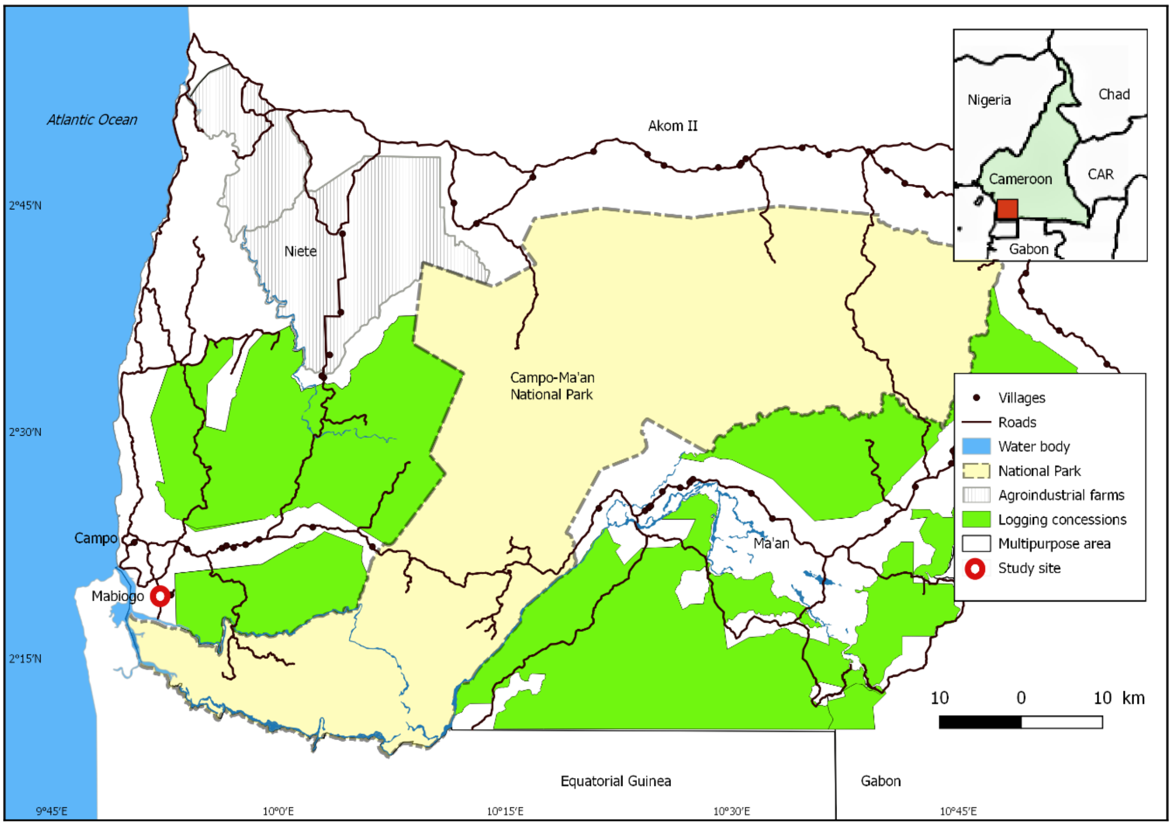


Figure 5.1 Location of Mabiogo, the study site in the Campo-Ma'an Technical Operational Unit, Cameroon.

5.4 Methods

5.4.1 Data collection

We collected data during 24 June–10 August 2019. In 2017 we had constructed a total of 22 Kenyan top bar hives (Supplementary Figure S5.1) following a previous conceptual model (King 2014), and had distributed these to two farmers to start apiculture. We numbered the hives H_1–H_{22} and placed them at the edges of the farms. We set the distance between neighbouring hives at 10 m (King 2014). Two years after we set up the hives only six hives, colonized at different time periods, had active colonies (H_1, H_6, H_{12} and H_{14} from one farmer H_8 and H_{17} from the other farmer) and we treated each colony as an experimental unit. For safety reasons we wore beekeeper suits, gloves and rubber boots when assessing bee activity (Nouvian, Reinhard, and Giurfa 2016). At each farm we collected data regarding both visual and physical disturbances at different times during the day (morning: 05.00–12.00, noon: 12.00–14.00, afternoon: 14.00–18.00) and at night (evening: 18.00–21.00, night: 21.00–00.00).

5.4.1.1 Activity level of the colonies

To assess whether the activity level of the colonies (a measure of defensive behaviour) would affect their ability to deter elephants, we recorded 5-minute videos of bees entering and leaving each beehive (Woyke, 1992; Ngama et al., 2016) using a high-resolution infrared camera (Sony HDR-SR12, Sony, Tokyo, Japan) that enabled us to record at night, for a total of six recordings per hive. We only included videos from which we were able to obtain counts of bees. We calculated the activity level using the following formula Ngama et al. (2016b)

Equation 3 : Number of bee movements/min = $(\text{Number}_{\text{leaving}} + \text{Number}_{\text{entering}})/5$

5.4.1.2 Defensive reaction of honeybees to an approaching observer

Hives are guarded by soldier bees who control the flow of bees in and out of the hive, ward off impeding threats and alert the colony in the event of incoming threats (Breed, Guzm, and Hunt 2004; Nouvian, Reinhard, and Giurfa 2016). To assess the ability of *A. m. adansonii* to repel encroaching intruders (using vision or scent) we walked at constant pace from random positions towards the hive entrance and stopped when an attack occurred. We measured the distance between the hive and the position of the observer to determine the defensive perimeter of the hives. We considered an attack to be the circular movement of bees around the person approaching the hive. Bee movements were passive (inoffensive) or active, potentially resulting in a bee sting (Lecomte 1961; Nouvian, Reinhard, and Giurfa 2016).

5.4.1.3 Response of honeybees to a physical threat

Physical disturbance triggers the defensive behaviour of honeybees (Breed, Guzm, and Hunt 2004; Fletcher 1978; King 2010). When elephants walk through a beehive fence they cause multiple hives to swing, leading to the bees releasing an alert pheromone, flying out or targeting and repelling intruders (King, Douglas-Hamilton, and Vollrath 2007; King 2010). To assess the bees' defensive response to a simulated disturbance, we used a stick to mimic an elephant entering the farm and noted whether at least one bee flew out of the hive beyond a distance of 1 m. We coded the responses in a binary fashion according to whether bees flew > 1 m away from their hive or not (i.e. flying ≤ 1 m from their hive).

We waved the stick at the entrance of the hive for 1 minute, and then gently touched the guard bees lying at the entrance of the hive, without introducing the stick inside the hive. We noted the start time of each disturbance to account for the effects of weather parameters on the bees' activity (Breed, Guzm, and Hunt 2004; Lecomte 1961). To control for the possible influence of temperature on bee activity, we measured the ambient temperature and that within the hives, the latter using a thermal probe placed inside the hive prior to the physical disturbance of the colony and removed after data collection (Burrill and Dietz 1981). We used a mini weather station to record air humidity.

We performed two successive disturbances at every visit for each hive, separated by a 5-minute break. Each sequence of data collection at a hive lasted c. 13 min, therefore totalling c. 31 min per hive per visit. At the end of the second sequence, we recorded the internal temperature of the hive before extracting the probe. During the disturbance a field assistant recorded the time, the air humidity and whether bees flew or not from the hive whilst remaining at least 4 m away from the hive, which corresponds to the minimum distance between hives when constructing beehive fences (King 2010). To allow the colonies to calm down during the 5-minute break we moved 10 m away from the hives. When bees from the disturbed colony remained agitated beyond the 5-minute break, we chased them away using a smoker before initiating the next sequence of data collection. We took precautions to avoid modifying the behaviour of the colonies with smoke (Woyke 1992).

5.4.2 Data analysis

We used repeated ANOVAs to assess the differences in activity level between colonies and between times of day, followed by a Tukey honestly significant difference test for post hoc analysis to compare colonies. In the analysis of the defensive perimeter before the physical disturbance we considered all values equal to 0 m to be the dormant state of the hives and omitted them from the analysis to avoid minimizing the mean defensive zone of the colonies, which could be misinterpreted by farmers. To assess the temporal variation of the defensive perimeter, we used the linear mixed-effect function of the *lme4* package in *R 3.6.3* (Bates et al. 2015; R Core Team 2020) fitted by restricted maximum likelihood. We considered the response variable to be the distance at which the defensive reaction was observed, and included the day (i.e. date) of the observation as a random term because we took repeated measures on the same day. For the explanatory variables we used the time of day (categorical variable with five values: morning, noon, afternoon, evening and night), the colonies (categorical variable with six values, representing the individual hives) and the order of the test (first or second approach). When we found a significant effect of time of day or colony, we performed a Tukey honestly significant difference test to compare the mean distance at which defensive behaviour was observed between different times of day and between colonies.

We used χ^2 tests to assess the dependency between disturbances and the occurrence of honeybees flying > 1 m away from the hive. We used the *lme4* package in *R* (Bates et al. 2015) fitted by maximum likelihood (Laplace approximation) with a binomial distribution and a logit link to assess the effects of the colony, temperature in the hives (a continuous variable) and time of day on whether or not bees flew > 1 m away from the hive. We used likelihood ratio tests to assess the significance of the effects of time of day and colony. We included the day (date) as a random term because we took repeated measures on the same day, and considered colony, time of day and temperature inside the hive to be fixed variables in the model. We used Tukey honestly significant difference tests when we observed differences between different times of day or between colonies. We performed statistical analyses with the significance level set at 0.05.

5.5 Results

5.5.1 Activity level of the colonies

The activity of bees prior to physical disturbance differed significantly between diurnal and nocturnal periods ($F_{(1,154)} = 565$, $p < 0.001$) and between colonies ($F_{(5,72)} = 7.45$, $p < 0.001$). Colonies were active during the day with a mean of 49 bee movements per minute (range: 35.69 ± SD 11–69.55 ± SD 16.53) and were inactive during the night. Colony H_{14} was significantly more active than colonies H_1, H_8, H_{12} and H_{17} (Tukey honestly significant difference test at 95% CI, all adjusted $p < 0.05$), and colony H_6 was significantly more active than colony H_{17} (Tukey honestly significant difference test at 95% CI, adjusted $p = 0.043$). All other pairs were not significantly different in terms of bee activity (Tukey honestly significant difference test at 95% CI, all adjusted $p > 0.05$, Figure 5.2).

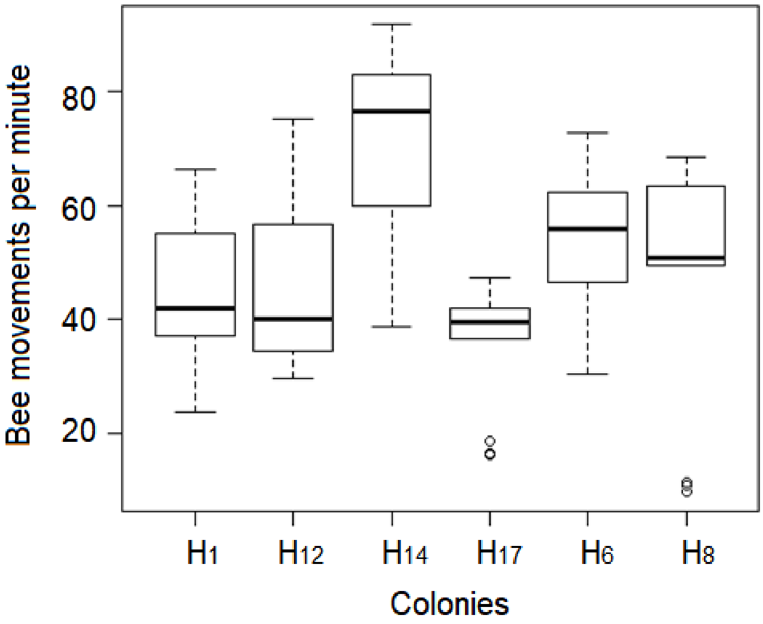


Figure 5.2 Distribution of the number of African honeybees *Apis mellifera adansonii movements* per minute (entering and exiting) at the entrance of each hive during daytime periods. The bars represent the median number of bee movements per minute. The boxes represent the 25, 50, 75 percentiles. The upper whiskers represent the maximum number of bee movements per minute that is within the 1.5 times the interquartile range over 75th percentile. The lower whiskers represent the minimum number of bee movements per minute that is within the 1.5 times the interquartile range under the 25th percentile. The circles denote the outlier values considered any number of bee movements per minute over 1.5 times the interquartile range over the 75th percentile or any values under 1.5 times the interquartile range under the 25th percentile.

5.5.2 Defensive reaction of honeybees to an approaching observer

We performed 276 approaches, of which 20% yielded a defensive response and 80% did not. Of the 134 nocturnal approaches (48.5% of all approaches), 95% yielded no reaction, and we recorded a defensive response rate of 5% in the evening. Of the 142 diurnal approaches (51.5% of all approaches), 65.5% yielded no reaction and 34.5% yielded a reaction. The mean defensive perimeter across different times of day and colonies was 4.05 ± SD 2.5 m. The distance from which bees responded to an approaching observer differed significantly between times of day ($F_{(4,25)} = 4.716$, $p = 0.006$; Table 5.1), with defensive perimeter being larger in the evening than at other times in the evening Table 5.1). The mean defensive perimeter also differed significantly between colonies ($F_{(5,25)}$ = 8.692, p < 0.001; Table 5.1), with colony H_1 having the largest defensive perimeter (7.0 ± SD 2.8 m). There was no difference in defensive perimeter ($F_{(1,54)}$ = 1.55, p = 0.219) between the first (mean 3.58 ± SD 2.58 m) and second approach (4.40 ± SD 2.34 m).

Table 5.1 Mean defensive perimeters (m) of African honeybee *Apis mellifera adansonii* colonies at different times of day in response to an approaching observer, and corresponding Tukey honestly significant difference (HSD) tests. All tests performed at p=0.05, and a, b, c and d refer to the result of the test between colonies: hives with the same letters were not significantly different from each other.

Colonies	**Diurnal periods**			**Nocturnal periods**		**Mean ± Sd**	**Tukey test**
	5:00 – 12:00	12:00 – 14:00	14:00 – 18:00	18:00 – 21:00	21:00 – 00:00		
H_1	7	9.50	4	6.60	0	7 ± 2.80	a
H_6	4.86	2.67	4.80	0	1	4.19 ± 1.87	b
H_8	1	0	0	5	0	3 ± 2.83	bc
H_{12}	2.50	1.50	3	0	0	1.89 ± 1.40	cd
H_{14}	5	3.36	3.50	0	0	3.6 ± 1.12	bd
H_{17}	0	1	2.50	0	0	2 ± 1.73	bc
Mean ± Sd	4.73 ± 2.22	3.22 ± 2.45	3.91 ± 1.58	6.33 ± 2.94	1	4.05 ± 2.50	

5.5.3 Response of honeybees to a physical threat

Of the 276 disturbances, 51% (n = 142) were diurnal, and 49% (n = 134) were nocturnal. The majority (63.4%, n = 175) of the disturbances resulted in a defensive flight of honeybees (χ^2 = 19.841, df = 1, p < 0.001), with 67% (n = 117) occurring during the day and 33% (n = 58) at night. When assessing whether bees responded to a threat, we found a significant difference between times of day (χ^2 = 20.2, df = 1, p < 0.001; Figure 5.3a) and colonies (χ^2 =

120, df = 1, $p < 0.001$; Figure 5.3b). The results from our mixed model showed that on average, compared to at night, bees flew more during the morning (3.842 ± SE 0.872, $p < 0.001$), noon (4.732 ± SE 1.039, $p < 0.001$) and afternoon (4.279 ± SE 1.053, $p < 0.001$). Response to a threat did not differ between morning, noon and afternoon (all pairwise comparisons $p > 0.05$). Similarly, compared to colony H_1, bees from colony H_{17} (–4.897 ± SE 0.930, $p < 0.001$) and colony H_8 (–2.708 ± SE 0.783, $p = 0.005$) responded less frequently with a defensive flight when threatened. Bees from colony H_{12} showed a defensive flight more often than those from colonies H_{17} (5.547 ± SE 1.115, $p < 0.001$) and H_8 (3.359 ± SE 1.069, $p = 0.015$), and bees from colony H_6 responded more than those from colonies H_8 (2.642 ± SE 0.787, $p = 0.007$) and H_{17} (4.830 ± SE 0.956, $p < 0.001$). All other pairwise comparisons were non-significant (all $p > 0.05$).

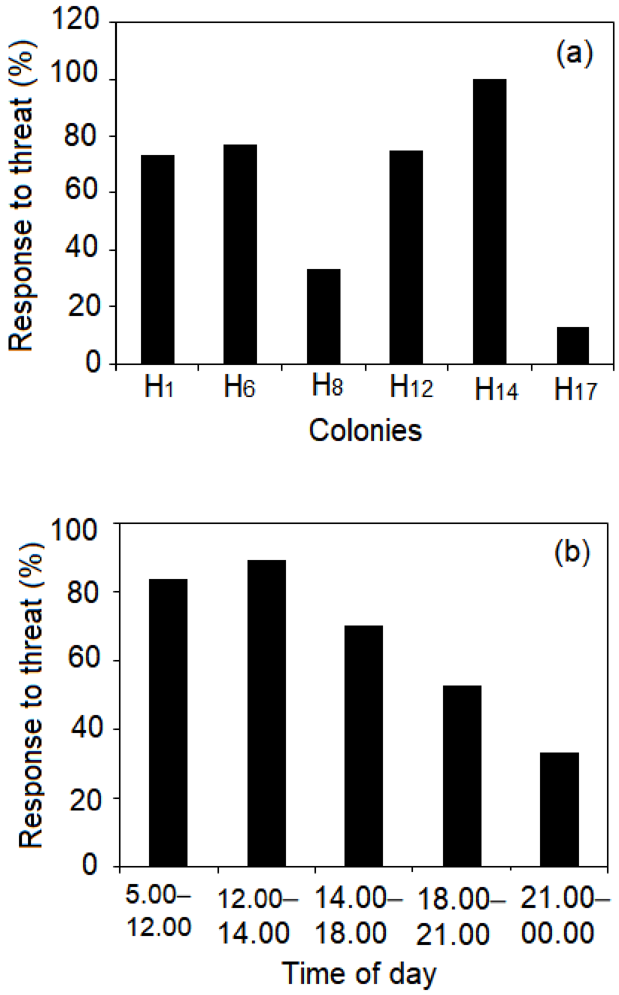


Figure 5.3 Percent response (defined as flying > 1 m away from hive) of African honeybees to physical disturbances (a) for different colonies and (b) for different times of day. There were 5 periods: morning (5.00—12.00); noon (12.00—14.00); afternoon (14.00—18.00), evening (18.00—21.00) and night (21.00—00.00).

5.6 Discussion

We found that honeybee colonies differed in their activity level and defensive behaviour when disturbed. In addition, honeybee colonies were only active during the day and their defensive perimeters were greater in the morning and evening when the bees appeared to be more sensitive to disturbance. These findings suggest that beehive fences may be less effective at deterring intruders at night.

5.6.1 Activity level of the colonies

We assessed the activity level of *A. m. adansonii* as an indicator of aggressive behaviour and found that the activity levels of most colonies were above the requirements for use as beehive fences. Four colonies exhibited daytime activity of 40–60 bee movements per minute, levels that have been found to be effective for deterring forest elephants in Gabon (Ngama et al. 2016). However, activity levels of two colonies were below the required range for an effective deterrent. This suggests that when setting up beehive fences, colonies should be selected for inclusion based on their activity levels (Ngama et al. 2016).

At night all colonies were clustered at the entrances of their hives and visibly inactive because of decreasing temperature (Burrill and Dietz 1981) and increasing humidity (supplementary Figure S5.2). We observed no bees flying prior to us disturbing the colonies at night. This corroborates findings from a study in Thailand using *A. m. scutellata* and *A. cerana* (Dror et al. 2020). However, it contradicts observations of *A. m. adansonii* foraging at dusk, under low light intensity. Had the bees been more active at night, it would have increased their potential use in beehive fences as most elephant intrusions into agricultural areas occur at night (King 2010; Ngama et al. 2016).

5.6.2 Defensive reaction of honeybees to an approaching intruder

In response to an approaching intruder, bees were mostly inactive, except in the morning and twilight periods when they were more likely to fly and attack intruders. Similar patterns of aggressive behaviour in *A. mellifera* have been reported previously by Lecomte (1961) in France and Woyke (1992) in Ghana. This finding is not surprising because most foraging bees exit the hive in the morning and return in the evening (King 2010). Hives are guarded by mature foragers who are more experienced and produce more pheromones than younger individuals (Nouvian, Reinhard, and Giurfa 2016). We argue that beehive fences would be more effective during the morning and dusk than during other times of day because mature foragers help defend the hives during these periods. These two periods have also been reported as the times when elephants frequently enter or leave plantations (King, 2009; Gunn et al., 2013; Ngama et al., 2016). Active colonies could thus potentially repel elephants approaching during the evening because, if disturbed, the bees would probably fly out and attack the elephants (it is not completely dark until 19:00 in this area).

5.6.3 Response of honeybees to a physical threat

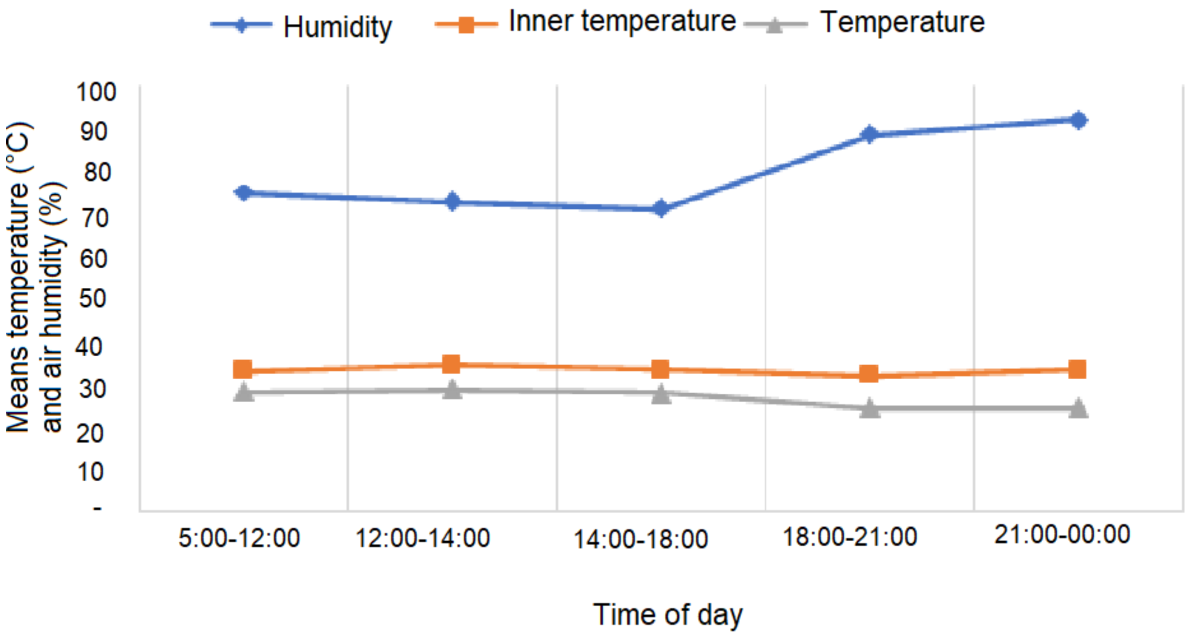
Our results showed that disturbed bees were more likely to fly out from the hive and repel intruders during the day than at night. All colonies reacted vigorously to physical disturbance during the daytime by flying in all directions to identify and sting the intruder. Similar responses of bees to physical threats during the daytime and at twilight have been reported previously (King et al. 2017; Ngama et al. 2016; Woyke 1992). However, their decreased level of defensive behaviour after dusk reduces their effectiveness in repelling animals with a high cognitive capacity such as elephants (Dror et al. 2020). At night, physical disturbances resulted in bees falling to the ground because they were unable to fly; they had to walk towards the support of the hive to climb up and return to it. The bees buzzed loudly in response to such night-time disturbances, except during periods of moonlight. Although colonies with high levels of activity were avoided by forest elephants in Gabon (Ngama et al. 2016), our results suggest that the inactivity of bees at night could be noticed and exploited by forest elephants through breaches in the fences at night, particularly if the elephants are exposed repeatedly to such bee behaviour (Dror et al. 2020).

Towards the end of the study, we noted that bees from the smallest colonies (H8, H12 and H17) flew inside their hives when disturbed rather than away from the hive and towards the source of disturbance, even during the daytime. This was unexpected as bees are usually aggressive during the daytime. We argue that repeated disturbances could reduce the aggressiveness of colonies, especially the smallest ones, because of the loss of mature guards, leaving the hives inadequately protected by less experienced guards (Nouvian, Reinhard, and Giurfa 2016). Therefore, colony size matters, although they could become inoffensive especially when the queen is not in the hive (Lecomte, 1961; Woyke, 1992; Supplementary Figure S5.3a). In contrast, larger colonies such as H1, H6 and H14 (Supplementary Figure S5.3b) were more reactive and never inactive during the day. Overall, our results highlight the need to combine other mitigation methods with beehive fences to improve their efficiency (King 2010; Nelson, Bidwell, and Sillero-zubiri 2003). Although we observed low levels of defensive flights around noon and at night, bees may still be able to deter elephants at these times as buzzing and pheromones could be part of their defensive mechanism and may have a deterrent effect on elephants. More research into these aspects of bee behaviour is required to improve our understanding of the efficacy of beehive fences.

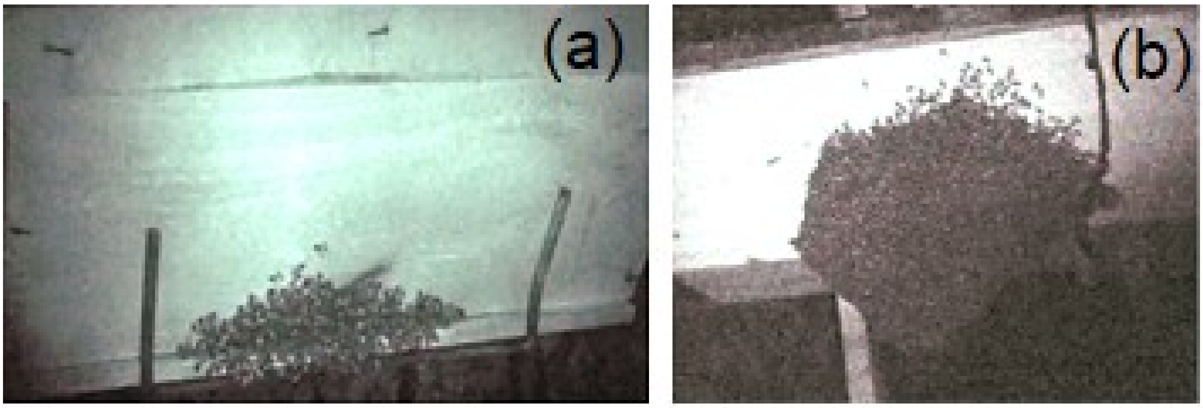
The predictive capacity of our study is limited because our experimental design did not involve beehives being disturbed by actual elephants, but it still provides valuable insights into the potential effectiveness and limitations of beehive fences to deter forest elephants and reduce crop losses that affect people living near protected areas. Our findings on the threat response of *A. m. adansonii* thus have the potential to facilitate informed decision-making regarding the use of beehive fences to address crop damage by elephants.

5.7 Supplementary materials

Supplementary Figure S5.1 Sample image of the Kenyan top bar hive on a stand.



Supplementary Figure S5.2 Variation of the air humidity, external and inner temperature of the hives per periods. There were 5 periods: morning (5:00-12:00); noon (12:00-14:00); afternoon (14:00-18:00), evening (18:00-21:00) and night (21:00-24:00).



Supplementary Figure S5.3 Illustration of the difference in colony size between hive H_{12} (a) and hive H_{14} (b) at night.

Chapter 6 General discussion

The goal of this thesis, conducted within the framework of the Campo-Ma'an National Park management plan, was to better understand the dynamics of human forest elephants' interactions for an integrated management of the landscape that maintain biodiversity while providing better coexisting conditions to local communities and forest elephants. To achieve this goal, I evaluated the extent of wildlife crop damage and identified humans' impacts on wildlife (Chapter 2). I also assessed the influence of habitat and anthropogenic factors on forest elephant occurrence and relative abundance over the existing land use types (Chapter 3). Further, I assessed the level of concordance between data from local ecological knowledge and field surveys for a rapid assessment of forest elephant feeding habits (Chapter 4). Finally, based on the local knowledge of honeybees and the necessity to develop site-specific methods prior to effective use of mitigation techniques, I assessed African honeybees' (*Apis mellifera adansonii*) diurnal and nocturnal defensive behaviour in response to visual and physical disturbances (Chapter 5). In the following paragraphs, I review the main findings of my thesis and give some perspectives for future research.

6.1 Extent of wildlife crop damage and impact on wildlife

Forest elephant was not the most reported animal engaged in crop damage in the CMTOU, but their impact on people livelihood was higher than impacts from other wildlife species (Chapter 2). Cane rats, forest elephants and talapoins were the species contributing the most to the farm abandonment in the CMTOU (Ole 2011). Crop damage by wildlife may therefore justify the resentments that farmers have towards wildlife in general and the culprit species particularly. It appeared that conflicts are not only physical and economical, but that they may also take on an invisible character through psychological and moral effects such as the fear of being killed, increase workload for farmers, fear of loss of food reserve and starvation or even health effects (Barua, Bhagwat, and Jadhav 2013; Dickman 2010; Breuer and Ngama 2020). Indeed, some farmers spend sleepless nights guarding farms where they are exposed to various disease vectors such as mosquitoes that transmit malaria, common in the region. Moreover, teenagers in the communities may abandon school as they have to guard their farm from intruding wildlife (Barua, Bhagwat, and Jadhav 2013). The economic losses suffered by farmers point to such invisible wounds that persist long after the physical conflict and they can worsen if no mitigation strategy is put in place to alleviate the negative impacts on people's livelihoods. For example, religious beliefs exist among local communities that cane rats as well as forests elephants are "humans" transformed into animal to damage their crops. This is the reason why farmers are against cane rat farming in the villages. Similar beliefs exist in other communities elsewhere (Eyebe, Dkamela, and Endamana 2012; Doumenge, Palla, and Itsoua Madzous 2021).

Human activity, such as illegal hunting, and habitat fragmentation through wood logging, agro-industrial plantations and has proven to be a threat that will intensify further to the point of threatening elephants' survival if nothing is done in the CMTOU. Indeed, several interviewees in the Ma'an subdivision have acknowledged that they no longer encounter traces of forest elephants in their surrounding and speculate that forest elephants might have backed off in the National Park. However, previous inventories have documented declines in large mammal populations as being related to human activities (Matthews and Matthews 2006; Nzooh-Dongmo et al. 2015). The density of forest elephants has decreased in the east side of the CMTOU, mainly due to poaching and habitat degradation by humans (Matthews and Matthews 2006). Therefore, this could justify why elephants damage to crop were particularly high in Campo, in the west side, recently known as the main stronghold of forest elephant population as compared to Niete and Ma'an which have been reported as hotspots of poaching and wildlife habitat degradation in the CMTOU (Tiani, Akwah, and Nguiébouri 2005; Eyebe, Dkamela, and Endamana 2012; Nzooh-Dongmo et al. 2015).

Almost all farmers suffered crop damage by wildlife, but the level of damage significantly increased when forest elephants were involved as they need huge amount of forage to satisfy their feeding requirements. Indeed, in the CMTOU, eighteen wildlife species were reported involved in crop damages and elephants came in second position in my records after cane rats. Most people in the study area reported their level of crop damage to be severe when also involving elephants whereas in absence of elephants the damage to crops by wildlife were said moderate.

A single incursion of elephant in a farm may lead to multiple crops being consumed or trampled (Mwakatobe et al. 2014; Ole 2011). Farmers were more afraid of forest elephants, but cane rats and talapoin monkeys also caused a lot of damage to farmer's crops (Chapter 2, Ole, 2011). Interestingly, most of the damaged crops were staple crops, suggesting that crop damage could jeopardise food security in the area. In Campo subdivision, the high presence of forest elephant in the CL and relatively short distance to the FMU, considered elephants habitat, with fruit availability (Chapter 3), make forest elephants consider farmlands as feeding sites.

6.2 Habitat use by forest elephant in Campo-Ma'an Technical Operational Unit

Like elsewhere, elephants in the CMTOU did not use their habitat randomly (De Boer et al. 2005; Mills et al. 2018; Blake et al. 2008; Blake and Inkamba-Nkulu 2004). There is a high concentration of forest elephants in the southwestern part of the conservation area (Nzooh-Dongmo et al. 2015). As consequence, it is the area where negative interactions between wildlife and farmers are exacerbated (Chapter 2). In Chapter 3, I explored whether fruit availability influences habitat use by forest elephants in this part of the conservation area. I have associated other covariates such as land use types, tree species richness, human activity, distance to the nearest permanent water point from the observation station and seasons. I added these covariates because they can modulate the movement of forest elephants. The study area spanned a gradient of human disturbance and included the NP, the FMU, and the CL, which are differently used by forest elephants. Indeed, forest elephants occurred more often in the CL than the FMU and the NP but occurred similarly in the FMU and the NP. However, there was a shift in land use with respect to the relative abundance of forest elephants. Forest elephants seemed relatively more abundant in the CL and the NP than in the FMU but comparable between the CL and the NP. Forest elephants are attracted by areas of high species richness that provide different fruits they consume.

As human disturbance is higher in the CL compared to the FMU and the NP, my results are inconsistent with the risk avoidance described by some studies where forest elephants occur far away from area of high human disturbances (Amin et al. 2020; Blake et al. 2008). Indeed their low density in the east side has been correlated to anthropogenic activities (Eyebe, Dkamela, and Endamana 2012; Matthews and Matthews 2006). However, these human disturbances create conditions of secondary vegetation described elsewhere as being appreciated by forest elephants (Doumenge, Palla, and Itsoua Madzous 2021; Breuer and Ngama 2020). Forest elephants take the risk of being killed when they visit the CL to get access to preferred fruits and other foods items that are unevenly distributed in the CMTOU. As there is no demarcation of boundaries of land use types on the field and the NP is not fenced, the vegetation is continuous, allowing for continued movement of forest elephants across land use types.

Tree species are patchily distributed with some stratification of the vegetation from western part to the sea through the continent (Tchouto 2004). In FMU, the presence of forest elephants was positively associated with increase in fruit availability whereas in the CL and the NP it was not significantly affected by fruit availability. In my study area like elsewhere (Blake and Inkamba-Nkulu 2004), forest elephants create and maintain trails to connect fruiting trees with important minerals deposits and water points. Therefore, forest elephant movement across land use types is mostly driven by their feeding needs and primarily by fruit availability.

The relationship between fruit availability and forest elephant relative abundance is similar between seasons, except between long and short rainy seasons when fruit availability had negative effect on forest elephant relative abundance. I argue that this difference is favored either by the variety of food the forest elephants can rely on or by the logging activity. Indeed, September and October are months when intense logging activities were taking place and where reports of crop raiding by elephants are highest (Ole 2011). Together, these conditions make it possible to predict the presence and relative abundance of forest elephants.

Water is a very important environmental resource for which elephants migrate hundred of kilometers across the savannah in search (Tchamba 1996a), but this is not the case in evergreen forest where water is not an acute constraint. Forest elephants' presence increased with the distance to the nearest permanent river. This finding is consistent with the hypothesis that the CMTOU is water rich as reported by other studies in the region (Bekhuis, De Jong, and Prins 2008; Tchouto 2004). However, the general distribution of this resource throughout the conservation area needs to be addressed regarding the edaphic variability of the landscape and the influence that this physical difference could have on the overall use of the protected area by forest elephants.

At the end of the study, the theft of seven CTs, including five in the NP, one in the CL and one in the FMU, suggests that no land use type is safe from illegal acts in the south- west of the CMTOU. Indeed, local communities had been made aware a few years earlier of the use of CTs for biomonitoring and feared being taken to court for illegal activities in a protected area. Therefore, significant law enforcement measures need to be taken in this protected area to limit human intrusion, which is a significant cause of conflict between humans and forest elephants. I suspect that the frequent presence of armed hunters in the park and FMU contributes to push the elephants out of the protected areas and amplifies human-elephant negative interactions (Chapter 2).

6.3 Local ecological knowledge in forest elephant study

In Chapter 4, I showed that given the elusive nature of forest elephants, one can rely on empirical information to rapidly assess forest elephants' diet. I combined data from the survey conducted in the communities (Chapter 2), transect monitoring and camera trap photos and videos (see Chapter 3 and chapter 4), to generate a list of 44 plant families potentially part of forest elephant's diet. Indeed, I found that forest elephant diet in the southwest of the CMTOU is diversified with at least 87 plant species consumed by forest elephants of which 62 were reported by LEK surveys and 47 by field investigation and camera traps. Twenty-two of these plant species co-occurred in the lists generated by field and LEK surveys methods. The reported elephant diet covers different parts of the plant including leaves, fruits, barks, roots, and stems. Although I used different approaches, my results are close to the 95 plant species found by De Boer et al. (2000) in a mosaic of forest and savannah in Mozambique, and 106 plant species consumed by Asian elephants in Shangyong National Natural Reserve in China (Jin et al. 2006).

Local knowledge are useful source of information that are gaining momentum nowadays in ecological studies (Buchholtz et al. 2020; Gilchrist et al. 2005; Pan et al. 2016; Mouafo et al. 2021; Fopa et al. 2020; Simo et al. 2020). However, its use is not explicit and is often diluted when it comes to studies of elephant ecology, making it difficult to appreciate its contribution to ecological research (Buchholtz et al. 2020; Biru and Bekele 2012). In chapter 4, I have shown that one can use local ecological knowledge to obtain qualitative information on animal feeding habit. It would therefore be interesting to involve local populations in conservation activities and thereby improve their attitude toward biodiversity conservation and wildlife managers.

In addition to crops species reported damaged by wildlife, this research showed that human and forest elephants relied on some common plant species for food (e.g. *Irvingia gabonensis, Hexalobus crispiflorus, Coula edulis,* see Chapter 2 and 4). Thus, their feeding habit may generate conflict with humans (Breuer and Ngama 2020). In addition, it indicates that local people and forest elephants interact and overlap in their use of habitat (chapter 3). Hence the urgency of mitigating negative interactions, which I attempt to address in Chapter 5. These findings can provide tools to conservationists when setting up mitigation strategies locally.

6.4 Diurnality in the defensive behaviour of African honeybees

Forest elephant damages to crops threaten people livelihood in the CMTOU and negative human wildlife interactions are expected to escalate in the future. Yet, reducing the negative impacts of human-elephant interactions to zero level is an utopia (Breuer and Ngama 2020). Farmers in my study area have developed various strategies to protect their crops from being raided by wildlife (Chapter 2), like elsewhere (Nelson, Bidwell, and Sillero-zubiri 2003; Branco, Merkle, Pringle, King, et al. 2019; Breuer and Ngama 2020). However, none of their methods has been efficient in preventing forest elephants crop damages (Chapter 2).

Political intervention is needed to set aside lands for large mammals such as elephants as they are vulnerable to habitat losses and range contraction. Using biological approaches to mitigate the conflict can be of great importance in Campo-Ma'an. For example, the use of bee may provide, in addition to crop protection, income to local people (Ngama et al. 2016; King et al. 2017; Branco, Merkle, Pringle, King, et al. 2019). However, conflict mitigation is a site-specific process for which proposed solutions should be locally accepted. I conducted surveys and field visits in communities within the CMTOU before deciding on which mitigation method could be investigated (Chapter 5).

In this research, I have highlighted the behavior of honeybees that may justify their use to deter forest elephants from raiding crops. It was observed that colonies did not exhibit the same activity level and were more active in diurnal periods and inactive during nocturnal periods. The activity level of the colony should also inform on the sound level that could warn any intruders on the farm (Cook et al. 2017; Soltis et al. 2014; King et al. 2018). This result confirms the hesitation of local farmers regarding the effectiveness of honeybees as an elephant repellent, given that elephants often visit farms during the night. Also, the results support the hypothesis that light intensity is an important environmental factor that affect bee activity (see Burrill and Dietz, 1981; Theobald et al., 2006). Fortunately, honeybee are more active during the mild hours of the day when forest elephants are likely more active in the search for fodder (Leggett 2009). Accordingly, honeybee fences around cropping lands could reduce to some extend the likelihood of crop raiding by elephants. Moreover, it may also improve the livelihood by reducing the opportunity cost of crop surveillance (Weinmann 2018; Sitati and Walpole 2006; Hariohay, Munuo, and Røskaft 2020) for those who still keep their farms, or would encourage those who have abandoned their farms due to forest elephants crop raiding to restart farming (see chapter 2). Promoting the cultivation of crops that are unpalatable to forest elephants (chapter 2) might be a good start for farmers experiencing elephant crop damage. Those crops may also be used as physical barriers around farms to repel elephants from farms thereby securing the main food crop species. Indeed, in agriculture, the push-pull strategies involve the behavioral manipulation of insect pests and their natural enemies via the integration of stimuli that act to make the protected resource unattractive or unsuitable to the pests (push) while luring them toward an attractive source (pull) from where the pests have been subsequently removed. Although forest elephants in this area are not yet considered a pest, this approach can be used to accommodate forest elephants and humans in this landscape where they are expected to coexist soon or later. This push-pull strategy consists of two distinct components. The pull strategy may consist of planting fruiting trees known to be preferred by elephants in order to favor their movement in the NP and FMU, away from edges. The push strategy on the other hand will consist of rendering the CL and farms unattractive to forest elephants. Hence, the beehive fencing tested in Chapter 5 and the unpalatable food crops identified in Chapter 2 could both be important assets in this local production system, when combined.

Honeybee colonies did not defend their hives during noon and night periods. Their defensive perimeter differed between the colonies and were generally higher in morning and evening periods. Also, in response to a physical threat (simulating an elephant breaking through the fence), honeybees were more willing to fly during daytime than nighttime periods, with variation among colonies. This reveals that for the same colony, the reaction in presence of an approaching forest elephant can be different depending on the period of the day. Also, there might be a positive correlation between the size of the colony and their defensive reaction. Indeed, the reaction of small colonies to disturbance decreased gradually over time, certainly a sign of them getting used to the disturbances. Another plausible explanation would be a gradual disappearance of bees suitable for guarding because not all bees are suitable for this task (Breed, Guzm, and Hunt 2004). Additionally, those small sized colonies may react unexpectedly by retreating rather than rushing to defend the hive. I concluded that since elephants has great ability to learn (Mumby and Plotnik 2018; Dror et al. 2020), they may be able to identify small size honey bee colonies or timeslot during which honeybees are less aggressive, to break through the beehive fences. Hence, there is a need to strengthen use of beehive fences with complementary mitigation methods.

6.5 Future areas of research

Although I infer from my field observation that trails are created and maintained by forest elephants in the southwestern part of the conservation area, their extent, density, distribution as well as the location of particularly important habitat sites (e.g., bais, minerals deposits) to which they all lead remain to be explored. For example, one of the potential bais found in the study area and once monitored by the WWF team in Campo was also monitored during this study. This site was only visited during the *Saccoglottis gabonensis* fruit production period (Chapter 3). Increasing the number of camera traps and expanding the study area to cover the entire CMTOU would allow verifying the existence of such useful sites. Moreover, it would help validate some of the hypotheses raised in this thesis and previous studies. Precisely, the last inventory of large fauna is from 2014 (Nzooh-Dongmo et al. 2015) while major changes have recently occurred in the CMTOU landscape, such as the recent creation of an oil palm agro-industry to replace the FMU n° 09025. Land use by human can lead to limited provision of ecosystem services to wildlife such as food and water (Mmbaga, Munishi, and Treydte 2017). Therefore, the establishment of this agro-industrial plantation would generate a new distribution of large mammals in the landscape including forest elephants and great apes. Also, oil palm is among the plant species on which elephants rely for food. Therefore, growing such a crop in their habitat would likely exacerbate the conflict.

In my thesis, I compared land use types in the most impacted elephant zone within the conservation area (Chapter 2). However, differences would exist between the camera stations according to the altitudinal gradient that increases as one moves away from the Atlantic coast. Indeed, along this gradient, there exist a stratification of vegetation from the sea to the continent (Tchouto 2004). Elephants have preferences for some food items and habitat types over others (Biru and Bekele 2012; De Boer et al. 2005; Loarie, van Aarde, and Pimm 2009). The distribution of vegetation, although continuous throughout most of the conservation area, varies in its floristic composition. This would suggest a preference for certain foods by forest elephants. The distribution and movement patterns of forest elephants remain unexplored and should be studied as they can help improving our knowledge of the effect of food preference on forest elephant habitat use in the southwest of the CMTOU.

To properly mitigate the negative impacts of human-forest elephant interactions, further research is needed. For example, when forest elephants start moving toward feeding sites at dusk (see Sitati and Walpole, 2005), insects can be very noisy. Savannah elephants were shown to retreat from buzzing sound from disturbed colonies (Cook et al. 2017; Soltis et al. 2014). Therefore, one may be interested in knowing whether forest elephants would differentiate the buzzing sound from beehives fence settled at the edges of the cropping lands and that produced by other insects. I suspect this sound may be confusing to forest elephants although they are used to wild bees. Indeed, this sound is drowned in a panoply of other sounds coming from various insects and nocturnal mammals. In addition, whether the pheromone released by the bees mainly during the colony defense reaction may affect forest elephants needs to be explored, as it has been shown that savannah elephants stayed away from bee pheromone (Wright et al. 2018).

The disturbances induced by the slash and burn agriculture system allow rapid growth of mixed vegetation of herbaceous and shrubs trees which would greatly reduce the visibility of an elephant coming to a plantation. Thus, the beehive fence being installed at the edge of the field might not be visible enough to be perceived as a barrier to the intruder before the latter hooks the fencing wire joining the hives (King 2014; King et al. 2017; 2009). Maintaining the fence in a forest context can be more expensive due to the risk of falling trees and the need to clear the edges of fields more frequently to make the fence visible to elephants. Therefore, the forest-crop interface distance needs to be explored to assess the operational and economic efficiency of the use of beehive fences in a forest context.

6.6 Conclusion

Human-wildlife interactions threaten the livelihoods of local communities in the CMTOU. Although not the main animal reported by farmers, forest elephants are responsible for significant damage to crops resulting in huge economic losses. This is even more serious as the damage is mainly caused to mature crops, often staple foods. Furthermore, forest elephants' presence in community land limits farmer's access to non-timber forest products, which gathering, and collection constitute alternative sources of food and income. This situation generates frustration within the local communities with whom wildlife interacts and may justify retaliatory behavior towards wildlife, but also could lead to negative attitude toward conservation and the park rangers. This could jeopardize in this area the long-term survival of forest elephants, a species currently critically endangered. The negative effects resulting from human-wildlife interactions in the CMTOU are expected to intensify with the recent creation of an oil palm plantation in an area known to be part of forest elephants habitat. These human actions need more attention as their requirements for space and resource overlap with those of forest elephants who, indeed are unaware of any land use plan. Developing mechanisms that allow humans to satisfy their basic needs without harming the satisfaction of those of forest elephants would facilitate tolerance and coexistence. Thus, the mitigation of the negative impacts of the activities of each of the two parties is essential. Therefore, I recommend the use of beehive fences for crop protection. However, it is essential to combine hive fencing with other proven methods (e.g., chilli (*Capsicum spp.*) based deterrents (Sitati and Walpole 2006; Ngama et al. 2018; Nelson, Bidwell, and Sillero-zubiri 2003)) that would help keeping elephants away from crops during periods of reduced bee colony efficiency. The unpalatable crops from chapter 2 that were not damaged by forest elephants could be used to reinforce the mitigation strategy. Also, based on the most frequently consumed fruits of the forest elephants determined in the area based on results from chapter 3 and chapter 4, I have recommended that the push - pull method should be implemented. The aim will be to facilitate the attractiveness of areas truly dedicated to the habitat of forest elephants so that they find no need to come close to human settlements where their presence and abundance could generate retaliatory actions from humans. Although elephants will always need large areas of forest to satisfy their enormous vital needs, I hope it will reduce their incidence on people's livelihood and enhance coexistence.

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