Comparative analysis of human-wildlife conflicts in Asia and Africa

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LIST OF ABBREVIATIONS

BA	Bardia/Nepal
BZ	Buffer Zone
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DS	Dry season
EN	Endangered
GIS	Geographic Information System
GMA	Game Management Area
GLM	Generalized Linear Model
GLMM	Generalized Linear Mixed Effect Model
GPS	Global Positioning System
HEC	Human-elephant conflict
HWC	Human-wildlife conflict
IS	Intermediate season
IUCN	International Union for Nature Conservation
LC	Least concern
MA	Manas/India
MNP	Manas National Park
MAP	Medicinal and aromatic plant
NE	Not evaluated
NGO	Non-governmental organisation
NT	Near threatened
PEC	Problem elephant control
RS	Rainy season
SL	South Luangwa/Zambia
TA	Tarangire/Tanzania
TAL	Terai Arc Landscape
UTM	Universal Transverse Mercator
VDC	Village Development Committee
SOM	Supplemental Online Material
VU	Vulnerable
WGS	World Geodetic System
WTLCP	Western Terai Landscape Complex Project

SUMMARY

The continuous conversion of natural wildlife habitats into agricultural areas, as well as the fragmentation of the last wildlife refuges, is increasing the interface between people and wildlife. When wildlife negatively impacts on people and vice versa, we speak about human-wildlife conflicts (HWCs). This definition includes losses on both sides and takes into consideration the rooting of most of these conflicts between different groups of interest, such as advocates for nature conservation and economic groups. The centres of highest biodiversity are located in developing countries, which are also characterized by poverty. In African and Asian countries, people living in the vicinity of national parks and other conservation areas mostly receive only little support through the government or conservation organisations. Especially for those people who are dependent on agriculture, damage to fields and harvests can have catastrophic consequences. If the species causing damage is protected by national or even international law, the farmer is not allowed to use lethal methods, but has to approach the authority in charge. If this agency, however, cannot offer appropriate support, resentment, anger or even hate develops, and the support for wildlife conservation activities declines. For this reason, HWCs were declared as one of the most important conservation topics today, being particularly relevant for large and threatened species such as the African and Asian elephant, hippopotamus and the greater one-horned rhino, as well as for large predators. Up to today, no general assessment scheme has been recommended for damage caused by protected wildlife species.

In my study, HWCs in Asia and Africa are compared, focussing on all herbivorous species identified which damaged crops. For the French NGO *Awely, des animaux et des hommes*, I developed a detailed assessment scheme suitable for all terrestrial ecosystems, and any type of HWCs and any species (Chapter 2). This HWC assessment scheme was used in four different study areas located in two African countries (South Luangwa/Zambia (SL), Tarangire/Tanzania (TA)) and two Asian countries (Bardia/Nepal (BA) and Manas/India (MA)). This scheme ran for six consecutive years (2009 to 2014) for Zambia, Nepal and India and two years (2010 to 2011) for Tanzania. To carry out the assessments, I trained local HWC officers (Awely Red Caps) to assess HWCs by field observations (measurement of damage, identification of species through signs of presence, landscape attributes etc.) and interviews with aggrieved parties (socio economic data). Results of this assessment are presented in Chapters 2-4.

To determine whether elephants prefer or avoid specific crop species, two field experiments were carried out, one in SL and one in BA (Chapter 5 and 6). For this, two test plots were set up and damage by elephants (and other herbivores) were quantified.

Within this doctoral thesis, 3306 damage events of 7408 aggrieved parties were analysed. In three out of the four study areas (SL, BA, MA), elephants caused the highest number of damage events compared to all other wildlife species, however, in TA, most fields were damaged by zebra. Furthermore, the greater one-horned rhino, hippopotamus, wild boar, bushpig, deer and antelope, as well as primates, caused damage to fields and harvests. Damage to houses and other property were nearly exclusively caused by elephants.

With this doctoral thesis I was able to show that season, crop availability, type and the phenological stage of the crop played an important role for crop damaging behavior of herbivores (Chapter 2). Elephants especially damaged rice, maize and wheat and preferred all crop types in a mature stage of growth. In contrast, rhinos preferred wheat to rice and similar to antelope and deer, they preferred crops at earlier stages of growth, before ripening. Crop damage by wildlife species varied strongly in size; most damages fell below 40% of the total harvest per farmer, but in several cases (3 to 8% depending on the study area), harvests were completely destroyed. Interestingly, during times of low nutritional availability in the natural habitat (dry season), crop damages in all four study areas were significantly less than during other seasons.

In all four study areas, crop protection strategies, such as active guarding in the fields, chasing wildlife with noise or fire torches or erecting barriers, were used. In some cases protection strategies were combined. Analysis of data revealed that traditional protection strategies did not reduce the costs of damage (Chapter 3). In some cases, costs of damage, on protected fields were even higher than for unprotected fields. Only in MA did strategic and cohesive guarding significantly reduce crop damage by wildlife species.

Besides damage in the fields, elephants also caused damage to properties in the villages. In search for stored staple crops, they damaged houses, grain stores and kitchens. Such damage was analysed in three study areas (SL, BA, MA) (Chapter 4). Although property damage occurred less frequently compared to crop damage in the fields, the mean cost of this damage was found to be double in BA/MA and four times higher in SL, compared to the costs of crop damage in the fields. It is further remarkable that property damage significantly increased towards the dry season, when the harvest was brought into the villages.

The findings of this study underpin the assumption that wildlife herbivores, especially elephants, are lured to fields and crops because the highly nutritional food (crop) being readily available. Traditional crop protection is cost and labour intensive and does not reduce the costs of damage. For this reason, crop types, which are thought to be not consumed by elephants were systematically tested on their attractiveness in field experiments in SL and BA (Chapter 5 and 6). In SL, lemon grass, ginger and garlic were proven to be less attractive to African elephants than maize and in BA, basil, turmeric, chamomile, coriander, mint, citronella and lemon grass were found to be less attractive to Asian elephants than rice.

The results of this doctoral thesis are relevant for the management of wildlife conservation as they can lead to new approaches to the mitigation of HWCs in African and Asian countries. Finally, specific needs for more scientific research in this field have been identified.

ZUSAMMENFASSUNG

Mit steigendem Bevölkerungswachstum und dem damit verbundenen Ressourcenverbrauch schwinden die natürlichen Lebensräume vieler Wildtiere. Die zunehmende Fragmentierung von Naturlandschaften und die Ausbreitung von besiedelten und bewirtschaften Flächen vermehrt die Interaktion zwischen Menschen und Wildtieren. Dort, wo Wildtiere einen negativen Einfluss auf Menschen ausüben (physisch, ökonomisch oder psychologisch) und diese einen negativen Einfluss auf die Wildtiere haben, sprechen wir von Mensch-Wildtier-Konflikten. Diese Definition beinhaltet, dass Schäden und Kosten auf beiden Seiten entstehen können. Weiterhin ist zu beachten, dass die Wurzel dieser Konflikte häufig in Auseinandersetzungen verschiedener Personengruppen liegt, beispielsweise der Vertreter des Arten- und Naturschutzes und wirtschaftlicher Interessengruppen. Die bedeutendsten Biodiversitätsvorkommen der Erde befinden sich in sog. Entwicklungsländern, die von hoher Armut geprägt sind. Die staatliche Unterstützung der ländlichen Bevölkerung ist meist gering, und die Umsetzung des Biodiversitätsschutzes erfordert Förderung durch Dritte.

Menschen, die am Rande von Nationalparks oder anderen Naturschutzgebieten leben, konkurrieren mit Wildtieren um die natürlichen Ressourcen und erfahren nur wenig Hilfestellung durch ihre Regierung und Naturschutzorganisationen. Besonders für Menschen, die allein von der Landwirtschaft abhängig sind und keine ökonomischen Alternativen haben, kann ein Wildtierschaden auf dem Feld, der Verlust von Vieh, die Zerstörung eines Getreidespeichers oder gar die Verletzung durch ein Wildtier katastrophale Folgen haben. Wenn das Wildtier, welches den Schaden verursacht, durch internationales oder nationales Gesetz geschützt ist, darf der Geschädigte nicht zu letalen Maßnahmen greifen, sondern muss sich an die zuständige Behörde wenden, die selten helfen kann. Unmut, Ärger oder gar Hass entsteht, und die Unterstützung für Arten- und Naturschutzaktivitäten sinkt.

Aus diesem Grund wurden Mensch-Wildtier-Konflikte von der IUCN (International Union for Nature Conservation) zu einem der wichtigsten Naturschutzthemen unserer Zeit erklärt, die besonders für große und bedrohte Tierarten, wie Afrikanische und Asiatische Elefanten (*Loxodonta africana* und *Elephas maximus*), aber auch für Flusspferde (*Hippopotamus amphibius*) und Panzernashörner (*Rhinoceros unicornis*) sowie die großen Prädatoren, wie Afrikanische Löwen (*Panthera leo*), Leoparden (*Panthera pardus*) und Tiger (*Panthera tigris*) eine herausragende Bedeutung haben. Seit sich die IUCN Species

Specialist Group seit Ende der 1990er Jahre mit diesem Thema befasst, sind viele Studien zu Mensch-Wildtier-Konflikten durchgeführt worden, die sich i.d.R. auf einzelne Gebiete oder Tierarten beziehen. Auch gibt es bisher kein allgemeingültiges oder empfohlenes Aufnahmeverfahren für Schäden, die durch geschützte Wildtierarten entstanden sind. Lediglich die *African Elephant Specalist Group* der IUCN hat 1998 eine Empfehlung zur Aufnahme von Ernteschäden durch Elefanten herausgegeben.

In der vorliegenden Arbeit werden Mensch-Wildtier-Konflikte in Asien und Afrika verglichen, wobei auf alle herbivoren Wildtiere mit einem Gewicht über 5 kg eingegangen wird, die als Schädlinge identifiziert wurden. Im Rahmen meiner Arbeit bei der französischen Naturschutzorganisation *Awely, des animaux et des hommes* entwickelte ich ein detailliertes Aufnahmeverfahren, welches in allen terrestrischen Ökosystemen Anwendung finden kann, für jegliche Art von Konflikten und jede Tierart (Chapter 2). Dieses Konflikt-Aufnahmesystem wurde in der vorliegenden Arbeit angewendet (Chapter 2-4). Es besteht aus der Begutachtung des Schadens durch geschulte, unabhängige Gutachter und einer Befragung der Geschädigten. Die Informationen werden in Formulare eingetragen und in eine eigens von mir dafür entwickelte Mensch-Wildtier-Konflikt-Datenbank übertragen. Dieses Aufnahmesystem besteht aus vier Konfliktkategorien: (1) Ernteschäden auf Feldern, (2) Schäden an Eigentum, (3) Schäden an Nutztieren und (4) Personenschäden durch Wildtiere. Die Gutachter wurden von mir selbst ausgewählt und geschult. Dabei hatte ich darauf geachtet, dass die Mitarbeiter aus dem Studiengebiet stammen, die lokale(n) Sprache(n) sprechen und die traditionellen Strukturen kennen. Sie wurden in der Aufnahme der Ernteschäden geschult (Vermessen der Schäden, Lesen von Wildtierspuren und Führen von Interviews) und berechneten die Schadenshöhe unter Berücksichtigung des voraussichtlichen Ernteverlustes und des aktuellen Marktpreises. Die Aufnahme der Wildtierschäden erfolgte in vier Studiengebieten in zwei afrikanischen und zwei asiatischen Ländern: Süd-Luangwa/Sambia (SL), Tarangire/Tansania (TA), Bardia/Nepal (BA) und Manas/Indien (MA). Die Daten wurden über einen Zeitraum von sechs Jahren (2009 bis 2014) in Sambia, Nepal und Indien und zwei Jahren (2010 bis 2011) in Tansania erhoben. Weiterhin wurden zwei Feldversuche, einer in Afrika (SL) und einer in Asien (BA), durchgeführt, um herauszufinden, ob Elefanten bestimmte Feldfrüchte bevorzugen oder meiden (Chapter 4 und 5). Dazu wurden Testfelder mit verschiedenen Nutzpflanzen angelegt und die Schäden, die durch Elefanten und andere Wildtiere auftraten, quantifiziert. Die Daten wurden statistisch ausgewertet unter Einbezug komplexer statistischer Modelle

(Generalized Linear Models und Generalized Mixed Models) sowie weiterer statistischer Tests, wie des Chi-quadrat- oder des Kruskal-Wallis-Tests.

In der vorliegenden Arbeit wurden 3,306 Schadensfälle mit insgesamt 7,408 Geschädigten analysiert. In drei der vier Studiengebiete (SL, BA und MA) richteten Elefanten häufiger Schäden an als alle anderen Wildtiere, während in TA die meisten Felder durch Zebras (*Equus quagga*) geschädigt wurden. Weiterhin richteten auch Nashörner, Flusspferde, Wildschweine (*Sus scrofa, Potamochoerus larvatus, Phacochoerus africanus*), Hirsche (*Axis axis*) und Antilopen (*Aepyceros melampus, Taurotragus oryx* und *Boselaphus tragocamelus*) sowie Affen (*Chlorocebus pygerythrus*, *Papio cynocephalus*, *Semnopithecus hector*) Schäden auf Feldern an. Schäden an Gebäuden und anderem Eigentum wurden fast ausschließlich durch Elefanten verursacht.

Mit dieser Arbeit konnte gezeigt werden, dass die Jahreszeit, die Verfügbarkeit von Feldfrüchten sowie deren Art und Wachstumsphase das Verhalten von Wildtieren auf Feldern beeinflusst (Chapter 2). Feldfrüchte, die für den menschlichen Verzehr angebaut werden, sind auch für Wildtiere hoch attraktiv, da sie einen hohen Nährwert haben und nur in geringem Maße chemisch oder physisch verteidigt sind. Elefanten schädigten 16 verschiedene Kulturpflanzen und bevorzugten Reis (*Oryza sativa*), Mais (*Zea mays*) und Weizen (*Triticum aestivum*), die anteilig häufiger gefressen als zertrampelt wurden, im Vergleich zu anderen Feldfrüchten, wobei Elefanten alle Feldfrüchte besonders im reifen Zustand bevorzugten. Auch Zebras und Wildschweine bevorzugten reifere Feldfrüchte. Nashörner hingegen bevorzugten Weizen gegenüber Reis, und ähnlich wie Antilopen oder Hirsche präferierten sie Feldfrüchte vor der Reifephase. Für Affen und Flusspferde konnten keine signifikanten Unterschiede in der Präferenz von bestimmten Kulturpflanzen und ihrem Reifegrad festgestellt werden. Es ist zu bemerken, dass während der Trockenzeit, in der weniger Nahrung im natürlichen Lebensraum vorhanden ist, Schäden an Kulturpflanzen in allen vier Studiengebieten signifikant weniger auftraten als zu anderen Jahreszeiten.

Wildschäden auf Feldern können stark in der Größe variieren. In allen vier Studiengebieten lagen die meisten Schadensgrößen durch Wildtiere unter 40% der Ernte (Chapter 2). Die größten Schäden wurden von Elefanten (SL, BA, MA) und Elenantilopen (*B. tragocamelus*) (TA) verursacht. In den afrikanischen Studiengebieten wurde im durchschnittlichen Schadensfall mehr als das Monatseinkommen eines Bauern zerstört. In den asiatischen Studiengebieten beliefen sich die durchschnittlichen Schadensgrößen auf etwa die Hälfte des Monatseinkommens eines Bauern. In vielen Fällen (3 bis 8% je nach Studiengebiet) wurden Ernten komplett vernichtet. Solch katastrophale Ausmaße konnten besonders bei Schäden durch Elefanten beobachtet werden. In allen vier Studiengebieten wurden auf der Mehrheit der Felder Schutzmaßnahmen gegen Wildtiere ergriffen (Chapter 3). Bauern bewachten ihre Kulturen, indem sie die Nächte auf dem Feld verbrachten und Wildtiere mit Lärm und Feuer verscheuchten, sobald sie sie entdeckten (active guarding), oder sie schliefen im nahegelegenen Dorf oder in temporären Hütten und rannten hinaus, um die Tiere zu verjagen, sobald sie sie bemerkten (passive guarding). In anderen Fällen wurden Barrieren errichtet, z.B. Hecken aus dornigen Pflanzen, Draht- oder Elektrozäune (barriers). In einigen Fällen wurden verschiedene Schutzmaßnahmen kombiniert. Die Ergebnisse dieser Arbeit zeigten, dass sich die Bewachung nicht negativ auf die Schadenshöhe auswirkte, sondern im Gegenteil, die Bewachung die Schadenshöhe im Vergleich zu nicht bewachten Feldern in die Höhe trieb.

Nur in MA war eine geringere Schadenshöhe auf aktiv bewachten Feldern zu verzeichnen. Dies ist dadurch zu erklären, dass in MA die aktive Bewachung strategisch und von lokal organisierten Bauerngruppen durchgeführt wurde, die in Wachschichten arbeiteten und gemeinsam große landwirtschaftliche Flächen mit Feldern mehrerer Bauern bewachten. Dieses System unterscheidet sich stark von den Bewachungssystemen in den anderen Studiengebieten, in denen jeder Bauer sein eigenes Feld bewachte und die Tiere nicht-strategisch vertrieben wurden. Wenn aber große Wildtiere unbedacht verjagt wurden, konnten sie durch panikartiges Fluchtverhalten und Zertrampeln der Kulturpflanzen noch höhere Schäden verursachen oder auf das nächste Feld fliehen, wo sie weitere Schäden anrichteten.

Aufgrund der Ergebnisse dieser Studie wurde die Hypothese aufgestellt, dass nicht-strategisches Bewachen von Feldern keinen Vorteil gegenüber der Nichtbewachung bringt. Wurden Felder jedoch gemeinschaftlich und strategisch bewacht und die Wildtiere organisiert zurück in ihren natürlichen Lebensraum gescheucht, so konnte diese Maßnahme Wildschäden signifikant reduzieren.

Neben Schäden auf Feldern waren Elefanten auch für Schäden an Gebäuden verantwortlich. Auf der Suche nach Lebensmitteln und eingelagerter Ernte beschädigten sie Wohnhäuser, Getreidespeicher und Küchen. Solche Schäden wurden in den drei Studiengebieten SL, BA und MA beobachtet und analysiert (Chapter 4). Zwar traten Schäden durch Elefanten an Gebäuden wesentlich seltener auf als auf Feldern, doch die durchschnittliche Höhe der Schäden pro Schadereignis betrug je nach Studiengebiet das Doppelte bis Vierfache von Ernteschäden. In den beiden asiatischen Studiengebieten überstiegen die Gesamtschadenshöhen von Gebäudeschäden inklusive der Schäden an eingefahrener Ernte die der gesamten Ernteschäden auf den Feldern im Zeitraum von sechs Jahren. Weiterhin war auffällig, dass die Schäden an Gebäuden besonders in den Jahreszeiten auftraten, wenn die Ernte bereits eingefahren und eingelagert worden war.

Die Ergebnisse dieser Arbeit weisen darauf hin, dass große Herbivore, besonders Elefanten, gezielt auf Felder und in Dörfer eindrangen, da dort leicht verwertbares Futter großflächig verfügbar war. Bewachungssysteme waren kosten- und arbeitsintensiv und reduzierten die Schadenshöhe nicht wie gewünscht. Da von schmackhaften und nahrhaften Feldfrüchten immer eine Lockwirkung auf Elefanten ausgehen wird, werden auch die Bewachungssysteme immer notwendig sein. Mit dem Ziel, die Lockwirkung, die von den landwirtschaftlichen Flächen ausgeht, zu reduzieren, wurde in dieser Arbeit die Attraktivität verschiedener Feldfrüchte auf wildlebende Elefanten in Afrika (Chapter 5) und Asien (Chapter 6) getestet. Auf Testfeldern wurden Feldfrüchte angebaut, von denen Bauern berichtet hatten, dass Elefanten sie nicht anrühren würden und die größere Mengen sekundärer Pflanzeninhaltsstoffe enthielten. In SL waren dies Ingwer, Knoblauch, Zitronengras und Zwiebeln, in BA hingegen wurden Basilikum (*Ocimum basilicum*), Gelbwurz (*Curcuma longa*), Kamille (*Matricaria chamomilla*), Koriander (*Coriandrum sativum*), Minze (*Mentha arvensis*), Zitronella (*Cymbopogon winterianus*) und Zitronengras (*Cymbopogon flexuosus*) auf Testfeldern angebaut und gegen eine Kontrolle attraktiver Kulturpflanzen getestet. In beiden Versuchen wurden Mais bzw. Reis signifikant häufiger und mehr verzehrt als die Testpflanzen. Die Testpflanzen wurden in SL nur zu sehr geringen Anteilen von den Elefanten verzehrt, in BA gar nicht. Damit wurde der erste Beweis erbracht, dass Pflanzen mit einem hohen Gehalt von sekundären Inhaltsstoffen, sogenannten „Antifeedants", für Elefanten weniger attraktiv sind als die Getreidearten Mais und Reis. Ist der Markt für den Verkauf solcher aromatischer und medizinischer Pflanzen oder ihrer veredelten Produkte (z.B. ätherische Öle) vorhanden, kann mit ihnen ein mindestens genauso gutes Einkommen wie mit traditionellen Feldfrüchten erzielt und Mensch-Wildtier-Konflikte vermieden werden.

Die Ergebnisse dieser Arbeit zeigen neue Ansätze für die Lösung von Mensch-Wildtier-Konflikten in Asien und Afrika auf. Mit dem Wissen, dass Ernteschäden nicht das ganze Jahr über gleich häufig und gleich stark auftreten und bestimmte Tierarten/-gruppen bestimmte Reifegrade von Feldfrüchten bevorzugen, können Schutzsysteme zeitlich auf die Hauptkonfliktzeit begrenzt werden. Dafür sollte zuerst definiert werden, welche Tierarten/-gruppen die schwerwiegendsten Schäden verursachen, um dann den richtigen Zeitpunkt der Bewachung zu wählen. Des Weiteren ist dringend eine Veränderung der Bewachungssysteme geboten, da das unkoordinierte aktive und passive Bewachen von Feldern die Wildschäden nicht reduzierte, sondern im Gegenteil höhere Kosten verursachte, als die Kosten der Schäden bei unbewachten Feldern betrugen. Eine gut geplante, strukturierte und gemeinschaftliche Bewachungsstrategie jedoch kann die Wildschäden signifikant reduzieren. Weiterhin ist es zwingend notwendig, die Schäden an Gebäuden sowie weiterer Nach-Ernteverluste zu reduzieren. Elefanten, die in Dörfern nach Futter suchen, können große Sachschäden verursachen und darüber hinaus Menschen gefährden. Aus diesem Grund empfehle ich dringend die Trennung der Nahrungsquellen von Schlafplätzen. Getreide sollte außerdem elefantensicher verstaut werden, um zum einen möglichst wenig Lockwirkung auf Elefanten auszuüben und zum andern keine positive Verstärkung durch Erfolg zu bewirken. Anstatt mit arbeits- und kostenintensiven Maßnahmen Wildtiere von hochattraktiven Feldern fern zu halten, sollten neue Wege beschritten werden. Eine Möglichkeit ist die Anpflanzung von Feldfrüchten, die weniger oder unattraktiv für Wildtiere (insbesondere Elefanten) sind, in Grenzgebieten entlang von Nationalparks oder in wildtierreichen, landwirtschaftlich genutzten Gebieten. Auch zur Abgrenzung von attraktiven Wildtierkorridoren zu landwirtschaftlich genutzten Flächen ist die Nutzung solch unattraktiver Nutzpflanzen denkbar. Das besondere Potenzial der Nutzung dieser alternativen Feldfrüchte ist, dass anstelle von kostenintensiven Versuchen, sich mit den bisher üblichen Methoden gegen Elefanten zu wehren, mit diesen neuen Kulturpflanzen zusätzlich ein sicheres Einkommen geschaffen werden kann.

In diesem Bereich besteht weiterhin großer Forschungsbedarf. Es gilt zu klären, ob das Meideverhalten der Elefanten auch über längere Zeiträume bestehen bleibt, z.B. aufgrund einer Unverträglichkeit, oder ob nur Unbekanntes gemieden wird. Des Weiteren gibt es noch eine Vielzahl weiterer potenziell unattraktiver Pflanzen, die getestet werden sollten. Die Identifizierung von Pflanzen mit Inhaltsstoffen, die unattraktiv auf Elefanten oder andere große Herbivore wirken, wäre für die Verminderung und Vermeidung von Mensch-Wildtier-Konflikten sehr nützlich und würde langfristig dem Artenschutz dienen.

Um die Koexistenz großer Herbivoren und Menschen zu gewährleisten, müssen neue Wege beschritten werden. Mehr Zusammenarbeit verschiedener Forschungsdisziplinen wäre hierbei wünschenswert (Biologie, Chemische Ökologie, Sozioökonomie). Auch ist es zwingend notwendig, die Aufnahme von Daten zu Mensch-Wildtier-Konflikten in und am Rande von Naturschutzgebieten zu standardisieren, um tiefere und allgemein gültige Erkenntnisse über lange Zeiträume und Ländergrenzen hinweg zu erzielen.

1. GENERAL INTRODUCTION

1.1. People and wildlife in conflict

Since the beginning of farming, people have needed to protect their crops and livestock against certain wildlife species. The trapping and poisoning of rodents, as well as the use of cats to reduce crop damage by mice and rats, have been described as the first methods of wildlife damage management, about 3000 years B.C. in Egypt (Drummond 1992; Fitzwater 1990). Settlers in all parts of the world have fought against wildlife species to protect their crops, livestock and habitation. With the development of firearms, large herbivores and carnivores have been eradicated systematically, causing the local extinction of species, such as wolves in Europe or the bison in colonial America (Conover 2002).

More recently, with the increasing demand for space by a rising human population, wildlife habitats have been turned into human-dominated landscapes, leaving only islands of protected areas as refuges for wild species (DeFries et al. 2005). Furthermore, following the massive decline of many wildlife populations through unsustainable hunting, habitat degradation and fragmentation, many wildlife species have been protected by national and international law. Therefore, the use of lethal methods to decrease crop or livestock damage by such species has been banned or strongly restricted by governmental authorities. As a result, farmers saw their livelihoods threatened by wildlife species which were legally protected. When governmental authorities were facing economic and governance constraints they had great difficulties to address these problems adequately (Karanth and Nepal 2012).

Rural populations carrying the burden of wildlife conservation feel disadvantaged and neglected by their governments, which may result in opposition and open confrontation to organisations and institutions representing wildlife conservation (Dickman 2010). Conflicts arise between rural communities within or close to protected areas and the governmental bodies enforcing conservation laws. Consequently, human-wildlife conflicts (HWC) are highly important conservation issues, as they are linked to wildlife population declines and even to the extinction of entire species (Dickman 2012). I am using the term “wildlife” in the sense as defined by Henle et al. (2013): “medium to large-sized terrestrial vertebrates that are hunted by humans as resources, trophy or because they compete with humans for food and space”.

HWCs have been defined as situations where “wildlife impacts humans negatively, and where humans likewise negatively impact wildlife” (Draheim et al. 2015). The negative impact by wildlife species does not only include monetary costs through the loss of property, costs of protection strategies or costs caused by accidents with wildlife, but also includes the indirect costs caused by enforced labour needed to guard crops (Barua et al. 2013), illnesses contracted through unprotected exposure to, for example, malaria-harbouring mosquitos during night guarding in the fields, or negative effects on education due to children protecting livestock or crops instead of attending school (Mackenzie et al. 2015). In short, HWCs are complex scenarios with often underlying social dimensions (Dickman 2010).

1.2. Strategies of HWC assessment and analysis

Up to this day, the determinants for HWCs have not been fully understood. To be able to tackle this conservation issue effectively, ecological and social factors have to be taken into consideration and comparable HWC data need to be produced.

A first step was made to produce more comparable data with the African Elephant Specialist Group of the IUCN. This group discussed and set-up plans to foster the research on human-elephant conflicts and has published and recommended a standardized approach for the assessment of elephant conflicts (Hoare 1998; Parker et al. 2007). However, this effort was limited to conflicts with African elephants (*Loxodonta africana* Blumenbach) and Asian elephants (*Elephas maximus* L.) and with a focus on crop damage incidents. Furthermore, multiple studies have been conducted using different research designs and methods, mostly focussing on one species or taxon (Dickman 2012). Many research and conservation organisations have developed their own methods and tools to evaluate and monitor HWCs, however, most of them have been developed without using comparable formats. In Colorado, USA livestock predation by coyotes (*Canis latrans* Say) is documented in coyote reports by official sites (Poessel et al. 2013) and in Ontario, Canada the Ministry of Natural Resources keeps a database on reported American black bear (*Ursus americanus* Pallas) conflicts (Howe et al. 2010). In addition, governmental databases of wildlife-vehicle collisions exist in the USA (Snow et al. 2015). For attacks by crocodiles (*Crocodylus* spp.) the internet based database CrocBITE has been developed to monitor frequencies of attacks on humans and to identify problem areas (Pooley 2015). In Sumatra, Indonesia an online database for conflicts with tigers (*Panthera tigris* L.) has been launched (WWF 2015), whilst in Cambodia a national database for elephant crop damage has been installed in 2004 (Webber et al. 2011), and a system to record crop damage by elephants by SMS has been developed at the experimental level in Zimbabwe and Mozambique (Le Bel et al. 2016). However, the lack of comparable data decreases the possibility of analysing factors and drivers of HWCs between different regions and species, thus making a global understanding impossible (Sitati et al.

2003). The need for a uniform system of data collection and a standardized database has been identified for the support of management decisions to reduce livestock losses and human attacks by tigers (Goodrich 2010; Nyhus and Tilson 2004) as well as fish predation by otters (*Lutra* spp.) (Poledníková et al. 2013) and could also be applied to other species and regions. Thus, a database with accurate spatial indication and defined terms is needed (Poessel et al. 2013).

To be able to compare different types of HWCs, involving multiple species in different countries and social settings, I have developed an HWC assessment scheme taking into consideration spatial, ecological, social and economic factors (Fig. 1). Damage caused by wildlife species was assessed by locally trained independent enumerators (HWC officers). In each study area an informant was selected in each village, to inform the trained HWC officers about the occurrence of damage. Within 24 hours a detailed assessment was carried out. The assessment comprised of field observations (tracks, marks, damage size, and landscape characteristics), marking of the geo-reference, as well as structured interviews with victims and witnesses (Plate 1). Further details on the assessment scheme are found in Chapter 2.

For this assessment four types of HWCs were categorized: crop damage (crops on farmland damaged by herbivores), property damage (houses, food storages, livestock shelters, fences or vehicles damaged), livestock predation (livestock injured, killed and/or displaced by predators), and human accidents with wildlife species, either herbivores or carnivores, leading to human injuries or death (Plate 2).

The assessments were based on damage events; these were defined as damage by one wildlife species (group or individuals) caused during one time period (e.g. one night) in a defined area. During the detailed conflict assessment for each damage event one *General Conflict Information Form* was filled (Fig. 1a), followed by one specific damage form per victim (*Crop Raiding Form, Property Damage Form, Livestock Predation Form and Human Injuries/Death Form*). An elephant damaging the fields of four different farmers and a shelter in one night, for example, was recorded as one damage event with four crop damage victims and one property damage victim. In cases where conflicts could not be visited in due time, information was recorded in the *Brief Conflict Assessment Form* (Fig. 1b). The HWC assessment forms are found in the Appendix of Chapter 2.

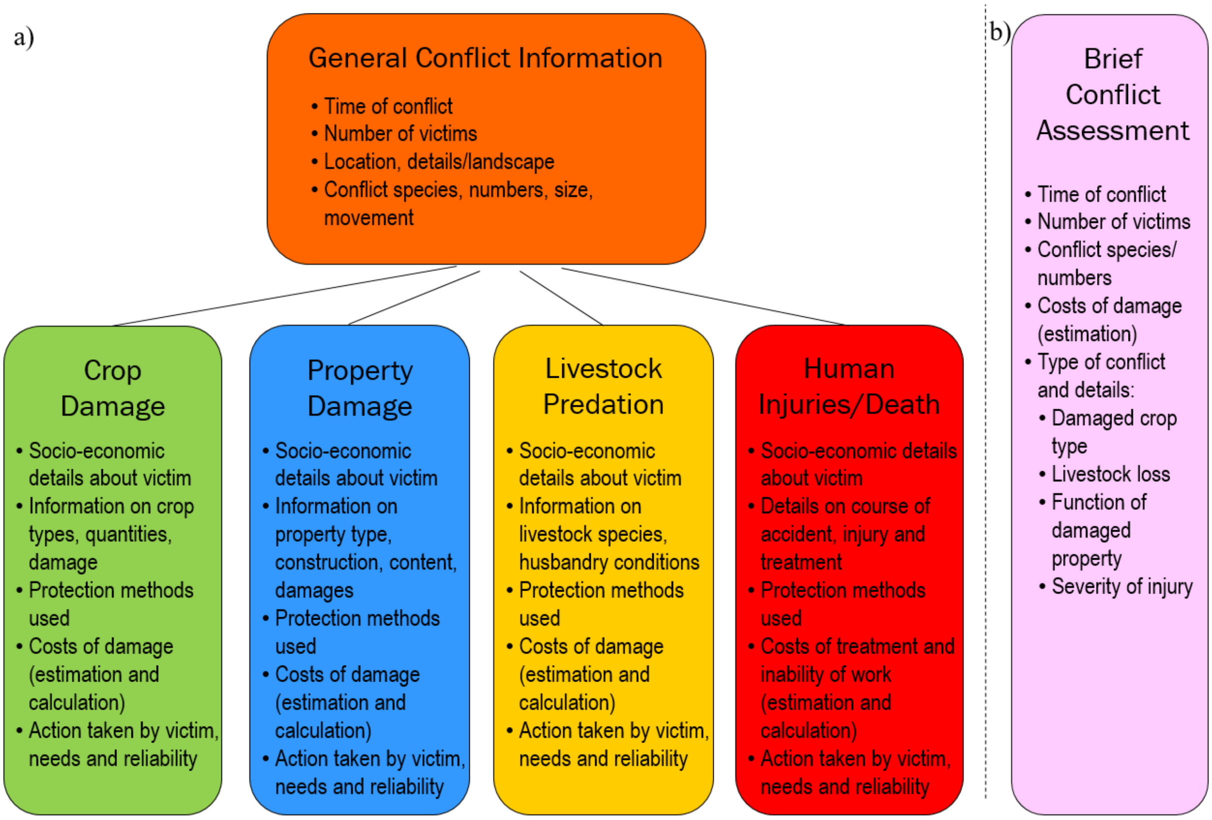


Fig. 1: Structure of the HWC monitoring scheme including a) detailed and b) brief conflict assessment. For the detailed conflict assessment the "General Conflict Information" form (orange) is combined with one "Crop Damage", "Property Damage", "Livestock Predation" and/or "Human injuries/Death" form for each damage per victim. The "Brief Conflict Assessment" is conducted instead of the detailed assessment, only in exceptional cases.

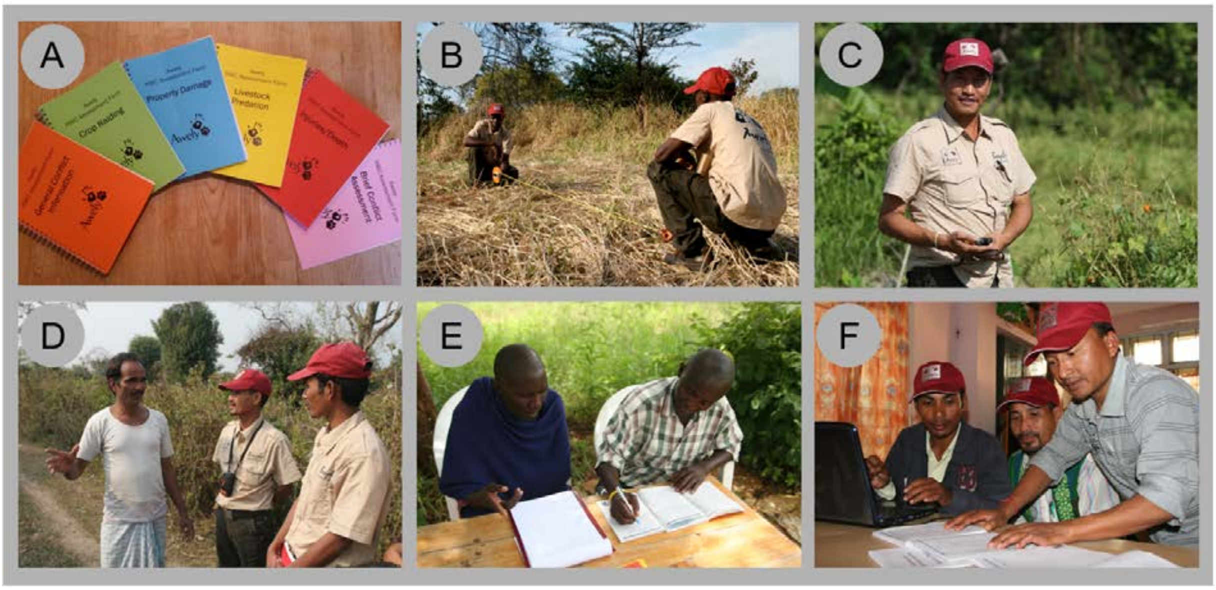


Plate 1: Pictures showing steps of the HWC assessment. (A) Six booklets with HWC conflict assessment forms, colours corresponding to Fig. 1. (B) HWC officers in Zambia measuring the size of a crop damage. (C) Marking of the GPS location by HWC officer in Nepal. (D) Interview with a victim by HWC officers in India. (E) An HWC officer in Tanzania taking down information on the HWC assessment form. (F) Data entry into the HWC database by an HWC officer team in India. Pictures taken by Eva Gross and Renaud Fulconis/*Awely*.

Plate 2: Pictures of wildlife damage in the study areas. (A) Crop damage (rice) by the greater one-horned rhino in Manas/India. (B) Property damage by elephants in South Luangwa/Zambia. (C) Livestock predation by hyenas in Tarangire/Tanzania. (D) Woman killed by elephant in Bardia/Nepal. Pictures taken by *Awely Red Caps.*

1.3. Areas of human-wildlife conflicts

Damage caused by endangered wildlife species to humans or their property are reported from all over the world. Garbage habituated black bears (*U. americanus*) are attracted to urban areas and readily adapt to artificial food sources in North America or damage apiaries or orchards (Spencer et al. 2007). In the heather moorlands of the UK, hen harriers (*Circus cyaneus* L.) are accused of predating on privately managed grouse (Thirgood and Redpath 2008). Conflicts between fish-eating vertebrates and fishermen are common in many European countries. Grey seals (*Halichoerus grypus* Fabricius) in Finland and Sweden, Eurasian otters (*Lutra lutra* L.) from Czech Republic to Germany and Portugal, and great cormorants (*Phalacrocorax carbo* L.) in Denmark, have been illegally hunted and poisoned as they have been regarded as an economic threat to fish farmers and fishermen (Henle et al. 2013; Jepsen and Olesen 2013; Myšiak et al. 2013; Poledníková et al. 2013), whilst wolves (*Canis lupus* L.) were completely eliminated from Germany in the late 19th century by organized persecution from farmers due to livestock predation (Ansorge and Schellenberg

2007). Whereas the fear of livestock losses to predators is comprehensible to some extent, other species have been hunted to near extinction, due only to superstition or misinformation. The bearded vulture (*Gypaetus barbatus* L.), which mainly feeds on bones, was said to prey not only upon livestock, but also on human babies (Robin et al. 2003; Schaub et al. 2009). As a consequence of this unjustified bad image this species was eradicated from the Alps in the early 20th century.

In African and Asian countries, where the remaining habitats of wildlife species overlap with expanding rural populations, HWCs are especially numerous and intense (Distefano 2005; Naughton-Treves and Treves 2005). In the Sundarbans in Bangladesh tigers are perceived as the most common risk to the lives of inhabitants living close to the tiger habitat (Inskip et al. 2013). Primates, such as baboons (*Papio* spp. Erxleben), redtail monkey (*Cercopithecus Ascanius* Audebert) or chimpanzees (*Pan troglodytes* Blumenbach) damage crops, causing massive losses to farmers in African countries (Hoffman and O'Riain 2012; McLennan and Hill 2012; Naughton-Treves 1998), whilst langurs (*Semnopithecus* spp. Presbytina) and macaques (*Macaca* spp.) are found to damage crops in Asia (Knight 1999; Linkie et al. 2007). Elephants, both African and Asian, are known to cause massive damage to crops in areas where their habitats overlap with human dominated landscapes (Chen et al. 2016; Naughton-Treves and Treves 2005; Pant et al. 2015; Santiapillai et al. 2010). Besides the damage of crops in fields, they can also damage stored crops in the villages, by breaking down granaries or houses. In the semi-arid parts of Africa, red-billed queleas (*Quelea quelea* L.) cause massive damage to rice and sorghum fields, with losses of up to 50% of the harvest (Oschadleus 2009). Furthermore, poverty and low resilience increases the severity of HWC consequences. Farmers who do not have the means to absorb crop or livestock losses, are more likely to face substantial problems than those able to compensate the losses (Dickman et al. 2011; Mackenzie and Ahabyona 2012).

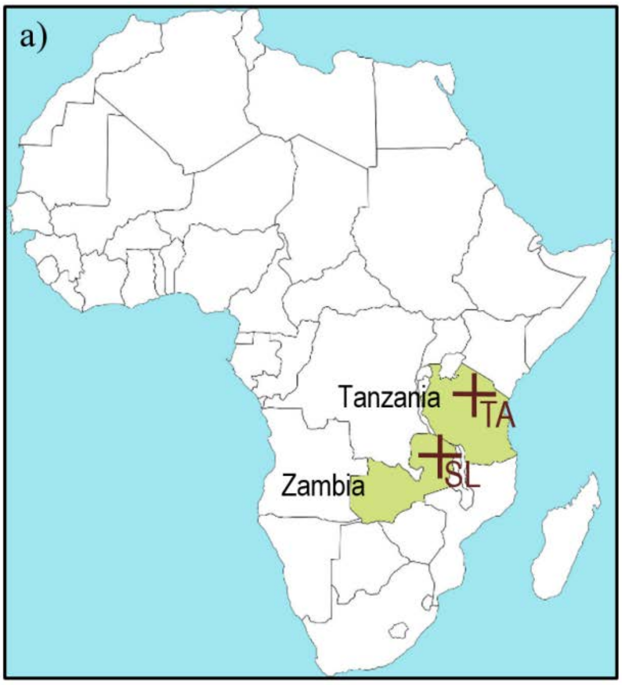
This thesis studies HWCs from two African and two Asian countries for six consecutive years. All study areas were part of the "Red Caps programme" of the French conservation organisation, *Awely, des animaux et des hommes*, which aims to develop community based methods to achieve a peaceful coexistence between people and wildlife (Fulconis and Gross 2011).

1.3.1. South Luangwa, Zambia (SL)

The South Luangwa National Park (9050 km^2) is located in the Luangwa valley in the Eastern Province of Zambia (Fig. 2 a, lower cross). To the east the Luangwa River forms the natural border with the adjacent Lupande Game Management Area (GMA) (4840 km^2), which is subdivided into six chiefdoms (Nshimbi and Vinya 2014). The study area encompasses five chiefdoms (Kakumbi, Malama, Mnkanya, Msoro and Nsefu) located at 13°05’S to 13°32’S and 31°33’E to 31°57’E. The dominant vegetation types in this area are miombo woodlands *(Brachystegia, Julbernardia and Isoberlinia)* on higher elevations and mopane *(Colophospermum mopane)* woodlands as well as a mosaic of grasslands and alluvial woodland on the valley floor (Astle et al. 1969). The Luangwa valley holds the largest elephant (*L. africana*) and African lion (*Panthera leo* L.) populations of the country (Becker et al. 2013), large populations of herbivores such as Crawshay’s zebra (*Equus quagga crawshayi* De Winton), African buffalo (*Syncerus caffer* Sparman) and impala (*Aepyceros melampus* Lichtenstein), as well as top predators such as leopards (*Panthera pardus* L.) and African wild dogs (*Lycaon pictus* Temminck) (Frederick 2009). Human-wildlife conflicts have been recorded, especially with elephants, but also with the common hippopotamus (*Hippopotamus amphibious* L.), bushpig (*Potamochoerus larvatus* Cuvier) and yellow baboon (*Papio cynocephalus* L.) (Nyirenda et al. 2011).

The rainy season occurs from December to April, with annual rainfalls of <830 mm, followed by a cooler, green and dry intermediate season from May to July, with a minimum mean temperature of 15 °C, and then, a very hot dry season from August to November, with a maximum mean temperature of 36 °C (Astle et al. 1969).

Small-scale subsistence farming is the main agricultural activity in the study area. On rain-fed fields maize (*Zea mays* L.), sorghum (*Sorghum bicolor* Moench), finger-millet (*Eleusine coracana* (L.) Gaertn), pumpkins (*Cucurbita spp.* L.), and groundnuts (*Arachis hypogaea* L.) are cultivated for consumption and cotton (*Gossypium herbaceum* L.) is farmed as a cash crop (Nyirenda et al. 2011). The population of the Lupande GMA is calculated at 51,457 people living in 9,962 households (CSO 2012), utilizing about 45.4% of the GMA for living, agriculture and infrastructure (Watson et al. 2014).



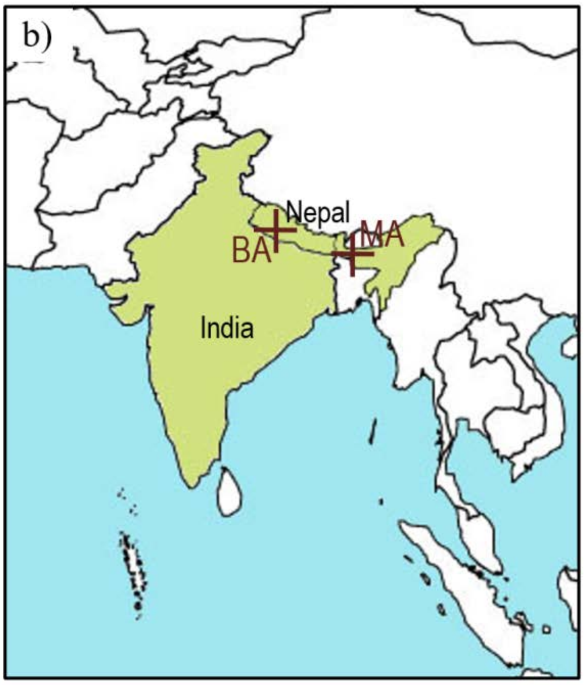


Fig. 2: Location of study sites indicated as brown crosses a) in Africa: South Luangwa (SL) in Zambia and Tarangire (TA) in Tanzania, b) in Asia: Bardia (BA) in Nepal and Manas (MA) in India.

1.3.2. Tarangire, Tanzania (TA)

The Tarangire National Park of Tanzania (2800 km^2) (Kissui 2008) is located in northern Tanzania (Fig. 1a), upper cross) and is part of the Tarangire-Manyara Ecosystem encompassing 35,000 km^2 (Prins 1987). The data collection in TA was conducted east of the Tarangire National Park, in the community of Loibor Siret in the Simanjiro District, with a total land holding of 550 km^2 (Lichtenfeld et al. 2014), located at 04°08' S to 04°64'S and 36°18'E to 36.43'E. The area is characterized by a diverse grassland ecosystem with bush thickets and acacia woodlands (Prins 1987) and belongs to one of East Africa's most important wildlife habitats with large numbers of migratory ungulates (Kissui 2008) such as the eastern white-bearded wildebeest (*Connochaetes taurinus albojubotus* Thomas), Burchell's zebra (*E. quagga burchellii* Gray), Thomson's gazelle (*Eudorcas thomsonii* Günther), Grant's gazelle (*Nanger granti* Brooke) and impala (*A. melampus*) (Prins 1987). Abundant large herbivores in this area include African elephants (*L. africana*), African buffalo (*S. caffer*) and common eland (*Taurotragus oryx* Pallas) (Kissui 2008). Livestock predation, mainly by spotted hyenas (*Crocuta crocuta* Erxleben), lions (*P. leo*) and leopards (*P. pardus*), has been described for the Tarangire-Manyara Ecosystem by Koziarski et al. (2016). Crop damage by elephants has been described by Pittiglio (2008) north of the study area. Furthermore, zebra, bushpig (*Potamochoerus larvatus* F. Cuvier), warthog (*Phacochoerus africanus* Gmelin), olive baboon (*Papio anubis* Lesson) and crested porcupine

(*Hystrix cristata* L.) have been recognised as crop damaging species in the area (Lewis et al. 2016).

With an annual rainfall between 450 and 600 mm the study area lies in the semi-arid ecological zone (Lichtenfeld 2005; Pratt et al. 1966). The long rainy season from March to June is followed by a long dry season from July to October. Short rains can occur in the months from November to February, but are not consistent (Kissui 2008; Lichtenfeld 2005). With a mean minimum temperature of 16 °C, July is the coldest month and temperatures rise to a mean maximum of 27 °C in March.

With seven people per km^2, the Simanjiro District is one of the lowest populated districts of Tanzania (Davis 2011). This area has been under agro-pastoral use for centuries. The most dominant ethnic group today are the Kisongo Maasai who started to utilise the Simanjiro plains in the mid-nineteenth century (Cooke 2007). Traditionally, they employed transhumant pastoralism (Baird and Leslie 2013), keeping cattle, goats and sheep, but in recent decades agricultural activities have increased, especially the farming of maize (*Z. mays*), groundnuts (*A. hypogaea*) and beans (*Phaseolus vulgaris* L.) so the description of herder-farmers, today, better reflects their economic activities (Cooke 2007).

1.3.3. Bardia, Nepal (BA)

The Bardia National Park (968 km^2) is located in the lowlands of Nepal (Fig. 2b, left cross), within the Terai Arc Landscape (49500 km^2), a transboundary conservation endeavour, linking 14 protected areas in Nepal and India (Gurung et al. 2015). South of the national park a buffer zone (BZ) of 327 km^2 was created in 1997, encompassing 17 Village Development Committees (VDC), the smallest political unit in rural Nepal (Thapa 2010). The study area is located in the western part of the BZ, comprising four VDCs (Manau, Pashupatinagar, Gola and Pathabhar) on the western bank of the Geruwa River and four VDCs (Suryapatuwa, Thakurdwara, Shivapur and Neulapur) on the eastern side, at 28°35’N to 28°22’N and 81°06 E to 81°19’E. Tropical deciduous Sal forest (*Shorea robusta–Buchanania latifolia* forest), as well as early riverine forests (*Dalbergia sissoo-Acacia catechu* forest) and tall grass flood plains (*Saccharum spontaneum-Tamarix* flood plain) (Dinerstein 1979; Jackson et al. 1994), characterize the vegetation of the south-western Bardia National Park. With 200 ungulates per km^2, the national park holds a high density of wildlife; the most abundant ungulate is the spotted deer (*Axis axis* Erxleben) followed by the hog deer (*A. porcinus* Zimmermann) and barking deer (*Muntiacus muntjak* Zimmermann) (Wegge et al. 2009). A small population of blue bull or nilgai (*Boselaphus tragocamelus* Pallas), the largest Asian antelope, is also found here. Furthermore, this area holds the largest number of resident elephants (*E. maximus*) in Nepal, a small population of reintroduced greater one-horned rhinoceros (*Rhinoceros unicornis* L.) and one of the highest recorded tiger (*P. tigris*) densities in the world (Flagstad et al. 2012; Wegge et al. 2009). The Terai grey langur (*Semnopithecus hector* Pocock) is frequently found in the forest areas and porcupines (*Hystrix indica* Kerr) are common nocturnal rodents. Elephant, rhino, blue bull, wild boar (*S. scrofa*), spotted deer and peacock (*Pavo cristatus* L.) have been described as species frequently damaging crops in the villages of the BZ (Thapa 2010). In addition, livestock predation by tigers has been documented in the BZs of the national park and, between 1994 and 2007, twelve people were killed due to tiger attacks (Bhattarai and Fischer 2014).

The climate of Bardia is influenced by the monsoon with rainfalls between July to October of around 1,500 mm annually (Dinerstein 1979). During monsoon, temperatures remain at the same level and fall in November to February, with January being the coldest month (14-16 °C) (Jackson et al. 1994). The hottest months are April/May with 35-40 °C, until the monsoon breaks. During the hot dry season, from March to June, severe water deficiency can occur (Flagstad et al. 2012; Jackson et al. 1994).

With about 306 people/km^2 (Thapa and Chapman 2010), the southern buffer zone of Bardia National Park is densely populated by the indigenous Tharu (50%), Hindu casts (44%) and people of Tibeto-Burman origin (6%) (Studsrod and Wegge 1995). Subsistence farming of rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), maize (*Z. mays*), lentils (*Lens culinaris* Medikus) and mustard (*Brassica campestris* L.), as well as livestock keeping, are the main economic activities (Studsrod and Wegge 1995; Thapa Karki 2013). BZ community forests make up 27% of the BZ and serve as sources of firewood, timber and fodder. Resources of the national park (firewood, thatch grass, fodder), however, play a major role in fulfilling household requirements, although collection of these resources is prohibited (Thapa and Hubacek 2011). In the eastern part of the study area, fields and farms are located directly at the forest border, whilst on the western part the river forms the natural boundary to agricultural land.

1.3.4. Manas, India (MA)

The Manas National Park (500 km^2) is located in the State of Assam in North-East-India (Borah et al. 2013) (Fig. 2b, right cross). In the north, it borders on the trans-boundary Royal Manas National Park of Bhutan and to the west and east it is framed by forests of the Manas Tiger Reserve (2840 km^2) (Goswami and Ganesh 2014). Towards the south, private agricultural and community lands and villages directly border on the Manas National Park without any BZ. The study area comprises 156 villages bordering on the national park, and a small part of the Tiger Reserve further west, within a belt of 3 km of width, falling under the ranges of Panbari, Bansbari and Bhuyanpara belonging to the Baksa and Chirang districts of the Bodoland Territorial Area District (Sarma et al. 2015). This area is located at 26°48’N to 26°36’Nand 90°46’E to 91°16’E. The Manas National Park is characterized by Sub-Himalayan high alluvial semi-evergreen forest, dominated by *Tetrameles nudiflora* R.Br., *Amoora wallichii* King, *Duabanga grandiflora* (DC.) Walp. and *Sterculia villosa* Roxb., Eastern Himalayan moist mixed meciduous forest dominated by *Lagerstroemia parviflora* Roxb., *Pterospermum acerifolium* (L.) Willd., *Bombax ceiba* L. and *Terminalia bellirica* (Gaertn.) Roxb., Assam valley semi-evergreen forest, dominated by *Dillenia indica* L., *Bischofia javanica* Blume, and Eastern wet alluvial grasslands (*Phragmites-Saccharum-Imperata*) (Champion and Seth 1968; Dabadghao and Shankarnarayan 1973). With approximately 50% coverage of the national park, grasslands play a major role for its ecological composition (Lahkar 2008). Due to its diversity in habitats, the Manas National Park is home to a wide diversity of fauna, including the tiger (*P. tigris*), leopard (*P. pardus*), pygmy hog (*Porcula salvania* Hodgson), hispid hare (*Caprolagus hispidus* Pearson) and Asian elephant (*E. maximus*) (Borah et al. 2013). Ungulates, such as wild water buffalo (*Bubalus arnee* Kerr), gaur (*Bos gaurus* Smith), hog deer (*A. porcinus*) and wild boar (*S. scrofa*) are abundant (Goswami and Ganesh 2014). Whilst the greater one-horned rhino (*R. unicornis*) had been poached to extinction in Manas in the 1990s, the re-introduction of rhinos from other Indian national parks, started in 2008, has led to a slowly increasing population (Lahkar et al. 2011; Sarma et al. 2009). Regular crop and property damage by elephants in the fringe villages of Manas National Park have also been observed (Lahkar et al. 2007; Nath et al. 2009).

Assam is influenced by the Southwest monsoon with heavy rains from June to September (Dikshit and Dikshit 2014). After the rains have stopped (October/November), the temperature slowly decreases, with January being the coldest month. The winter season from December to February has the driest months of the year. From March to May pre-monsoon rains occur (Jhajharia et al. 2012). This intermediate season is characterized by a rapid rise in temperature up to 30 °C, before the monsoon breaks (Lahkar 2008).

With approximately 191,700 people (38,500 households in 156 villages), the study area is heavily populated (1,280 people/km^2) and the population is still growing; between 2001 and 2011 the population of this area increased by 12.3% (India 2011). The indigenous

Bodo people make up 35.7% of the population, followed by Muslims with 15.7%, Bengalis with 11.6% and Koch with 10.3%. Assamese, Nepali, Adivasi and others complete the ethnically diverse make-up of the area (Sarma et al. 2015). Rice cultivation (*O. sativa*) and farming of black gram (*Vigna mungo* (L.) Hepper), mustard seeds and jute (*Corchorus spp.* L.), as well as animal husbandry and handlooming, are the main livelihood activities. The cultivation of various plants such as betel nut (*Areca catechu* L.), banana (*Musa spp.* L.) and vegetables, such as pumpkin (*Cucurbita pepo* L.), cucumber (*Cucumis sativus* L.), white gourd (*Benincasa hispida* (Thunb.) Cogn) and okra (*Abelmoschus esculentus* (L.) Moench), in homestead gardens is characteristic for the villages of the study area (Sarma et al. 2015).

1.4. Pre- and post-harvest protection strategies against wildlife herbivores in Africa and Asia

Since the beginning of farming from around 10,000 BC, people have developed methods to deter wildlife species and prevent crop damage (Larson et al. 2014). Children guarding the fields against birds, is one of the first methods of crop protection conveyed from the past (Conover 2002). In African and Asian countries, where subsistence farming requires low-cost measures which can be applied easily by the farmers themselves, various techniques to protect crops against wildlife species are in use to this day.

1.4.1. Barriers

Installations which aim at preventing species to enter crop fields, are frequently applied measures in African and Asian countries. Mostly, they were set up to keep out multiple species, not only wildlife but also free-ranging livestock. Plants with spines which hinder easy access by animals were planted systematically around fields, such as the common milk-hedge (*Euphorbia neriifolia* L.) to protect against deer or wild boars in India (Thapa 2010), or fast growing thorny trees and myrrhs (*Commiphora* spp. Jacq.) in Tanzania to protect against predators (Lichtenfeld et al. 2014). Bamboo fences have been erected to protect against wild and domestic herbivores in Asia, whilst the placement of thorny bushes around fields is used in semi-arid African countries. The digging of trenches to hinder elephants crossing has been used in Uganda (MacKenzie 2012) and India (Gubbi et al. 2014). Fences, electric or non-electric, have been installed around villages, around fields or along national parks (Hoare 2003). A disadvantage of all of these barrier systems was that they required high maintenance; the voltage of electric fences was reduced when high grasses were touching the stances, trenches needed to be dug out after the rains and natural fences needed to be re-planted regularly.

1.4.2. *Early warning systems*

Early warning systems were used to warn farmers about approaching wildlife, such as trip-alarm techniques that produce noise when wildlife crosses (O'Connell-Rodwell et al. 2000), or watchtowers used for guarding. After being alerted, farmers would then start scaring wildlife with the aim of chasing it away from the fields. A modern type of early warning system has been developed in India, in areas where elephants use tea gardens as a refuge or need to move through them to reach de-connected forest patches. To decrease the likelihood of walking into a herd of elephants on the way home or to work, warning SMS were sent out to registered villagers to alert them about the presence of elephants on their way (Sugumar and Jayaparvathy 2013). Furthermore, well visible red LED lights were switched on at specific landmarks to warn villagers, in case of elephants' presence in certain areas (Kumar and Raghhunathan 2014).

1.4.3. *Frightening devices*

Fear-provoking stimuli, which were used to increase animals' fear of areas where crops were located, included visual, acoustic or olfactory techniques. Typical visual scaring devices included scarecrows or reflecting objects against birds (Marsh et al. 1991), reflective tape against deer or antelopes (Gilsdorf et al. 2002), or spotlights against elephants (Davies et al. 2011; Zimmermann et al. 2009). Acoustic deterrents included fire crackers or carbide-canons which were used against birds (Long 1981; Mott 1980) or elephants (Hedges and Gunaryadi 2009). In addition, alarm calls recorded and played back to wildlife species were used as acoustic deterrents; experiments to ward off Asian elephant bulls from food sources through the playback of vocalizations from a wild Asian elephant matriarchal group had resulted in flight responses by the bulls (Wijayagunawardane et al. 2016). One main constraint with the use of visual and acoustic deterrent techniques was the effect of habituation, where the noise or object had no biological relevance to the species. Such habituation to sounds has been shown for captive elephants with the playback sounds of buzzing by a disturbed beehive and the sound created by banging on pots and pans (Goodyear and Schulte 2015). Elephants were said to learn that the sound of blank cartridges had no direct effect on them and start ignoring it (Rachel McRobb 2014, personal communication), or birds stopped reacting to static raptor figures (Conover 2002). The combination of visual and acoustic techniques was, therefore, recommended (Conover 2002). A promising combination of acoustic, visual and barrier techniques was the bee-hive fence against elephants (King et al. 2017). In this strategy, beehives were connected to a fence wire; once the elephants tried to break the fence, the beehives would move resulting in the alarmed bees starting buzzing and moving out of the hives, thus prompting the elephants to move away from the nuisance.

1.4.4. Olfactory repellents

Olfactory repellents are used against herbivores, by placing a repellent odour in crops and orchards to keep herbivores away. Extensive experiments have been conducted with small and medium sized herbivores and the odour of sympatric predators (faeces, urine, and fur) (Apfelbach et al. 2005; Sullivan et al. 1985). The repellent effect of predator odours was enhanced when the odour was applied on the plant needing protection, but was less effective in large crop fields. Other olfactory repellents which have been tested against African and Asian elephants were based on the extract from the fruit of the chilli plant (*Capsicum* spp. L.).; when sprayed against elephants, they were deterred from fields much faster than without the use of these repellents (Osborn 2002). This repellent effect of the chemical capsaicin, contained in the fruit of the chilli pepper, has been further used for other elephant repellents, such as chilli smoke produced by burning chilli briquettes, or chilli smokers made from dried chilli, tobacco leaves (*Nicotiana tabacum* L.), straw and cardboard (Osborn and Parker 2002; Zimmermann et al. 2009), or the application of a chilli-grease mixture on cotton cloth and sisal rope fences, so-called chilli fences (Karidozo and Osborn 2015).

The difficulty about all of these olfactory techniques is that the smell easily evaporates or washes off in the rain and, therefore, may not produce the expected results in field situations (Conover 2002; Sitati and Walpole 2006).

Besides the use as an olfactory repellent, chilli has been propagated as an alternative cash crop, as its fruits are not consumed by elephants and other herbivorous mammals (Parker and Osborn 2006). Other crops, containing high amounts of plant secondary metabolites (e.g. medicinal and aromatic plants), may also be less attractive to wildlife herbivores. The cultivation of such crops has been initiated in several areas adjacent to national parks, especially in Nepal, India and Sri Lanka (Martin and Martin 2010; Santiapillai et al. 2010; Thapa 2010; Tiller 2010). A profound knowledge on the repellent effects of crops containing plant secondary metabolites on the feeding behaviour of herbivores, did not exist before this study was conducted.

1.5. Thesis outline: Questions and hypothesis

Ever since biologists and conservationists became aware of the importance of HWCs, crop damaging behaviour particularly of endangered wildlife species, has been studied (Jnawali 1989; Kiiru 1995; Lahm 1996; Naughton-Treves 1997; Newmark et al. 1994). These studies, however, mainly concentrated on a single species or on one specific area (Bobek et al. 2017; Gunaryadi et al. 2017; Lamichhane et al. 2017; Mech 2017). Furthermore, only a few evidence based evaluations of the effectiveness of crop protection strategies have been conducted, whilst many HWC mitigation strategies were based upon experiences, opinions or even anecdotes (Davies et al. 2011; Hedges and Gunaryadi 2009; Sitati and Walpole 2006).

In this study, all herbivorous wildlife species causing pre- or post-harvest damage in all four study areas were taken into consideration. The analysis of HWC data of six consecutive years (2009 to 2014) was supported by field experiments on the crop choice by wild herbivores (2011 to 2013). This study is therewith covering a large proportion of important crop damaging wildlife species from Africa and Asia and allows a generalized view on the HWCs they are associated with. This doctoral thesis is aiming at answering the following questions:

1) Do seasons, crop phenology and crop types influence crop damage by wildlife herbivores in Africa and Asia?

In order to design ecologically and culturally suitable strategies to prevent damage by wildlife or to reduce its severity, it is important to understand the factors influencing human-wildlife interactions in detail. It needs to be understood during which times wildlife species damage crop fields, and to identify patterns of this damage and factors determining the severity of damage. For this reason, I analyzed crop damage data (pre-harvest) collected over six years in two Asian and two African regions to identify factors that influence the frequency and severity of crop damage by wild herbivores (Chapter 2). To structure the analysis, four questions were constructed: (1) Which wildlife species are the most frequent crop raiders? (2) Does the frequency of crop consumption change throughout the seasons? (3) Does the phenology of crops influence the frequency of crop consumption by wildlife species? (4) Which crop types are damaged through consumption and which through trampling?

2) Do local crop protection measures have an influence on the economic loss through crop damage in Africa and Asia?

Especially in low-income countries, rural populations farming adjacent to protected areas mostly live below the international poverty line. As subsistence farmers they are strongly dependant on the crops they grow and are vulnerable to crop damage by wildlife species. In Chapter 3, crop damage data were analysed at the farmers' level, using social and economic criteria. In this chapter I focussed on 1) the demography of farmers experiencing crop damage, 2) the economic dimension of crop damage for different species groups and 3) the potential of local crop protection strategies to decrease crop losses.

3) Which factors influence property damage behaviour by elephants in Africa and Asia?

HWC studies mainly focus on crop damage, livestock predation or human accidents with wildlife. Not much, however, is known about the damage wildlife species cause in rural villages to houses, by foraging for stored food products and post-harvest crops, or even in suburban or exurban areas, in search for food. A focus on the determination of causes for the destruction of properties, including post-harvest damage, is set in Chapter 4. This chapter focusses on African and Asian elephants, providing answers to the questions of when and why elephants damage properties, the economic dimensions of such damage for villagers, and whether guarding crops reduces the cost of property damage.

4) Are crops containing plant secondary metabolites (PSM) less attractive to African and Asian elephants and, do they bear the potential for safe income generation in agricultural areas within elephant habitats?

To enable a less conflict-laden coexistence between rural populations sharing the same landscape with elephants, new strategies need to be developed. One promising strategy could be reducing the attractiveness of agricultural areas for elephants (and other herbivorous wildlife species). Although the plantation of so called "unpalatable" crops has been supported by some conservation organisations, not much is known about the extent of the attractiveness or unattractiveness of such crops. We have conducted the first structured field experiments, testing the attractiveness of medicinal and aromatic plants (MAPs) to elephants against a control sample of staple crops; the experiment in Chapter 5 involves African elephants and the test crops garlic (*Allium sativum* L.), ginger (*Zingiber officinale* Roscoe), lemon grass (*Cymbopogon citratus* Stapf) and onion (*Allium cepa* L.). Reactions of Asian elephants to the crops basil (*Ocimum basilicum* L.), chamomile (*Matricaria chamomilla* L.), coriander

(*Coriandrum sativum* L.), lemon grass (*Cymbopogon flexuosus* (Nees ex Steud.) W.Watson), mint (*Mentha arvensis* L.), turmeric (*Curcuma longa* L.), and citronella (*Cymbopogon winterianus* Jowitt.) are studied in Chapter 6.

2. SEASONALITY, CROP TYPE AND CROP PHENOLOGY INFLUENCE CROP DAMAGES BY WILDLIFE HERBIVORES IN AFRICA AND ASIA

Erklärung zu den Autorenanteilen
an der Publikation: **Seasonality, crop type and crop phenology influence crop damages by wildlife herbivores in Africa and Asia**
Status: eingereicht
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Was hat die Promovierende bzw. was haben die Koautoren beigetragen?

(1) zu Entwicklung und Planung

Promovierende (EMG) hat die Planung und Entwicklung der Studie geleitet und durchgeführt (100%)

(2) zur Durchführung der einzelnen Untersuchungen und Experimente

EMG hat die Durchführung der Datenaufnahme angeleitet und Mitarbeiter für Datenaufnahme angelernt und diese koordiniert (70%)
BPL hat die Mitarbeiter bei der Datenaufnahme logistisch unterstützt und die die Verbindung zur Wildtierbehörde in Indien hergestellt (10%), NS hat die Verbindung zur Wildtierbehörde in Nepal hergestellt (5%), VRN hat die Verbindung zur Wildtierbehörde in Sambia hergestellt (5%), LLL hat die Mitarbeiter in Tansania bei der Datenaufnahme logistisch unterstützt und die die Verbindung zur Wildtierbehörde hergestellt (10%).

(3) zur Erstellung der Datensammlung und Abbildungen

EMG hat alle im Feld erhobenen Daten gesammelt und für die Analyse aufgearbeitet sowie Abbildungen erstellt (70%), OJ hat einen Teil der Abbildungen erstellt (30%)

(4) zur Analyse und Interpretation der Daten

EMG hat die Daten interpretiert und analysiert (70%) OJ hat bei der Interpretation und Analyse der Daten mitgewirkt (30%)

(5) zum Verfassen des Manuskripts

EMG hat das Manuskript hauptsächlich verfasst (70%), OJ hat einen Teil der Statistik verfasst (20%), die weiteren Co-Autoren haben Teile des Manuskripts überarbeitet BPL (2,5%), NS (2,5%), und VRN (5%)

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Seasonality, crop type and crop phenology influence crop damages by wildlife herbivores in Africa and Asia

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Abstract

Wildlife species feeding on crops can cause substantial losses to farmers and at the same time create negative attitudes against wildlife and conservation resulting in the rise of human-wildlife conflicts (HWC). For the analysis of negative interactions between humans and terrestrial wildlife species, a globally applicable scheme for monitoring was developed and was applied over six years in study areas of two Asian (Nepal and India) and two African (Zambia and Tanzania) countries. Factors influencing crop consumption by eight different groups of herbivores were monitored and analyzed using generalized linear models. Seasonality, crop availability, type and the phenological stage of the crop seem to play an important role for crop damaging behavior of herbivores. Crop consumers such as elephants (*Loxodonta africana* and *Elephas maximus*), zebra (*Equus quagga spp.*) and boars/hogs (*Sus scrofa, Potamocherus larvatus* and *Phacochoerus africanus*) show preferences for harvested and/or maturing crops. Rhinos (*Rhinoceros unicornis*) and antelopes/deer (*Taurotragus oryx, Aepyceros melampus, Boselaphus tragocamelus* and *Axis axis*) damage the highest numbers of fields with crops in intermediate growth stage. The findings of this study have a high importance to the management of HWCs in areas where people and wildlife coexist. This study further demonstrates the benefits of standardized HWC assessments in order to compare data from different continents and between different species to be able to draw generalized conclusions for the management of HWCs.

Keywords: crop raiding; crop preferences; human-wildlife conflict management; human-wildlife conflict database; land-use planning; conflict mitigation

2.1 Introduction

With rising awareness about the importance of the interaction between wildlife and people, more and more conservation organizations put their focus on this topic (Hoare 2012; Madden 2004; Osborn and Parker 2003; Peterson et al. 2010). Human-wildlife conflict (HWC) generally refers to situations where "wildlife impacts humans negatively (physically, economically, or psychologically), and where humans likewise negatively impact wildlife" (Draheim et al. 2015). This definition includes the fact that interactions between wildlife and people can cause damages and costs to both sides and even result in disagreements between different groups of people (human-human conflicts) (Madden 2004; Marshall et al. 2007). In many cases underlying conflicts between conservation and other human interests are to be considered when analyzing human-wildlife interactions (Redpath et al. 2014).

When wildlife damages crops, human properties, or lives, this can easily influence the attitude towards wildlife and conservation issues in a negative way (Kansky and Knight 2014; Sukumar 1991). Especially in rural landscapes close to wilderness and conservation areas, where people and wildlife compete for the same natural resources like water, grazing land and space for cultivation, losses through wildlife can be substantial. For people with a strong dependency on natural resources and without economical alternatives such damages can have catastrophic dimensions (Thirgood et al. 2005). The development of activities to reduce the pressure of wildlife on farms and properties is a consequence that organizations increasingly foster and support with the objective to create higher acceptance and to reduce animosities towards conservation efforts (Hoare 2012; King et al. 2011; Lichtenfeld et al. 2014; Ogra and Badola 2008).

The development of effective strategies to reduce needs to be based on detailed and systematic research, taking into consideration ecological and social factors. The French based organization *Awely* developed a standardized system to assess and analyze damages by wildlife (crop damage, property damage, livestock predation and accidents with humans) as well as the socio-economic setting in which they appear for any species in any terrestrial ecosystem (Gross and Fulconis 2009). This system has been tested in four African and Asian countries (Zambia and Tanzania, and India and Nepal, respectively). The main purpose is to facilitate the analysis of wildlife damages based on a standardized monitoring scheme to understand which factors are related to wildlife damages so that their occurrence becomes more predictable in time and space (Hoare 1999; Karanth et al. 2012). Understanding the factors influencing crop consumption by herbivores is an important step to designing effective crop protection methods and has strong relevance for the management of HWCs in the vicinity of national parks or other areas where people and wildlife coexist.

Here, we analyze crop damage data (pre-harvest) collected over six years in two Asian and two African regions to identify factors that influence the frequency and severity of crop damage by wild herbivores. To structure the analysis four questions were defined: (1) Which wildlife species are the most frequent crop raiders? (2) Does the frequency of crop consumption change throughout the seasons? (3) Does the phenology of crops influence the frequency of crop consumption by wildlife species? (4) Which crop types are damaged through consumption, which through trampling?

2.2 Material and methods

2.2.1 Study sites

This study was carried out in four different regions adjacent to national parks in two African and two Asian countries. Data were collected continuously throughout the years from January 2009 to December 2014 in three defined study areas (Zambia, Nepal and India) and from January 2010 to December 2011 in Tanzania. All farms suffering from crop damages were included into the study.

South Luangwa/Zambia (SL): South Luangwa National Park (9050 km^2) is located in the Luangwa valley in the Eastern Province of Zambia. To its east the Luangwa River forms the natural boarder to the adjacent Lupande Game Management Area (GMA) (4840 km^2), which is subdivided into six chiefdoms (Nshimbi and Vinya 2014). The study area encompasses five chiefdoms (Kakumbi, Malama, Mnkanya, Msoro and Nsefu) located at 13°05'S to 13°32'S and 31°33'E to 31°57'E (Fig. 1a). The Luangwa valley holds the largest elephant (*Loxodonta africana*) population of the country as well as large populations of other herbivores (Table 1). The rainy season (RS) occurs from December to April, with annual rainfalls of <830 mm, followed by a cooler, green and dry intermediate season (IS) from May to July and a very hot dry season (DS) from August to November (Astle et al. 1969). Small-scale subsistence farming on rain fed fields is the main agricultural activity in the study area. On rain-fed fields maize (*Zea mays*), sorghum (*Sorghum bicolor*), finger-millet (*Eleusine coracana*), pumpkins (*Cucurbita spp.*) and groundnuts (*Arachis hypogea*) as well as cotton (*Gossypium herbaceum*) as cash crop are cultivated (Nyirenda et al. 2011).

Tarangire/Tanzania (TA): The Tarangire National Park of Tanzania (2800 km^2) (Kissui 2008) is located in northern Tanzania and is part of the Tarangire-Manyara Ecosystem encompassing 35000 km^2 (Prins 1987). The data collection in TA was conducted east of

Tarangire National Park, in the community of Loibor Siret in Simanjiro District, with a total land holding of 550 km^2 (Lichtenfeld et al. 2014), located at 04°08' S to 04°64'S and 36°18'E to 36.43'E (Fig. 1b). The area belongs to one of East Africa's most important wildlife habitats with large numbers of migratory ungulates (Kissui 2008; Prins 1987) (Table 1). With an annual rainfall between 450 and 600 mm the study area lies in the semi-arid ecological zone (Lichtenfeld 2005; Pratt et al. 1966). The long RS from March to June is followed by a long DS from July to October. Short rains can occur in the months from November to February (IS), but not reliably (Kissui 2008; Lichtenfeld 2005). With seven people per km^2 the Simanjiro District is one of the lowest populated districts of Tanzania (Davis 2011). The most dominant ethnic group are Kisongo Maasai (Cooke 2007), who traditionally performed transhumant pastoralism (Baird and Leslie 2013), but today agricultural activities have increased, especially the farming of maize, groundnuts and beans (*Phaseolus vulgaris*) (Cooke 2007).

Bardia/Nepal (BA): The Bardia National Park (968 km^2) is located in the lowlands of Nepal. South of the national park a buffer zone (BZ) of 327 km^2 was created in 1997, encompassing 17 Village Development Committees (VDC), the smallest political unit in rural Nepal (Thapa 2010). The study area BA is located in the Western part of the BZ, comprising four VDCs (Manau, Pashupatinagar, Gola and Pathabhar) on the Western bank of the Geruwa River and four VDCs (Suryapatuwa, Thakurdwara, Shivapur and Neulapur) on the Eastern side, at 28°35'N to 28°22'N and 81°06 E to 81°19'E (Fig. 1c). With 200 ungulates per km^2 the national park holds a high density of wildlife (Flagstad et al. 2012; Wegge et al. 2009) (Table 1). The climate is influenced by the monsoon with rainfalls between July to October (RS) with around 1500 mm annually (Dinerstein 1979). The cool mostly dry green season from November to February (IS) is followed by the hot DS from March to June, during which severe water deficiency can occur (Flagstad et al. 2012; Jackson et al. 1994). With about 306 people/km^2 (Thapa and Chapman 2010) the southern buffer zone of Bardia National Park is densely populated. Subsistence farming of paddy (*Oryza sativa*), wheat (*Triticum aestivum*), maize, lentils (*Lens culinaris*) and mustard (*Brassica campestris*) are the main agricultural activities (Studsrod and Wegge 1995; Thapa Karki 2013). In the eastern part of the study area fields and farms are located directly at the forest border, on the western part the river forms the natural boundary to agricultural land.

Manas/India (MA): Manas National Park (500 km^2) (MNP) is located in the state of Assam, India (Borah et al. 2013). In the north it is bordering to the transboundary Royal Manas National Park of Bhutan and to the west and east it is framed by forests of the Manas

Tiger Reserve (2840 km^2) (Goswami and Ganesh 2014). Towards the south private agricultural and community lands and villages are directly bordering MNP. The study area MA comprises 156 villages bordering the national park and a small part of the Tiger Reserve further west, within a belt of 3 km of width (Sarma et al. 2015), located at 26°48'N to 26°36'Nand 90°46'E to 91°16'E (Fig. 1d). Due to its various habitats MNP is home to a wide diversity of fauna (Table 1) (Goswami and Ganesh 2014). Assam is influenced by the southwest monsoon with heavy rains from June to September (RS) (Dikshit and Dikshit 2014) followed by a cool dry green season (October/November IS_1). The winter season from December to February (DS) has the driest months of the year, before from March to May pre-monsoon rains occur (IS_2) (Jhajharia et al. 2012). With approximately 1280 people/km^2 the study area is heavily populated. Paddy cultivation and farming of black gram (*Vigna mungo*), mustard seeds and jute (*Corchorus spp.*) are the main agricultural activities. The cultivation of plants like betel nut (*Areca catechu*) and banana (*Musa spp.*) in homestead gardens is particular for the villages of the study area (Sarma et al. 2015).

2.2.2 Collection of data on HWCs

The HWC assessment was carried out through observations of the crop damages by local trained independent enumerators (HWC officers) as well as structured interviews with victims. The HWC officers were trained by the corresponding author during a week's course on interviewing standards, measuring of damages, identification of wildlife tracks and estimation of costs of damage (Fulconis and Gross 2011). A local HWC coordinator supervised and monitored the HWC officers throughout the year. Follow-up trainings were conducted annually by the corresponding author and data reliability was verified on site. Each HWC officer was equipped with a set of HWC Assessment Forms (Appendix A), a GPS handheld (Garmin 60), a digital camera (Fuji Finepix XP50), a mobile phone and a bicycle or motor bike. As proactive reporting by victims was not reliable (Howe et al. 2010), voluntary HWC informants were identified in each village or cluster of the study area to inform the trained HWC officers about the occurrence of damages. After information, assessment was carried out within 24h. Further, regular site visits, including remote areas, were conducted by HWC officers. Information on HWCs was recorded on forms and entered it into the *Awely* HWC database based on Windows Access 2007.

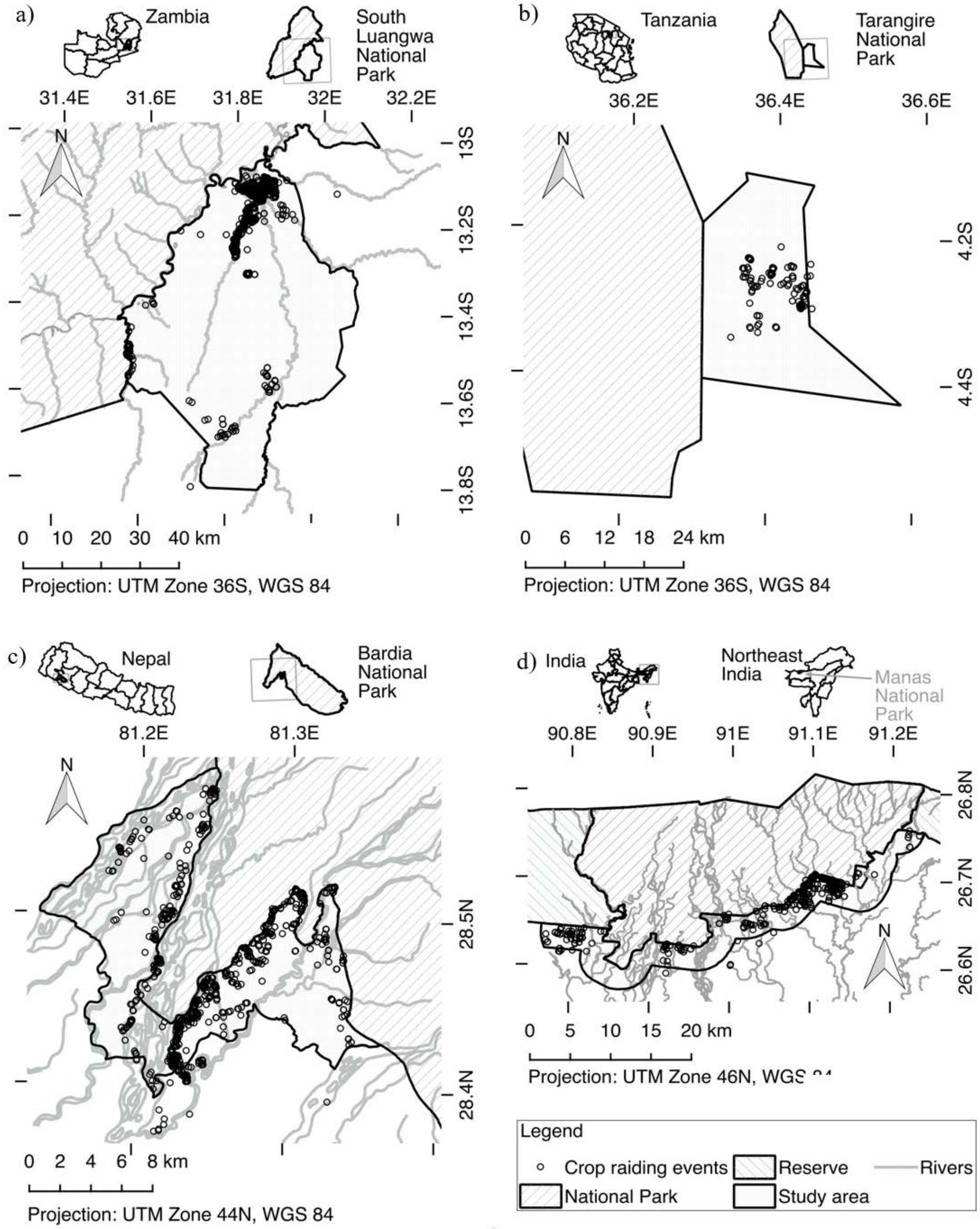

Fig. 1: Distribution of crop damage events in the study areas a) SL, b) TA, c) BA, d) MA. Permanent water bodies (rivers) are indicated as grey lines. Few crop raiding events located outside of the study area were included in the study. Author: Eva Klebelsberg.

The assessment scheme used incorporates the IUCN data collection protocol for Human Elephant Conflict Situations in Africa (Hoare 1998), which was further developed to encompasses any wildlife species causing crop damage (crops on farmland damaged by herbivores), property damage (houses, food storages, livestock shelters, fences or vehicles damaged mostly by large herbivores), livestock predation (livestock injured, killed and/or displaced by predators) and/or accidents leading to human injuries or death. Data were collected with a set of five different forms with open and close questions (Appendix A). For this particular study data of only three forms (General Conflict Information, Crop Raiding and Brief Conflict Assessment) were used. For each damage event, one assessment was carried out. Similarly as proposed by Naughton-Treves (1998), we defined a crop damage event as damage by an individual or group of one wildlife species during one time period (e.g. one night) in a defined area. For example, elephants damaging the fields of four different farmers in one night were recorded as one damage event with four crop damages. Through this, spatial autocorrelation is reduced, which could result from clustered damages by one species individual or group (Songhurst and Coulson 2014). The movement of an individual or group of wildlife species was determined by reading the tracks. In case of dubiety whether the same individual/group has caused the damages, multiple damage events were considered. The first form (*General Conflict Information*) took into consideration the ecological and geographical components about the conflict (location, time, species, number of individuals etc.) and was filled once for each damage event. Then the damages were further assessed, focusing on the damage per victim. For damages on fields, be it that wildlife has fed on the crops or just walked through them, the *Crop Raiding Form* was used. In case crops were already harvested and deposited on the field, this form was applied as well. In case the crops had been stored in granaries or other kinds of building, the *Property Damage Form* was used. However, these data were not included into this pre-harvest study. In case conflicts could not be visited by the HWC officer in due time, the information was recorded in the *Brief Conflict Assessment Form.* This form only captures a condensed version of the damage, and was also used in case victims were not willing to give detailed information. Capturing these conflicts despite the lack of detailed information was important to obtain a maximum coverage of conflicts in one area.

2.2.3 Mapping of crop damages

For each conflict event we recorded the location at its center with a global positioning system unit (Garmin GPS 60) with an accuracy of 15 m. We mapped crop damage events for each of the four study areas, using Quantum GIS Geographic Information System, Version 2.14.3 Essen (QGIS Development Team 2016).

2.2.4 Analysis of crop damage data

To compare crop damage frequencies per season, stage of growth during consumption and kind of damage per crop type by wildlife species throughout different study areas we formed species categories (Table 1). All Analyses were calculated with R version 3.2.5 (R Core Team 2016) using Generalized Linear Models (GLM). To identify the seasons with highest and lowest frequency of crop damages we used data on crop damage events per study area, species categories and season. For this analysis we used a quasipoisson distribution (with a log-link function), accounting for overdispersion in the data. Varying lengths per season in the respective study areas were taken into account (Table 3 Appendix B) by including the length of each season per study area (in months) into the GLMs as an offset.

To analyze preferences of growth stages for crop consumption per species categories, we used data on number of damaged fields per species category, study area, crop type and stage of growth. We also included the length of each growth stage per crop type in the analysis (Table 4 Appendix C). We only used data, where crops were eaten and assumed to have zero damages per sampling unit (i.e. combination of growth stage, year, crop and region) when no damages were reported if there was at least one damage reported for a certain crop in this regions. We also used a quasipoisson distribution (with a log-link function), accounting for overdispersion in the data.

For understanding crop preferences of species categories, we investigated the cause of the type of destruction (feeding or trampling) by a GLM using a binomial distribution (with logit-link function). For this we summarized the numbers of fields damaged by feeding versus fields damaged by trampling only, per species, study area, and crop type. We grouped staple crops (wheat, maize, rice) and compared them to crops which are farmed as cash crops or nutritional supplements (betel nut, cotton, lentil, mustard, vegetables). Each best model was chosen by downward model selection (Appendix D). For all p-value calculations we conducted a Holm-correction for multiple comparisons if necessary.

Table 1: Number of crop damage events per species category and percentage of damage events per region in four study areas from 2009 to 2014. In case species did not cause any damage, though present in the study area zero (0) was indicated, in case species were not present in a study area this was indicated with a dash (-)

	SL	TA*	BA	MA
elephant[1]	1036 (85.5%)	6 (6.1%)	455 (63.6%)	474 (95.2%)
rhino[2]	-	-	102 (14.3%)	11 (2.2%)
hippo[3]	71 (5.9%)	0	-	-
buffalo[4]	3 (0.2%)	8 (8.1%)	-	1 (0.2%)
zebra[5]	0	46 (46.5%)	-	-
antelopes/deer[6]	0	12 (12.1%)	67 (9.4%)	0
boars/hogs[7]	51 (4.2%)	24 (24.2%)	89 (12.4%)	12 (2.4%)
primates[8]	44 (3.6%)	1 (1.0%)	1 (0.1%)	0
porcupine[9]	7 (0.6%)	2 (2.0%)	1 (0.1%)	0

[1] SL and TA *Loxodonta africana*, BA and MA *Elephas maximus*
[2] BA and MA greater one-horned rhino (*Rhinoceros unicornis*)
[3] SL and TA *Hippopotamus amphibius*
[4] SL and TA African buffalo (*Syncerus caffer*) and MA Wild water buffalo (*Bubalus arnee*)
[5] SL Crawshay's zebra (*Equus quagga crawshayi*), TA Burchell's zebra (*Equus quagga burchellii*)
[6] TA common eland (*Taurotragus oryx*) and impala (*Aepyceros melampus*), BA blue bull (*Boselaphus tragocamelus*) and spotted deer (*Axis axis*)
[7] SL bushpig (*Potamochoerus larvatus*), TA bushpig (*Phacochoerus africanus*) and warthog, BA and MA wild boar (*Sus scrofa*)
[8] SL vervet monkey (*Chlorocebus pygerythrus*) and baboon (*Papio cynocephalus*), TA vervet monkey, BA common langur (*Semnopithecus entellus*)
[9] SL cape porcupine (*Hystrix africaeaustralis*), TA crested porcupine *(Hystrix cristata),* BA and MA Indian porcupine (*Hystrix indica*)
[*] Damage numbers for TA refer to the years 2010 and 2011 only

1.3 Results

In this study we analyzed 2524 crop damage events, encompassing 6236 individual victims/farms, to determine factors that are associated with crop damages by wildlife. The crop damage events were quite homogenously spatially distributed throughout the rural areas of the study sites (Fig. 1). In SL and TA, where agricultural areas are interspersed with natural habitats, crop damages occur much further away from the border of the national parks compared to BA and MA, where hardly any natural habitat is found outside the National Parks. Here, crop damages mainly occur within a 3 km wide belt around the national park boundary.

2.3.1 Most frequent crop consumers

In three out of four study areas (SL, BA, MA) the highest number of damages was caused by elephants (Table 1), in contrast, zebra was mostly involved in crop damage (46.5%) in TA. Boars/hogs were involved in crop damage in all four study areas, ranking second in terms of frequency in TA and MA, and third in SL and BA. Hippos and rhinos ranked second in terms of frequency of crop damage in SL and BA, respectively, whereas rhinos ranked third in MA and antelopes/deer ranked third in TA. With only six crop damages (6.1%) within the study period of two years in TA elephants ranked number six of crop consuming species.

2.3.2 Influence of seasonality on crop consumption

In three out of four study areas (SL, BA, MA), the DS is the season with the fewest crop damage events (Fig. 2a). In TA, a total of only two crop damages were observed during the DS, and none during the IS, while 94 crop damages occurred in the RS. Overall, the number of crop damage events were found to be highly significantly different between DS and RS ($\chi^2 = 32.157$; $p < 0.001$) as well as between DS and IS ($\chi^2 = 27.988$; $p < 0.001$). Between RS and IS, however, there was no significant difference in crop damage numbers ($\chi^2 = 0.472$; $p = 0.49$). The lowest number of crop damage events in the DS also applied for the species level (Fig. 2b). Nearly all eight wildlife species categories showed the lowest number of damages per month during the DS. An exception was observed for zebra with one crop damage event during the DS compared to none during the IS but 45 during the RS.

2.3.3 Influence of growth stage of crops on crop consumption

By analyzing the effect of the phenology of crop types on the number of damages by specific wildlife species category (Table 2), it was shown that elephants (Fig. 3a) damaged fields with harvested crops (laid out for drying on fields) as well as mature crops significantly ($p = 0.025$) more frequently than fields with crops in intermediate growth stage; and seed/seedlings were the least damaged. Additionally, zebras caused the highest number of damages by feeding on harvested and mature crop fields ($p \leq 0.011$) (Fig. 3b). Boars/hogs damaged harvested crops compared to fields with crops in intermediate or seed/seedling growth stages at a higher frequency significantly ($p = 0.021$) (Fig. 3c). In contrast, rhinos and antelopes/deer fed on crops in intermediate growth stage significantly ($p \leq 0.003$) more often than on fields with mature crops (Fig. 3d and e). Buffaloes did not consume any crops in seed/seeding and harvested stage of growth (Fig. 3f). For primates and hippos, the stage of growth appeared to have no significant impact on the numbers of crop damages on fields (Fig. 3g and 4h).

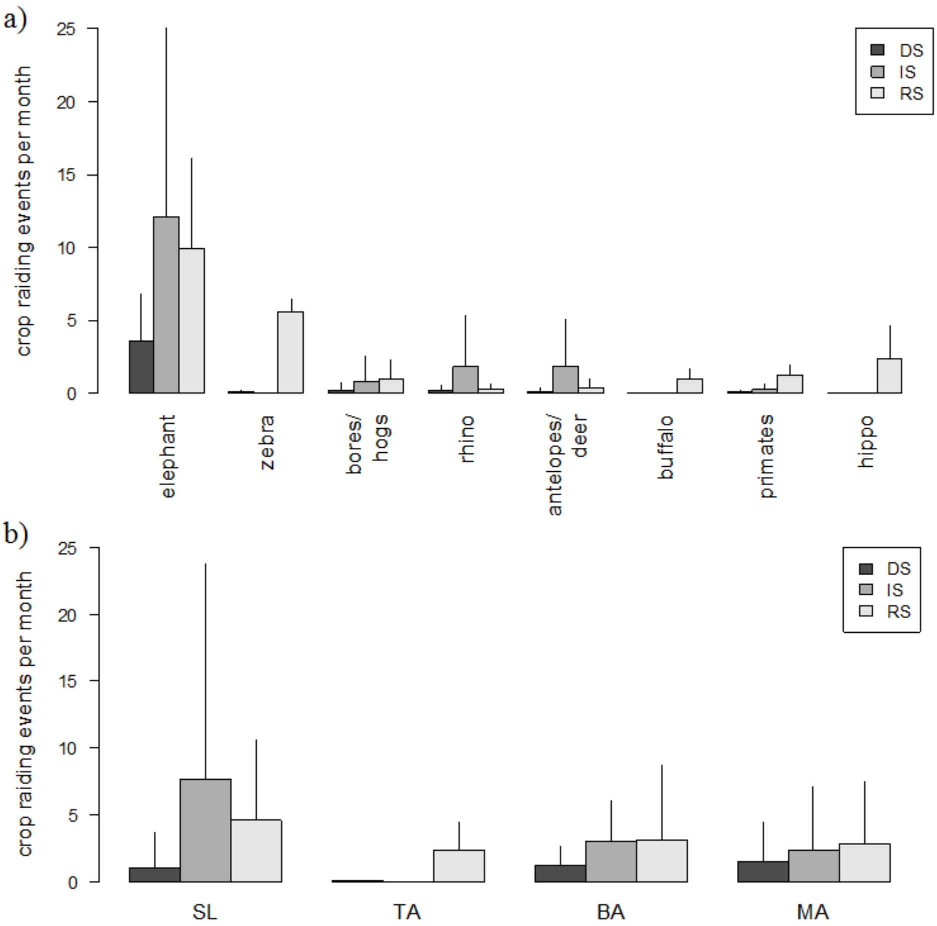

Fig. 2: Mean number of crop damage events per month for dry (DS), intermediate (IS) and rainy season (RS) per a) study site and b) per species category. Standard deviation is illustrated by whiskers.

Table 2: Results of tested comparison between numbers of damaged fields at different growth stages. For the best model per species (see Appendix D), χ^2-values are given with p-values in brackets, significant differences are indicated in bold (p-values < 0.05). For primates and hippos the growth stage was not included in the final model

	elephant	rhino	primate	hog/boar	deer	zebra	buffalo	hippo
harvested-mature	0.551 (0.458)	1.289 (1)	-	3.148 (0.228)	4.591 (0.161)	0.327 (1)	0 (1)	-
harvested-intermediate	**6.225 (0.025)**	0.243 (1)	-	**8.57 (0.021)**	0.044 (0.834)	**9.307 (0.011)**	0 (1)	-
harvested-seed/seedling	**25.596 (< 0.001)**	0.004 (1)	-	**8.537 (0.021)**	1.012 (0.629)	0 (1)	0 (1)	-
mature-intermediate	**11.843 (0.002)**	**11.92 (0.003)**	-	3.11 (0.228)	**14.25 (0.001)**	**24.75 (< 0.001)**	6.839 (0.054)	-
mature-seed/seedling	**28.32 (< 0.001)**	5.395 (0.101)	-	4.645 (0.125)	2.434 (0.356)	0 (1)	0 (1)	-
intermediate-seed/seedling	**16.935 (< 0.001)**	1.315 (1)	-	1.506 (0.228)	4.582 (0.161)	0 (1)	0 (1)	-

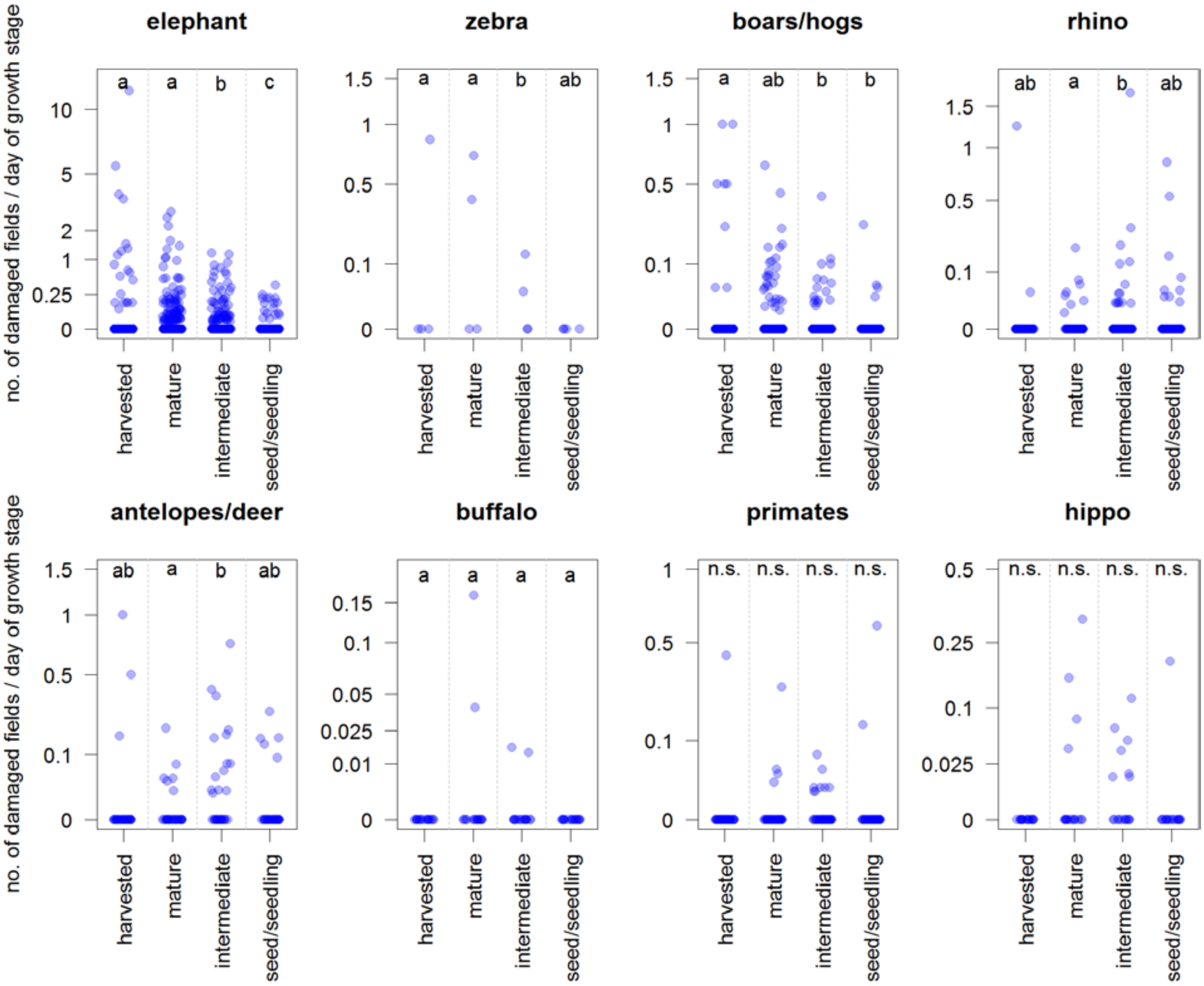

Fig. 3: Mean number of fields damaged per phenology stage by different wildlife species categories. Length of growth stage is accounted for: each dot shows the number of damaged fields in a respective growth stage for one crop type, region and year per day of growth stage. For better visibility y-axis is square root transformed. Different lower case letters on top indicate a statistical difference between the groups; n.s. indicates, that the factor growth state was not a significant factor in the final model.

2.3.4 Crop preferences of wildlife species

We further analyzed the difference in the proportions of damage types (crop consumption vs. trampling only) for different crop types by each species (Fig. 4). With 16 different types of crops, elephants (n = 2319 damaged fields) damaged the widest variety of crops compared to all other species. Fields with the staple crops rice (n = 971; 41.87%), maize (n = 660; 28.46%) and wheat (n = 205; 8.84%) were damaged most frequently. Elephants damaged fields through feeding significantly more often than through trampling, when the fields contained staple crops compared to those that contained cash crops and nutritional supplements (betel nut, cotton, lentil, mustard, vegetables) ($n = 2319$, $\chi^2 = 49.284$, $p < 0.001$).

Rhinos damaged fields (n = 240) with seven different crop types out of which wheat fields were most often visited (n = 188; 78.33 %). Wheat fields were damaged with a significantly higher proportion through feeding on it than through only trampling, compared to lentil and mustard (n = 240, χ^2 = 12.357, p < 0.001). Rice was damaged to a higher proportion (15.4%) through trampling by rhinos than wheat (0.5%).

Hippos damaged maize, rice and groundnut (n = 38) although there was no statistical evidence that the type of crop had an influence on the type of damage (consumption or trampling). Buffaloes damaged fields (n = 10) containing rice, maize and lentils, whereas zebras damaged maize and beans fields (n = 49). It was observed that buffaloes trampled lentils and zebras beans preferentially, although both animals did not feed on the respective crops. As boars/hogs (n = 226 on 9 crop types), antelopes/deer (n = 162 on 7 crop types) and primates (n = 32 on 5 crop types) hardly caused any damage through trampling without feeding a difference in preferences could not be determined.

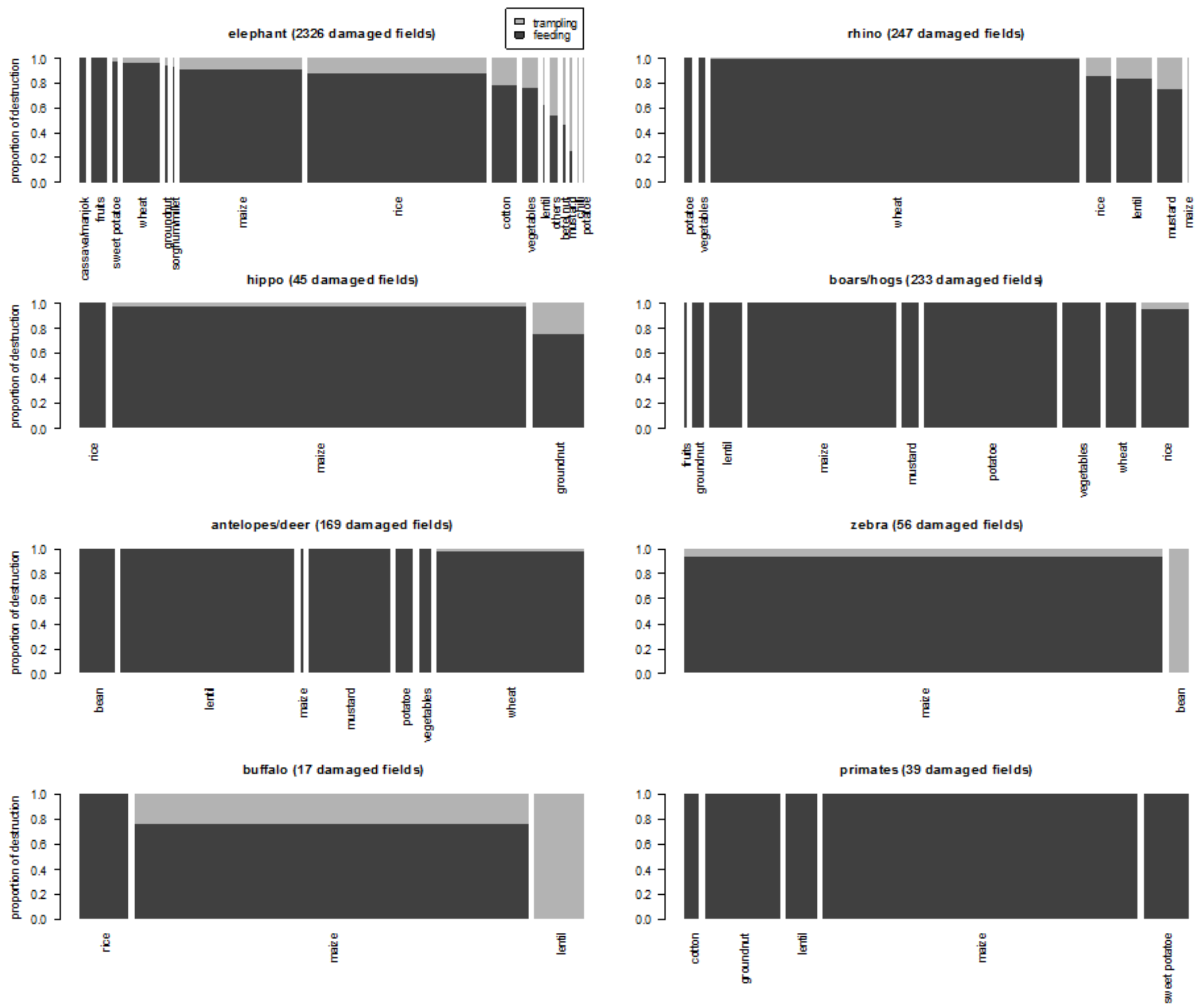

Fig. 4: Proportions of damage through feeding (black colour) or trampling (without feeding) (grey colour) per crop type by eight species categories. Each bar indicates one crop type. The bars are ordered from highest to lowest proportion of feeding. The width of each bar indicates the proportion of damaged crop type per species category.

2.4 Discussion

The damage of farm crops by wildlife species is one of the most frequently mentioned causes of HWCs (Hill and Wallace 2012). Through comparing observations of four areas prone to crop damages by wildlife species we were able to gain insight on seasonality of crop damages, species preferences on crop maturity and preferences of crop types.

2.4.1 General findings

Due to their sheer size and the potentially great amount of food intake within a short period, elephants are likely to be perceived as the most severe crop pests (Naughton-Treves and Treves 2005). On the other hand, less visibility of damages by smaller herbivores (antelopes/deer, primates, hogs/boars) as well as a greater difficulty in species identification, might cause underreporting (Gubbi 2012). Although the assessment of crop damages by wildlife species was standardized throughout the four study areas it is likely that the HWC officers were not able to obtain information on all of the crop damages. If damages were not noticed by the victims themselves or were not perceived as problematic, reports might have been missed. However, prediction models appeared to be robust to underreporting of damages, if underreporting was not spatially biased and damage events occur in non-random patterns (Snow et al. 2015).

Seasonality has been mentioned as an important factor to influence crop consumption by wildlife species (Lahm 1996; Linkie et al. 2007; Webber et al. 2011). In all four study areas farming of the main staple crops (maize for SL/TA, rice for BA/MA) started with the onset of rains and harvest started after rains had stopped (IS). After this, vegetables (SL, BA, MA), maize, wheat, lentils, mustard (BA, MA) were farmed in the intermediate and DS. Fruits (banana, mango and pawpaw) were available throughout all seasons (SL, BA, MA). Natural food sources for herbivores however were limited in the peak DS in the natural habitat (Lakshminarayanan et al. 2016; Van Aarde et al. 2008). Although crop damages by all eight wildlife species categories occurred throughout the year in the study areas they were significantly less during the DS, but high during times the main staple crops were cultivated (RS/IS).

The preference of food sources to herbivores can be determined by the degree of consumption and avoidance (Iason and Villalba 2006). As large and heavy wildlife species are moving through farms with different crop types available they can cause damage either by crop consumption (accompanied with trampling as well) or by trampling only, without consumption of crops. Through the comparison of proportions of crops that have been consumed (and thereby may to some extent got trampled as well) to crops that have been trampled only, without any signs of consumption, we inferred that various crop types are less or more attractive to wildlife species. A similar approach to determine the attractiveness of crop types to wild elephants was used in an experimental design in Zambia (Gross et al. 2016) and Nepal (Gross et al. 2017). In those studies significant differences between the attractiveness of staple crops like maize (Zambia) and rice (Nepal) compared to crops containing antifeedants (e.g. lemon grass, ginger, mint or basil) were determined.

2.4.2 Characteristics of crop damages by African and Asian elephants

African and Asian elephants are regarded as important pest mammals in farms close to national parks or within other protected areas (i.e. BZ, GMA), which have the objective of preserving these threatened species (Hoare 2000; Schmutterer et al. 1969; Sukumar 2006; Thirgood et al. 2005). The data collected and analyzed in this study underlines the importance of damages by elephants in three out of four study areas (SL, BA, MA). In TA, however, elephants caused only a few crop damages, although this species is present in the area and damages of crops have been described for villages 10-20 km further north of the study area (Pittiglio et al. 2014). Particularly in the rainy season, when maize and other attractive crops are planted, elephants disperse into larger areas (Shrader et al. 2012; Van Aarde et al. 2008), travelling long distances to exploit nutritious food sources (Thouless 1995). The seasonal presence of elephants was therefore expected on the farms of TA. As a main elephant migration route is located in our study area, connecting the Tarangire national park and a wet season dispersal area (Pittiglio et al. 2012), elephants might have passed the farms of TA before crop growth had started and returned after harvest, thus explaining the low elephant crop damage incidences. Another reason may be due to the guarding practices by the Maasai people, who are famous for their martial lifestyle and cultivation of warrior status (Hazzah et al. 2009), as the elephants can distinguish different ethnic groups by smell and visually avoiding those that are associated with danger (Bates et al. 2007).

The temporal distribution of crop damages by elephants has been found varying depending on the habitat: In African forest habitat most crop damages occur during the dry season (Chiyo et al. 2005), whereas in savannah habitats the late wet season was identified as the main time for crop damages (Osborn 2004). During those seasons the nutritional value of the natural forage (moisture and crude protein content) decreased under the nutritional value of the crops. The coincidence with the time of crop ripening however makes it difficult to determine whether the decline of the nutritional value of the forage or the availability of highly nutritional crops triggers crop damage behavior (Webber et al. 2011). In this study it is shown that elephants clearly preferred harvested and mature crops to crops in other stages of growth; the riper a crop got, the more frequently it was damaged. Due to multiple factors that can influence movement and behavior of species (Chiyo and Cochrane 2005; Songhurst et al. 2015) we cannot determine what exactly affects elephants to move on farms to consume crops. For the development of strategies to reduce crop losses however, it is important to understand that maturing crops and harvested crops laid out for drying are especially susceptible to damage by elephants. Further, this study took into consideration crop damage on fields, only. Post-harvest losses and search for food in villages by elephants however follow a different seasonal pattern (Gross et al. *subm*.b).

In our study elephants mainly fed on staple crops, damaging them less through trampling only (without consumption) than crops like cotton, vegetables, lentils, betel nut or mustard. For this reason a higher attractiveness can be attributed to maize and rice for elephants. However, the less attractive crops were still damaged by feeding to some extent. Even cotton, which is in some cases seen as a potential buffer crop unpalatable to elephants (Gubbi 2012; Rode et al. 2006), has been consumed in 78.1% of all observed cotton damage cases. Whether some of these crops could be used as less attractive buffer crops, e.g. due to lower feeding quality index than natural forage or chemical defense, needs to be determined through chemical analysis and experimental approaches, taking into consideration long term learning effects.

2.4.3 Crop preferences of rhinos in Asia

Rhinos were observed as crop damaging species only in the Asian study areas. Although the black rhino (*Diceros bicornis*) was formerly found in TA and SL, this species has been hunted to extinction in both areas in the late 1980 to early 1990s (Emslie and Brooks 1999).

The natural diet of the greater one-horned rhino is mainly made up of tall grasses, especially during the rainy season (Laurie 1982) and browse contributes to their diet in a smaller quantity, mainly in the dry season, when grasses are less available and less nutritious (Pradhan et al. 2008). In contrast to elephants, rhinos preferred feeding crops in younger and fresh green growth stage (intermediate and seed/seedling). Although the main staple crop farmed in the Asian study sites was rice, rhinos showed a stronger preference for feeding on wheat. This leads to the assumption that wheat is the most attractive crop for rhinos. This finding is supported by an earlier interview-based study on farmers perception of crop losses due to wildlife in Bardia/Nepal, where wheat and lentils were identified as the most damaged crops by rhinos (Studsrod and Wegge 1995).

2.4.4 Crop damage by hippo

Due to the preference of low grasses by hippos (Owen-Smith 1988; Snyder 2015), a higher number of damages on fields in seed/seedling and intermediate stage of growth could have been expected. A majority of damage of crops in early growth stage was reported in a study on crop damage by hippos in Ruaha/Tanzania (Kendall 2011), however in our study no preference for a certain growth stage of crops was observed. Hippos have long been described as selective grazers, feeding especially on stoloniferous grasses (C_4 grasses) and coping well with very low feeding level (Field 1970). More recent studies showed that they do not only consume C_4 grasses, but also C_3 plants (Boisserie et al. 2005). Later it was found that some individual hippos even fed purely on C_3 plants (Cerling et al. 2008). In our study hippos consumed maize (C_4 plant), rice and groundnuts (both C_3 plants). This corresponds with observations from Ruaha/Tanzana, where maize and rice were described as most damaged crop by hippos (Kendall 2011). The increase of C_3 plants in hippo diets as described by Cerling et al. (2008) might be due to an increase of C_3 crop availability to hippos through an expansion of agricultural fields in the vicinity of hippo habitats.

2.4.5 The role of zebras and buffaloes for crop damage

As obligate grazers (Cerling 2008) zebra and buffaloes have only consumed crops belonging to the family of *Gramineae* (maize and rice), but no dicotyledonous plants (beans, lentils), even though they passed through these fields (trampling 100%). As most herbivores zebra and buffalo disperse further away from water sources in the rainy season (Ogutu et al. 2014), when staple crops are planted. Zebras exclusively caused damages in TA and mainly in the rainy season, during which their density is highest in the Simanjiro plains of the study area, due to breeding (Rija and Hassan 2011). Zebras were previously mentioned as crop damaging species in the area (Lewis et al. 2016; Pittiglio et al. 2014), but don’t play a major role for crop damage in other zebra habitats (SL). In Kenya, however, zebra is ranked fourth as problem wildlife species, after antelopes, elephants and primates (Naughton-Treves and Treves 2005). Similar to elephants, Zebras showed a clear preference for mature and harvested crops, as they are able to feed on fibrous and coarse plant materials, like husks and stems (Owaga 1975). Highly nutritious mature and harvested maize seems to be an attractive crop for zebra to feed on during the late rainy season. Crop damage through buffaloes was not frequent in our study areas, and no preference for any growth stage was determined.

2.4.6 Crop damage by antelopes/deer

All four antelope/deer species (of TA and BA) assembled under this group are mixed feeders, feeding on browse and grass to varying proportions, where browse is consumed during the dry season and freshly re-growing grasses are consumed during the rainy season (Cerling et al. 2003; Khan 1994). Coinciding with their grazing preference during the rainy season, these species preferred visiting farms with crops in green and soft intermediate growth stage. In total they fed on a variety of seven crop types but trampling alone hardly ever occurred. The moderately sized impala and spotted deer are relatively light in weight (<100 kg), therefore it was unlikely to cause damage through trampling. In contrast, the heavier blue bull (up to 300 kg) and eland (up to 1000 kg) could have caused damage by trampling.

2.4.7 The role of boars/hogs for crop damage

Boars/hogs were implicated in crop damages within all four study areas. Wild boars and bushpigs are opportunistic feeders (Ballari and Barrios-García 2014; Breytenbach and Skinner 1982), consuming browse, grasses, roots, barks, larvae and even scavenge. Warthogs in contrast are selective grazers (Botha and Stock 2005), consuming mainly grasses and small amounts of forbs during the rainy season but feeding on underground plant parts during the dry season. The generalist diet, especially of boars is reflected in the variety of nine different consumed crop types in this study. Similarly in Sumatra, it was found that wild boars seemed to consume whatever was available to them (Linkie et al. 2007). Warthogs, however, only caused damage through feeding on maize. Furthermore, boars/hogs show destructive feeding habits through digging up the soil in search for food, causing damage patterns, which are hard to distinguish from feeding (Barrios-Garcia and Ballari 2012). The high proportion of destruction through feeding in contrast to trampling could also be a result of this behavior. Boars/hogs show a preference for harvested and mature crops. Similar observations in Sumatra on *S. scrofa* suggest that crop consumption might be determined by seasonal ripening of crops (Linkie et al. 2007). Boars/hogs are important crop pests in many countries, even Europe (Herrero et al. 2006; Keuling et al. 2016; Linkie et al. 2007; Nyirenda et al. 2011), but due to their low conservation status (IUCN Red List Least Concern) (Cumming 2008; Oliver and Leus 2008; Seydack 2016) they receive little attention by nature conservationists. From a farmers perspective the family of *Suidae* however should not be neglected when developing measures to manage HWC.

2.4.8 Crop damage by primates

In our study the highest numbers of crop damage by primates were found in fields with seed/seedlings and harvested crops. The damages this group causes in a very early stage of growth agrees with findings from Uganda, where a high rate of primate damages was observed just after or even while seeding was carried out (Wallace 2010). Earlier studies observed crop damage by primates throughout the year with a climax during the time of ripening (Hill 2000). To reduce crop losses, the protection of crops in areas prone to primates seems especially important during the seeding and after harvest stages. High nutritional value of food can induce primates to crop raid (Taylor et al. 2016), so the choice for mature crops and seeds seems obvious. Seeds on freshly prepared fields are easily accessible and easy to collect by primates and high damages can be caused within a short time. The same applies to harvested crops, which are laid out for drying. Due to the light body weight of primates, damage through trampling does not occur.

2.5 Conclusion

Crop consumption by wildlife species has been described as part of an optimal foraging strategy (Sukumar 1990). The high nutritional value, palatability and ease of handling during foraging make these crops highly attractive for consumption (Biru and Bekele 2012). The influence of the phenological stage of the crop on the frequency of damage by various wildlife species has a strong relevance for the management of HWCs and the timing of appropriate conflict mitigation strategies. In general, crops are most attractive to elephants, zebra and boars/hogs when they are harvested and laid out for drying on the fields. The enhancement of crop protection during this fairly short time of a few days could strongly decrease a substantial number of crop damages. For staple crops like rice or maize, the time of maturing (a time span that last only two to three months of crop production) is highly sensitive as well. Focusing on the installment of effective crop protection measures during this specific period bears the potential to decrease crop damage in a time and cost effective manner.

In areas where greater one-horned rhino is present, crop protection measures need to be in place in the early stage of farming. At a later stage, when crops are maturing, protection measures could be lowered, but need to be enforced again during the time after harvest, when crops are laid out for drying in the fields. In African wildlife areas populated by hippos, such as close to entry points at rivers (Kendall 2011) or at hippo pools, measures for crop protection need to be taken from an early stage of growth onwards. Also in case of primates, mitigation strategies to prevent damages have to be implemented at an early stage of farming.

Factors like habitat fragmentation, degradation of habitat quality, loss of forest cover or laxity in management of physical barriers are causes for HWC (Fall and Jackson 2002; Gubbi 2012; Sukumar 1990). However, the attractiveness of crops planted in the vicinity of or even within natural wildlife habitat has to be included into this list and has to be taken more seriously in HWC management. Highly nutritional staple crops will always bear a high attractiveness to wildlife species. Even when protected by fences, chili smoke or human guarding crops like maize, rice and wheat will be susceptible to crop damage (Gross et al. *subm*.a; Karidozo and Osborn 2005). For this reason, we emphasize on the necessity to include the presence of large herbivores as another ecological factor to be taken into consideration when taking farming decisions on crop selection in areas where people and large herbivores coexist. This aspect further needs to be included into the land-use planning of BZ and GMA. As long as the attractiveness of crops is not reduced, crop protection will constantly have to be kept on a high labor and cost intensive level. Choosing crops with a lower nutritional level than wild forage could disable the trigger for crop damaging behavior. The installation of buffer zones with agroforestry (Nyhus and Tilson 2004) or the replacement of staple crops by alternate cash crops less attractive to wildlife species (Gross et al. 2017; Gross et al. 2016; Rode et al. 2006) should be taken more strictly into management strategies and land use planning of protected areas in which people and wildlife coexist.

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2.8 Appendices

- **Appendix A:** Awely HWC Assessment Forms
    - **General Conflict Information**
    - **Crop Damage**
    - **Property damage**
    - **Livestock Predation**
    - **Injuries/Death**
    - **Brief Conflict Assessment**
- **Appendix B:** Table 3
- **Appendix C:** Table 4
- **Appendix D:** Analysis of crop raiding events depending on the season

Awely Human-Wildlife Conflict Assessment Form – General Information

A. Code of conflict event: __________ _ ______________________________ (YY/MM/DD _ location)

B. Name of HWC Officer: ______________________________

C. Date of assessment: ______ / ______ / 20______

D. Start of assessment: ______ : ______ End of assessment: ______ : ______

1. GPS point of general conflict site: *(centre of entire damage/conflict event)*

Latitude (N/S): ____°____ . ______' Longitude (W/E): ____°____ . ______'

Region: ______________________________

Name of waypoint (stored in GPS): ______________________________

Name of village/conflict area: ______________________________

2. Date at which conflict occurred: ______ / ______ / 20______

3. a) Ethnic group involved in this conflict: ______________________________

b) How many victims suffered from this conflict? ____ No. of households questioned: ____

4. Which season is it? ☐ rainy season ☐ dry season ☐ intermediate season

5. a) Did anyone witness the conflict?

☐ yes ☐ no ☐ unknown b) If yes, how many people? ____________

6. Please describe the area where the conflict occurred: *(close to/by = distance up to 300m)*

☐ in village	☐ close to village	☐ far away from village	*Mark 1 only*
☐ river close by	☐ irrigation system close by	☐ well close by	*Mark min. 1*
☐ waterhole close by		or: ☐ no water availability	
☐ close to cultivated land	☐ close to natural habitat	☐ close to barren land	*Mark min. 1*
☐ fruit trees near conflict site	☐ traditional wildlife corridor nearby		*Mark 0,1 or 2*

Further comments: ______________________________

____

7. At what time did the conflict occur? ☐ evening *(17:00 – 20:00)* ☐ night *(20:00 – 5:00)*

☐ morning *(5:00 – 7:00)* ☐ daytime *(7:00 – 17:00)* ☐ unknown

GI/ 1

Awely Human-Wildlife Conflict Assessment Form – General Information

8. How long did the animal(s) stay?

☐ less 15 min ☐ 15-30 min ☐ 30-60 min ☐ 1-2 hrs ☐ 2-5 hrs ☐ more 5 hrs ☐ unknown

9. a) How many individuals of which species were involved?

___ elephant(s)	___ hippo(s)	___ wild boar(s)
___ baboon(s)	___ rhino(s)	___ buffalo(s)
___ lion(s)	___ hyena(s)	___ cheetah(s)
___ leopard(s)	___ tiger(s)	___ crocodile(s)

☐ other: ____ ____________ ____________ (no. species scientific name (only if English name is inexact))

b) Identification of species is:

☐ absolutely reliable ☐ quite reliable ☐ not sure

c) Information available about conflict animals: *(mark every column)*

	Tracks seen by HWC Officer	Tracks seen by witness	Sighting by HWC Officer	Sighting by witness	Signs of presence
clear					
unclear					
not seen					

d) Age and sex of conflict animals: *(enter numbers)*

	Calf/Young*	Juvenile*	Sub-adult/Adult*	Age unclear
Male				
Female				
Sex not identified				

*For definition use wildlife identification chart

e) Particular marks: *(tusks, tail, mane, marks on ears, injuries)*

____

f) Size of tracks: *(exact measurement only for single conflict animals, measure in mm)*

	Circumference	Length	Width
Front right			
Front left			
Hind right			
Hind left			

Tracks found in/on:

☐ dust

☐ moist soil

☐ sand

☐ mud

GI/ 2

Awely Human-Wildlife Conflict Assessment Form – General Information

10. Please describe where the animals were coming from:

Direction: ☐ N ☐ NW ☐ W ☐ SW ☐ S ☐ SE ☐ E ☐ NE ☐ unknown

a) Protection status *(one answer only)*

☐ National Park
☐ Conservation Area
☐ GMA/hunting block
☐ Buffer Zone
☐ communal land
☐ unknown
☐ __________ (other)

b) Main landscape *(one answer only)*

☐ forest
☐ bushland
☐ grassland
☐ wetland/River
☐ farmland
☐ unknown
☐ __________ (other)

c) How do you know the direction the animals were coming from? *(one answer only)*

☐ clear tracks from one direction
☐ tracks but direction not very clear
☐ animals were directly seen by witnesses
☐ assumption based on previous experience
☐ no proofs available
☐ others: ______________________________

11. Where did the animals head to after the incident?

Direction: ☐ N ☐ NW ☐ W ☐ SW ☐ S ☐ SE ☐ E ☐ NE ☐ unknown

a) Protection status *(one answer only)*

☐ National Park
☐ Conservation Area
☐ GMA/hunting block
☐ Buffer zone
☐ communal land
☐ unknown
☐ __________ (other)

b) Main landscape *(one answer only)*

☐ forest
☐ bushland
☐ grassland
☐ wetland/River
☐ farmland
☐ unknown
☐ __________ (other)

c) How do you know the direction the animals were heading to? *(one answer only)*

☐ clear tracks from one direction
☐ tracks but direction not very clear
☐ animals were directly seen by witnesses
☐ assumption based on previous experience
☐ no proofs available
☐ others:

GI/ 3

Awely Human-Wildlife Conflict Assessment Form – General Information

E) Assessment continued with following Conflict Assessment Form(s):

	Crop Raiding	Property Damage	Livestock Predation	Human Injuries/Death
Number of filled forms				

F 1) Photos taken by Red Cap at conflict site?

☐ yes ☐ no

F 2) In case not all victims of one conflict event were interviewed, estimate total conflict costs:

a) Crop Raiding: ______________________________

b) Livestock Predation: ______________________________

c) Property Damage: ______________________________

d) Injuries/Death: ______________________________

F 3) Space for notes, drawings, further information:

GI/ 4

Awely Human-Wildlife Conflict Assessment Form – Crop Raiding

A. Code of conflict event: ___________ __ ________________________ Form No. ______
(YY/MM/DD __ location)

B. Name of HWC Officer: ____

1. GPS point of individual conflict site: *(centre of this raided field)*

Latitude (N/S): _____°_____ . ________' Longitude (W/E): _____°_____ . ________'

Name of waypoint (stored in GPS): ________________________

2. Details about the interviewee(s): *(owner/victim, worker, witness)*

Interviewee 1

name ________ position/profession ________ ☐ man ☐ woman

Status regarding conflict:
☐ owner of crops ☐ farmer on raided field ☐ witness of conflict ☐ other: ________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

Interviewee 2

name ________ position/profession ________ ☐ man ☐ woman

Status regarding conflict:
☐ owner of crops ☐ farmer on raided field ☐ witness of conflict ☐ other: ________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

Interviewee 3

name ________ position/profession ________ ☐ man ☐ woman

Status regarding conflict:
☐ owner of crops ☐ farmer on raided field ☐ witness of conflict ☐ other: ________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

3. Name of crop owner, if not among interviewed: ______________________________

CR/ 1

Awely Human-Wildlife Conflict Assessment Form – Crop Raiding

4. How much of which type of crops has been damaged?

Crop type	Quality* G/M/P	Stage** S/I/M/H	Field Size (m x m)	Damage Area 1	Damage Area 2	Damage Area 3	Damage Area 4
			x	x	x	x	x
			x	x	x	x	x
			x	x	x	x	x
			x	x	x	x	x

** Good/Medium/Poor **Seed or Seedling/Intermediate/Mature/Harvested Areas: meter x meter*

5. How were the crops destroyed?

☐ animal(s) passing through the field ☐ crops eaten by the animal(s)

☐ destruction by stressed animal(s) ☐ others: ________________

6. a) Were the crops protected or secured in any way?

☐ yes ☐ no ☐ unknown

b) If yes, what was done?

☐ shouting by people ☐ firecrackers ☐ banging materials/drums
☐ shooting in the air ☐ torch/beam light ☐ fire
☐ wire fence ☐ thorny fence ☐ electric fence
☐ chilli fence ☐ burning incense/chilli ☐ dogs
☐ others: ________________

c) Did anyone actively guard the field?

☐ yes ☐ no ☐ unknown

d) If yes, how many people of which ages were guarding?

	under 5 yrs	6 to 10 yrs	11 to 15 yrs	16 to 25 yrs	over 25 yrs
Male					
Female					

e) If yes, how was guarding done?

☐ sitting outside ☐ patrolling/walking ☐ guarding in huts ☐ guarding in towers

CR/ 2

Awely Human-Wildlife Conflict Assessment Form – Crop Raiding

7. a) How high are the costs of damage?

Owners estimation: ____________ HWC Officers calculation: ____________

b) Which percentage of the whole crops owned by the victim were destroyed?
(this refers to all grown crops, also crops from other fields)

☐ all ☐ almost everything ☐ more than half
☐ half ☐ less than half ☐ just a bit

8. Where do the earnings of the farmer and his/her family mainly come from?

☐ agriculture ☐ livestock keeping ☐ crafts person
☐ employment ☐ others

9. a) How many family members directly depend on that income? *(re. question 8)*

No. of adults (over 15 yrs): __________ No. of children (under 15 yrs): __________

b) Since when are you farming on the crop raided land? ________________ years

10. a) Where your crops raided by animals before in the past 12 months?

☐ yes ☐ no ☐ unknown

b) If yes, which crops mainly: ________________ how often: ____________

c) Which animals were mainly involved? ________________________

11. a) Which actions were taken by you/your family after the conflict?

☐ I/We did nothing ☐ I/We informed the HWC Officer
☐ I/We informed the official wildlife authority ☐ I/We applied for compensation
☐ I/We improved our guarding system ☐ other: ________________

b) Which mitigation measures would you like to take?

☐ There is nothing I/we can do ☐ I would like to get training on HWC mitigation strategies
☐ I would like to improve my guarding system ☐ I would like to find assistance in guarding
☐ I want the wildlife authority to take action ☐ I want the conflict animal to be killed
☐ other: ________________________________

12. Thank you for your information, would you like to add any comment?

____

____

CR/ 3

Awely Human-Wildlife Conflict Assessment Form – Crop Raiding

HWC Officers estimation: Not to be asked to interviewee!

13. How severe do you estimate the damage? Please score on a scale from 1 to 6
(1 marginal; 2 small; 3 medium; 4 big; 5 severe; 6 life threatening)

1	2	3	4	5	6

14. In your opinion, were the crops well protected?
☐ yes ☐ no ☐ unknown If no: What would you suggest to improve?

____

15. Please score the reliability of the information on a scale going from 1 to 6
(1 not reliable at all; 2 not really reliable; 3 partly rel.; 4 quite rel.; 5 very reliable; 6 absolutely rel.)

1	2	3	4	5	6

Further HWC Officers comments:

____

____

____

CR/ 4

Awely Human-Wildlife Conflict Assessment Form – Property Damage

A. Code of conflict event: ________ __ ________________ **Form No.** _____
(YY/MM/DD __ location)

B. Name of HWC Officer: ______________________________

1. GPS point of individual conflict site: *(directly at damaged property)*

Latitude (N/S): ____°____ . ______'   Longitude (W/E): ____°____ . ______'

Name of waypoint (stored in GPS): ____________________

2. Details about the interviewee(s) (owner/victim, worker, witness)

Interviewee 1

name ______ position/profession ______ ☐ man ☐ woman

Status regarding conflict:
☐ owner of property ☐ worker at property ☐ witness of conflict ☐ other: ______

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

Interviewee 2

name ______ position/profession ______ ☐ man ☐ woman

Status regarding conflict:
☐ owner of property ☐ worker at property ☐ witness of conflict ☐ other: ______

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

Interviewee 3

name ______ position/profession ______ ☐ man ☐ woman

Status regarding conflict:
☐ owner of property ☐ worker at property ☐ witness of conflict ☐ other: ______

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

3. Name of owner, if not among interviewed: ______________________

PD / 1

Awely Human-Wildlife Conflict Assessment Form – Property Damage

4. What type of property has been damaged or destroyed?

a) Function of property:

☐ granary store ☐ food storage ☐ kitchen
☐ haystack ☐ drying rack ☐ agricultural depot
☐ warehouse ☐ house for living ☐ farmhouse (people and store or animals)
☐ chicken shelter ☐ beehive ☐ vehicle

☐ others: ______________________

b) Size of property:

☐ less than 2 m^2 ☐ 2 - 5 m^2 ☐ 5 - 10 m^2 ☐ 10 - 20 m^2
☐ 20 - 50 m^2 ☐ 50 - 100 m^2 ☐ over 100 m^2

c) Construction of property:

Walls: ☐ no walls ☐ mud ☐ straw/grass ☐ bamboo ☐ wood ☐ metal sheet ☐ stone ☐ bricks ☐ concrete ☐ ______ (other)

Roof: ☐ no roof ☐ mud ☐ straw/grass ☐ bamboo ☐ wood ☐ metal sheet ☐ stone ☐ bricks ☐ concrete ☐ ______ (other)

d) What was kept in the property?

☐ rice ☐ maize ☐ millet/sorghum ☐ wheat ☐ other cereals
☐ banana ☐ mango ☐ papaya (pawpaw) ☐ jackfruit ☐ other fruits
☐ pumpkin ☐ cabbage ☐ beans/lentils ☐ green leaves ☐ other vegetables
☐ alcohol ☐ honey ☐ sugar ☐ salt ☐ sugar cane
☐ meat ☐ cotton ☐ straw/hay
☐ define other food: ______________________ or: ☐ no eatable goods

5. How did the animal(s) damage or destroy the property?

☐ animal(s) tried to get food from property
☐ animal(s) destroyed property by accident
☐ animal(s) panicked and ran through property
☐ animal(s) was/were aggressive and attacked property

☐ others: ______________________

PD / 2

Awely Human-Wildlife Conflict Assessment Form – Property Damage

6. a) Was the property protected or secured in any way?

☐ yes ☐ no ☐ unknown

b) If yes, what was done?

☐ shouting by people ☐ firecrackers ☐ banging materials/drums
☐ shooting in the air ☐ torch/beam light ☐ fire
☐ wire fence ☐ thorny fence ☐ electric fence
☐ chilli fence ☐ burning incense/chilli ☐ dogs

☐ others: ______________________

c) Did anyone actively guard the property?

☐ yes ☐ no ☐ unknown

d) If yes, how many people of which ages were guarding?

	under 5 yrs	6 to 10 yrs	11 to 15 yrs	16 to 25 yrs	over 25 yrs
Male					
Female					

e) If yes, how was guarding done?

☐ sitting outside ☐ patrolling/walking ☐ guarding in huts ☐ guarding in towers

7. a) How high are the costs of damage at property: *(reconstruction costs)*

Owners estimation: __________ HWC Officers calculation: __________

b) How high are costs of crop damage, if any: *(market price of crops)*

Owners estimation: __________ HWC Officers calculation: __________

c) How much of the property was destroyed (only building not crops):

☐ all ☐ almost everything ☐ more than half
☐ half ☐ less than half ☐ just a bit ☐ none

d) If the property damage was combined with raiding of stored crops, which percentage of the crops was destroyed?

☐ all ☐ almost everything ☐ more than half
☐ half ☐ less than half ☐ just a bit ☐ none

8. Where do the earnings of the victim and his/her family mainly come from?

☐ agriculture ☐ livestock keeping ☐ crafts person
☐ employment ☐ others: ______________________

PD / 3

Awely Human-Wildlife Conflict Assessment Form – Property Damage

9. How many family members directly depend on that income? *(re. question 8)*

No. of adults (over 15 yrs): ________ No. of children (under 15 yrs): ________

10. a) Did your property get damaged by animals before in the past 12 months?

☐ yes ☐ no ☐ unknown

b) If yes, which property: ______________ **how often:** ________

c) Which animals were mainly involved? ______________________

11. a) Which actions were taken by you/your family after the conflict?

☐ I/We did nothing ☐ I/We informed the HWC Officer
☐ I/We informed the official wildlife authority ☐ I/We applied for compensation
☐ I/We improved our guarding system ☐ other: ______________

b) Which mitigation measures would you like to take?

☐ There is nothing I/we can do ☐ I would like to get training on HWC mitigation strategies
☐ I would like to improve my guarding system ☐ I would like to find assistance in guarding
☐ I want the wildlife authority to take action ☐ I want the conflict animal to be killed
☐ other: ______________________

12. Thank you for your information, would you like to add any comment?

____

HWC Officers estimation: Not to be asked to interviewee!

13. How severe do you estimate the damage? Please score on a scale from 1 to 6
(1 marginal; 2 small; 3 medium; 4 big; 5 severe; 6 life threatening)

1	2	3	4	5	6

14. In your opinion, was the property well protected?

☐ yes ☐ no ☐ unknown **If no: What would you suggest to improve?**

____

15. Please score the reliability of the information on a scale going from 1 to 6
(1 not reliable at all; 2 not really reliable; 3 partly rel.; 4 quite rel.; 5 very reliable; 6 absolutely rel.)

1	2	3	4	5	6

Further HWC Officers comments:

____

PD / 4

Awely Human-Wildlife Conflict Assessment Form – Livestock Predation

A. Code of conflict event: ___________ __ ___________________________ Form No. ______
(YY/MM/DD __ location)

B. Name of HWC Officer: ____

1. **GPS point of individual conflict site:** *(where livestock was killed or injured)*

Latitude (N/S): ____°____ . _______'   Longitude (W/E): ____°____ . _______'

Name of waypoint (stored in GPS): _______________________

2. **Details about the interviewee(s):** *(owner/victim, worker, witness)*

Interviewee 1

______________ name   ______________ position/profession   ☐ man ☐ woman

Status regarding conflict:
☐ owner of livestock ☐ herder of livestock ☐ witness of conflict ☐ other: __________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

Interviewee 2

______________ name   ______________ position/profession   ☐ man ☐ woman

Status regarding conflict:
☐ owner of livestock ☐ herder of livestock ☐ witness of conflict ☐ other: __________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

Interviewee 3

______________ name   ______________ position/profession   ☐ man ☐ woman

Status regarding conflict:
☐ owner of livestock ☐ herder of livestock ☐ witness of conflict ☐ other: __________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

3. **Name of livestock owner if not among interviewed:** ______________________________

LP/ 1

Awely Human-Wildlife Conflict Assessment Form – Livestock Predation

4. **a) How many of which livestock species have been injured or killed?**

	Suckling young		Young/juvenile		Adult male		Adult female	
	injured	killed	injured	killed	injured	killed	injured	killed
Cattle								
Sheep								
Goat								
donkey								
horse								
poultry								
other								
other								

b) The attacked livestock has been:

☐ just killed by predator ☐ partly eaten up by predator ☐ fully eaten up by predator
☐ slightly injured by predator ☐ severely injured by predator ☐ only scared by predator

c) Is any livestock missing, without knowing whether it's killed or injured?

☐ yes ☐ no ☐ unknown

d) If yes, please define: ____

5. **a) Where was the livestock held as it was attacked?**

☐ in corral/shelter/cage near houses
☐ in corral/shelter in the pastures
☐ around houses without shelter
☐ on the pasture guarded by herdsmen
☐ on the pasture without herdsmen
☐ moving between corral/shelter and pasture
☐ moving to/from market
☐ others: ____

LP/ 2

Awely Human-Wildlife Conflict Assessment Form – Livestock Predation

b) The livestock killed or injured was held in a herd/group of how many?

livestock	
☐ only 1	☐ 61-100
☐ 2-4	☐ 101-250
☐ 5-20	☐ 251-500
☐ 21-40	☐ 501-700
☐ 41-60	☐ over 700

livestock	
☐ only 1	☐ 61-100
☐ 2-4	☐ 101-250
☐ 5-20	☐ 251-500
☐ 21-40	☐ 501-700
☐ 41-60	☐ over 700

livestock	
☐ only 1	☐ 61-100
☐ 2-4	☐ 101-250
☐ 5-20	☐ 251-500
☐ 21-40	☐ 501-700
☐ 41-60	☐ over 700

6. **a) Was the livestock protected or secured in any way?**

☐ yes ☐ no ☐ unknown

b) If yes, what was done?

☐ shouting by people ☐ firecrackers ☐ banging materials/drums
☐ shooting in the air ☐ torch/beam light ☐ fire
☐ wire fence ☐ thorny fence ☐ electric fence
☐ chilli fence ☐ burning incense/chilli ☐ dogs
☐ others: ______________________________

c) Did anyone actively guard the livestock?

☐ yes ☐ no ☐ unknown

d) If yes, how many people of which ages were guarding:

	under 5 yrs	6 to 10 yrs	11 to 15 yrs	16 to 25 yrs	over 25 yrs
Male					
Female					

e) If yes, how was guarding done?

☐ sitting outside ☐ patrolling/walking ☐ guarding in huts ☐ guarding in towers

7. **a) How high are the costs of damage?**

Owners estimation: _____________ HWC Officers calculation: _____________

8. **Where do the earnings of the owner and his/her family mainly come from?**

☐ agriculture ☐ livestock keeping ☐ crafts person
☐ employment ☐ others: ______________________________

9. **How many family members directly depend on that income?** *(re. question 8)*

No. of adults: ___________ No. of children: ___________

LP/ 3

Awely Human-Wildlife Conflict Assessment Form – Livestock Predation

10. **a) Was your livestock attacked by predators before in the past 12 months?**

☐ yes ☐ no ☐ unknown

b) If yes, which livestock: ____________________ **how often:** ____________

c) Which predators were mainly involved? ______________________________

11. **a) Which actions were taken by you/your family after the conflict?**

☐ I/We did nothing ☐ I/We informed the HWC Officer
☐ I/We informed the official wildlife authority ☐ I/We applied for compensation
☐ I/We improved our guarding system ☐ other: ____________________

b) Which mitigation measures would you like to take?

☐ There is nothing I/we can do ☐ I would like to get training on HWC mitigation strategies
☐ I would like to improve my guarding system ☐ I would like to find assistance in guarding
☐ I want the wildlife authority to take action ☐ I want the conflict animal to be killed
☐ other: ____

12. **Thank you for your information, would you like to add any comment?**

____

HWC Officers estimation: Not to be asked to interviewee!

13. **How severe do you estimate the damage? Please score on a scale from 1 to 6**
(1 marginal; 2 small; 3 medium; 4 big; 5 severe; 6 life threatening)

1	2	3	4	5	6

14. **In your opinion, was the livestock well protected?**

☐ yes ☐ no ☐ unknown **If no: What would you suggest to improve?**

____

15. **Please score the reliability of the information on a scale going from 1 to 6**
(1 not reliable at all; 2 not really reliable; 3 partly rel.; 4 quite rel.; 5 very reliable; 6 absolutely rel.)

1	2	3	4	5	6

Further HWC Officers Comments:

____

____

LP/ 4

Awely Human-Wildlife Conflict Assessment Form – Injuries/Death

A. Code of conflict event: __________ __ ______________________ Form No. ______
(YY/MM/DD __ location)

B. Name of HWC Officer: ____

1. GPS point of individual conflict site: *(location where victim was killed or injured)*

Latitude (N/S): ____°____ . ________' Longitude (W/E): ____°____ . ________'

Name of waypoint (stored in GPS): ________________________

2. Details about the interviewee(s): *(owner/victim, worker, witness)*

Interviewee 1

________ name ________ position/profession ☐ man ☐ woman

Status regarding conflict:
☐ victim ☐ family of victim ☐ witness of conflict ☐ other: __________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

Interviewee 2

________ name ________ position/profession ☐ man ☐ woman

Status regarding conflict:
☐ victim ☐ family of victim ☐ witness of conflict ☐ other: __________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

Interviewee 3

________ name ________ position/profession ☐ man ☐ woman

Status regarding conflict:
☐ victim ☐ family of victim ☐ witness of conflict ☐ other: __________

Age:
☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

3. Details about victim, if not among interviewed:

________ name ________ position/profession ☐ man ☐ woman

Age: ☐ under 12 ☐ 12 to 19 ☐ 20 to 35 ☐ 36 to 50 ☐ 51 to 65 ☐ over 65

ID/ 1

Awely Human-Wildlife Conflict Assessment Form – Injuries/Death

4. a) Which injuries does the victim have?

	head	throat	neck	arm	leg	back	chest	stomach
Bites (S/M/L)*								
Hits/Blows (S/M/L)*								
Scratches (S/M/L)*								

* severity of injury: Small / Medium / Large

b) How severe is the victim injured?
☐ slightly *(small injuries but able to follow daily business)*
☐ badly *(the victim will need some days to recover from the injuries)*
☐ severe *(it will take weeks to months until victim is recovered)*
☐ very severe *(it will take at least a year to fully recover)*
☐ fatal *(will never fully recover anymore)*
☐ dead
☐ unknown

c) Did the victim visit a doctor?
☐ yes ☐ no ☐ unknown

d) If yes, please give details:

Location/Town of hospital/doctor: ______________________

How long did it take to bring victim there?
☐ less than 1 h ☐ 1-3 hrs ☐ 3-5 hrs ☐ 5-8 hrs
☐ 8-12 hrs ☐ 12-24 hrs ☐ 2 days ☐ more than 2 days

How was victim brought there?
☐ by foot ☐ by bicycle ☐ on a horse
☐ on a horse/oxen/donkey cart ☐ by motor bike ☐ by a private car
☐ by public bus/pickup ☐ by ambulance ☐ others: __________

5. a) What did the victim do, as he/she got attacked?
☐ travelling on bicycle ☐ travelling by foot ☐ walking through the bush
☐ guarding crops/village ☐ scaring away animals from crops/village
☐ working on field ☐ guarding livestock ☐ others: __________

b) Did the victim consume alcohol, before the conflict occurred?
☐ yes ☐ no ☐ unknown

c) Please describe what has happened in detail:

____

____

ID/ 2

Awely Human-Wildlife Conflict Assessment Form – Injuries/Death

6. a) Did the victim try to protect himself/herself?
☐ yes ☐ no ☐ unknown

b) If yes, what was done?
☐ screaming ☐ shooting ☐ running away
☐ fire ☐ knife ☐ banging materials
☐ dogs ☐ others: ______________________

7. a) How much does the treatment cost for the victim?

Victims estimation: ____________ HWC Officers calculation: ______________

b) How much loss will the family have through missing (wo)man power?

Victims estimation: ____________ HWC Officers calculation: ______________

8. Where do the main earnings of the victim and his family come from?
☐ agriculture ☐ livestock keeping ☐ crafts person
☐ employment ☐ others: ______________________

9. How many family members directly depend on income of victim? (re. question 8)

No. of adults: ____________ No. of children: ____________

10. a) Did anyone in the village of the victim already experience an animal attack before in the past 12 months?
☐ yes ☐ no ☐ unknown

b) If yes, when?
☐ a few days ago ☐ 1-2 weeks ago ☐ 2-4 weeks ago ☐ 1-6 months ago
☐ 6-12 months ago ☐ about 1-2 years ago ☐ more than 2 years ago

c) If yes, which animals? ______________________

d) If yes, were the conflict animal(s) individually known to victim or village before?
☐ yes ☐ no ☐ unknown

e) If yes, please give details on the previous attacks: ______________

____

____

ID/ 3

Awely Human-Wildlife Conflict Assessment Form – Injuries/Death

11. a) Which actions were taken by you/your family after the conflict?
☐ I/We did nothing ☐ I/We informed the HWC Officer
☐ I/We informed the official wildlife authority ☐ I/We applied for compensation
☐ I/We improved our guarding system ☐ other: ______________

b) Which mitigation measures would you like to take?
☐ There is nothing I/we can do ☐ I would like to get training on HWC mitigation strategies
☐ I would like to improve my guarding system ☐ I would like to find assistance in guarding
☐ I want the wildlife authority to take action ☐ I want the conflict animal to be killed
☐ other: ______________________________________

12. Thank you for your information, would you like to add any comment?

____

____

HWC Officers estimation: Not to be asked to Interviewee!

13. How severe do you estimate the Injury? Please score on a scale from 1 to 6
(1 marginal; 2 small; 3 medium; 4 big; 5 severe; 6 life threatening)

1	2	3	4	5	6

14. In your opinion, did the victim protect his/herself well?
☐ yes ☐ no ☐ unknown **If no: What would you suggest to improve?**

____

15. Please score the reliability of the information on a scale going from 1 to 6
(1 not reliable at all; 2 not really reliable; 3 partly rel.; 4 quite rel.; 5 very reliable; 6 absolutely rel.)

1	2	3	4	5	6

Further HWC Officers comments:

____

____

____

ID/ 4

Awely Human-Wildlife Conflict Assessment Form – Brief Conflict Assessment

a) Code of conflict event (GI-A): __________ __ ____________________________________
(YY/MM/DD __ location)

b) Name of HWC Officer (GI-B): ____

c) Date of assessment (GI-C): ________ / ________ / 20________

d) GPS point of general conflict site (GI-1): *(centre of entire damage/conflict event)*

Latitude (N/S): _____°_____ . ________' Longitude (W/E): _____°_____ . ________'

Region: ____

Name of village/conflict area: ___________________________________

e) Date at which conflict occurred (GI-2): ________ / ________ / 20________

f) How many victims suffered from this conflict in total (GI-3b)? __________

g) How many individuals of which species were involved (GI-9a)?

___ elephant(s)	___ hippo(s)	___ wild boar(s)
___ baboon(s)	___ rhino(s)	___ buffalo(s)
___ lion(s)	___ hyena(s)	___ cheetah(s)
___ leopard(s)	___ tiger(s)	___ crocodile(s)

☐ other: ____ __________________ ____________________________________
no. species scientific name (only if English name is inexact)

h) Estimation of total conflict costs (GI-F2):

a) Crop Raiding: ______________________ c) Property Damage: ______________________

b) Livestock Predation : ________________ d) Injuries/Death: ________________________

i) Details about the interviewee (CR-2/LP-2/PD-2/ID-2):
☐Man ☐Woman Name: ____

j) Details about damage (CR-4/LP-4/PD-4/ID-4):

CR: Crop type that has been damaged?	LP: How many of which species of livestock have been injured or killed?	PD: Function of property	ID: Gender of victim/ severity of injury

BCA

Appendix B

Table 3: Definition of seasons per study area. Seasons differ in length per months

	SL	TA	BA	MA
RS[1]	Dec – April 5 months	March – June 4 months	Jul – Oct 4 months	June – Sept 4 months
IS[2]	May – July 3 months	Nov – Feb 4 months	Nov – Feb 4 months	Oct/Nov; March-May 5 months
DS[3]	Aug – Nov 4 months	Jul – Oct 4 months	Mar – June 4 months	Dec – Feb 3 months

[1]RS (Rainy season), [2]IS (Intermediate season), [3]DS (dry season)

Appendix C

Table 4: Length of growth stages per crop type and study area in days; seed/seedling stage begins with sowing and ends with the full development of the first leaves and roots, intermediate stage ends with the development of fruits, mature crops are fruit bearing, and harvested crops are harvested but remaining on fields either for drying, storage or collection

study area	crop type	seed/seedling	intermediate	mature	harvested
MA	betel nut	52	95	130	25
MA	chilli	27	47	47	7
MA	fruits/banana	45	270	85	1
MA	lentil	27	47	47	1
MA	maize	27	50	47	7
MA	mustard	27	47	47	1
MA	rice	45	50	60	2
MA	sweet potato	50	85	65	65
MA	vegetables/pumpkin	27	50	47	25
MA	wheat	27	47	47	1
BA	fruits/banana	45	270	85	1
BA	lentil	25	50	50	2
BA	maize	30	50	47	7
BA	mustard	22	47	55	2
BA	potatoe	40	50	125	30
BA	rice	42	50	60	4
BA	vegetables/pumpkin	27	47	57	25
BA	wheat	32	52	55	3
SL	cassava/maniok	14	60	100	1
SL	chilli	14	70	84	7
SL	cotton	5	60	90	4
SL	fruits/banana	14	45	90	1
SL	groundnut	7	80	90	10
SL	maize	5	60	25	7
SL	rice	5	70	90	7
SL	sorghum/millet	5	80	100	7
SL	sweet potato	6	30	90	1
SL	vegetables/pumpkin	5	45	80	3
TA	bean	5	40	25	7
TA	maize	5	60	25	7

Appendix D

Analysis of crop raiding events depending on the season

Parameters of the final generalized linear models for analyzing the relationship between amount of crop raiding events and the season (i.e. dry, intermediate, or rainy season) of the year, the species, the study region and the year after model selection. Summary of fitted parameters is shown for the most parsimonious models.

For each GLM a quasipoisson distribution using a log-link was assumed to account for overdispersion in the data. The log of the length of the season (in month) was used as an offset.

```
Final model:
conflict ~ season + spec + reg/year

                   Estimate Std. Error t-value Pr(>|t|)
(Intercept)         1.70563    1.60360   1.064 0.288715
seasonIS            1.28999    0.22749   5.671 4.64e-08
seasonRS            1.18762    0.22449   5.290 3.05e-07
specelephant        1.45572    1.33471   1.091 0.276664
spechippo          -1.18724    1.40011  -0.848 0.397419
specprimates       -1.66573    1.43653  -1.160 0.247542
specrhino          -0.66150    1.37694  -0.480 0.631432
speczebra           1.74920    1.32441   1.321 0.188019
specbores/hogs     -0.96009    1.35768  -0.707 0.480252
specantelopes/deer -0.54549    1.38496  -0.394 0.694078
regMA               1.69244    1.39438   1.214 0.226197
regSL               0.52638    1.09891   0.479 0.632434
regTA               0.19273    7.54610   0.026 0.979648
regBA:year         -0.19054    0.07852  -2.426 0.016086
regMA:year         -0.37941    0.10282  -3.690 0.000285
regSL:year         -0.17946    0.06013  -2.985 0.003175
regTA:year         -0.37949    0.71848  -0.528 0.597927

Residual deviance: 1881.3 on 211 degrees of freedom
```

Analysis of crop damages depending on growth stage for each species

Parameters of the final generalized linear models for analyzing the relationship between number of damaged fields per species and the growth stage, the crop type, and the study region after model selection. Summary of fitted parameters is shown for the most parsimonious models.

For each GLM a quasipoisson distribution using a log-link was assumed to account for overdispersion in the data. The log of the length of growth stages (in days) was used as an offset.

Elephant (n = 696)

```
Final model:
conflicts ~ growth_stage + crop + region
                            Estimate         SE t-value  p-value
(Intercept)                 -3.83662    1.23031  -3.118  0.00190
growth_stagemature          -0.19906    0.26809  -0.743  0.45803
growth_stageintermediate    -0.69064    0.27682  -2.495  0.01284
growth_stageseed/seedling   -2.47671    0.48955  -5.059 5.43e-07
cropcassava/maniok           1.23315    1.31176   0.940  0.34752
cropchilli                 -15.24376 1040.93109  -0.015  0.98832
cropcotton                   2.43314    1.24473   1.955  0.05103
cropfruits                   0.66824    1.24599   0.536  0.59192
cropgroundnut                0.25996    1.44131   0.180  0.85692
croplentil                  -0.33755    1.58510  -0.213  0.83143
cropmaize                    3.55794    1.20967   2.941  0.00338
cropmustard                 -1.34504    2.07038  -0.650  0.51613
croppotato                -16.67482 1620.33099  -0.010  0.99179
croprice                     3.59877    1.20886   2.977  0.00302
cropsorghum/millet           0.06621    1.47613   0.045  0.96424
cropsweet_potato             0.74973    1.31934   0.568  0.57005
cropvegetables               1.00052    1.25805   0.795  0.42672
cropwheat                    2.79186    1.22165   2.285  0.02260
regionMA                    -1.37572    0.20880  -6.589 8.94e-11
regionSL                    -0.39989    0.15935  -2.510  0.01232
regionTA                    -4.18693    1.46530  -2.857  0.00440

deciance: 3340.6
```

Buffalo (n = 72)

```
Final model:
Conflicts ~ growth_stage + region
                          Estimate         SE t-value  p-value
(Intercept)               -42.7271  5651.2425  -0.008    0.994
growth_stagemature         18.2321  3786.8484   0.005    0.996
growth_stageintermediate   16.5321  3786.8484   0.004    0.997
growth_stageseed/seedling  -0.5602  7035.1202   0.000    1.000
regionSL                   18.4637  4194.7972   0.004    0.997
regionTA                   21.6057  4194.7971   0.005    0.996
```

deciance: 15.750

Hippo (n=72)

Final model:
Conflicts ~ crop

	Estimate	SE	t-value	p-value
(Intercept)	-5.9243	0.7351	-8.059	1.56e-11
cropmaize	2.9918	0.7699	3.886	0.000231
croprice	-0.3219	1.1624	-0.277	0.782692

deciance: 75.093

Rhino (n = 312)

Final model:
conflicts ~ growth_stage + crop + region

	Estimate	SE	t-value	p-value
(Intercept)	-3.93000	1.16254	-3.381	0.000819
growth_stagemature	-1.23558	1.08839	-1.135	0.257177
growth_stageintermediate	0.49762	1.00923	0.493	0.622325
growth_stageseed/seedling	0.06476	1.03869	0.062	0.950325
cropmaize	-16.23869	1210.99577	-0.013	0.989310
cropmustard	-0.45690	1.00680	-0.454	0.650293
croppotato	-1.72905	1.35220	-1.279	0.201992
croprice	-0.47947	0.94853	-0.505	0.613587
cropvegetables	-1.48569	1.35245	-1.099	0.272859
cropwheat	2.42429	0.64092	3.783	0.000187
regionMA	-4.19436	1.38788	-3.022	0.002726

deciance: 528.82

Hog/Boar (n = 504)

Final model:
conflicts ~ growth_stage + crop + region

	Estimate	SE	t-value	p-value
(Intercept)	-6.8748	2.1348	-3.220	0.00137
growth_stagemature	-0.6958	0.3922	-1.774	0.07662
growth_stageintermediate	-1.3040	0.4454	-2.928	0.00358
growth_stageseed/seedling	-2.1945	0.7511	-2.922	0.00364
cropgroundnut	3.0468	2.2993	1.325	0.18576
croplentil	4.0567	2.1666	1.872	0.06175
cropmaize	4.6558	2.1231	2.193	0.02878
cropmustard	3.3338	2.2295	1.495	0.13547
croppotato	4.5537	2.1223	2.146	0.03239
croprice	3.6063	2.1502	1.677	0.09415
cropvegetables	3.3786	2.1575	1.566	0.11800
cropwheat	3.8897	2.1710	1.792	0.07381
regionMA	-3.3829	1.2311	-2.748	0.00622
regionSL	-0.5207	0.4796	-1.086	0.27822
regionTA	0.1310	0.5339	0.245	0.80629

deciance: 806.65

Primate (n = 168)

Final model:
conflicts ~ crop + region

	Estimate	SE	t-value	p-value
(Intercept)	-26.070	2149.117	-0.012	0.99034
cropgroundnut	1.447	1.376	1.052	0.29431
croplentil	20.127	2149.117	0.009	0.99254
cropmaize	3.490	1.287	2.712	0.00741
cropsweet_potato	1.323	1.450	0.913	0.36277
regionSL	19.209	2149.116	0.009	0.99288
regionTA	16.213	2149.117	0.008	0.99399

deciance: 115.66

Zebra (n = 16)

Final model:
Conflicts ~ growth_stage + crop

	Estimate	SE	t-value	p-value
(Intercept)	-23.1240	6797.9208	-0.003	0.997
growth_stagemature	0.2675	0.4676	0.572	0.579
growth_stageintermediate	-1.6376	0.5368	-3.051	0.011
growth_stageseed/seedling	-19.8112	6103.7993	-0.003	0.997
cropmaize	22.2767	6797.9208	0.003	0.997

deciance: 14.491

Antelope/Deer (n = 128)

Final model:
conflicts ~ growth_stage + crop + region

	Estimate	SE	t-value	p-value
(Intercept)	-17.2840	1547.6265	-0.011	0.9911
growth_stagemature	-1.9456	0.9080	-2.143	0.0342
growth_stageintermediate	0.1612	0.7678	0.210	0.8341
growth_stageseed/seedling	-0.8734	0.8682	-1.006	0.3165
croplentil	15.6311	1547.6264	0.010	0.9920
cropmaize	-2.8170	2.1138	-1.333	0.1852
cropmustard	14.9223	1547.6264	0.010	0.9923
croppotato	12.8748	1547.6266	0.008	0.9934
cropvegetables	12.6824	1547.6267	0.008	0.9935
cropwheat	15.3634	1547.6264	0.010	0.9921
regionTA	14.2940	1547.6262	0.009	0.9926

deciance: 302.53

Analysis of type of crop destruction for Elephants and Rhinos

Parameters of the final generalized linear models (assuming a binomial distribution using a logit-link) for analyzing the relationship between the type of destruction (i.e. feeding or trampling) and the growth stage, the crop type, the study region and the year after model selection. Summary of fitted parameters is shown for the most parsimonious models.

Elephant (n = 2319)

Final model:
destruction_type ~ crop + growth_stage + region/year

	Estimate	Std. Error	z-value	p-value
(Intercept)	-4.952e-01	1.096e+00	-0.452	0.65151
cropcassava/maniok	-1.525e+01	6.692e+02	-0.023	0.98182
cropchilli	1.908e+01	1.258e+03	0.015	0.98789
cropcotton	9.410e-01	7.319e-01	1.286	0.19853
cropfruits	-1.679e+01	3.871e+02	-0.043	0.96540
cropgroundnut	-8.522e-01	1.259e+00	-0.677	0.49830
croplentil	-2.934e-01	8.813e-01	-0.333	0.73922
cropmaize	-7.620e-01	6.876e-01	-1.108	0.26776
cropmustard	1.376e+00	9.964e-01	1.381	0.16728
cropothers	1.217e+00	7.513e-01	1.620	0.10527
croppotatoe	1.885e+01	2.263e+03	0.008	0.99335
croprice	-1.382e+00	6.595e-01	-2.096	0.03610
cropsorghum/millet	-6.531e-01	1.367e+00	-0.478	0.63284
cropsweet_potato	-1.128e+00	1.234e+00	-0.914	0.36080
cropvegetables	3.486e-01	7.281e-01	0.479	0.63213
cropwheat	-2.508e+00	7.663e-01	-3.273	0.00106
growth_stageintermediate	2.066e+00	4.884e-01	4.229	2.35e-05
growth_stagemature	8.209e-01	4.939e-01	1.662	0.09648
growth_stageseed/seedling	3.901e+00	5.472e-01	7.130	1.00e-12
regionMA	5.311e+00	1.331e+00	3.990	6.60e-05
regionSL	-2.495e+00	1.175e+00	-2.123	0.03377
regionTA	-1.889e+02	3.044e+04	-0.006	0.99505
regionBA:year	-1.850e-01	7.036e-02	-2.630	0.00855
regionMA:year	-6.488e-01	1.124e-01	-5.772	7.84e-09
regionSL:year	-3.179e-02	7.971e-02	-0.399	0.69006
regionTA:year	1.722e+01	2.767e+03	0.006	0.99504

Residual deviance: 1352.9 on 2293 degrees of freedom

Rhino (n = 240)

Final model:
destruction ~ crop + region

	Estimate	Std. Error	z-value	p-value
(Intercept)	-1.6094	0.6325	-2.545	0.01094
cropmaize	21.1755	10754.0130	0.002	0.99843
cropmustard	0.5108	0.9189	0.556	0.57829
croppotato	-17.9566	5377.0065	-0.003	0.99734
croprice	-17.9566	3802.1178	-0.005	0.99623
cropvegetables	-17.9566	5377.0065	-0.003	0.99734
cropwheat	-3.6217	1.1855	-3.055	0.00225
regionMA	19.1606	3802.1179	0.005	0.99598

Residual deviance: 48.914 on 232 degrees of freedom

3. DOES TRADITIONAL AND ADVANCED GUARDING REDUCE CROP LOSSES DUE TO WILDLIFE? A COMPARATIVE ANALYSIS FROM AFRICA AND ASIA

Erklärung zu den Autorenanteilen

an der Publikation: **Does traditional and advanced guarding reduce crop losses due to wildlife? A comparative analysis from Africa and Asia**
Status: under review
Beteiligte Autoren und Autorinnen:

- Eva M. Gross (EMG)
- Bibhuti P. Lahkar (BPL)
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- Oliver Jakoby (OJ)

Was hat die Promovierende bzw. was haben die Koautoren beigetragen?

(1) zu Entwicklung und Planung

Promovierende (EMG) hat die Planung und Entwicklung der Studie geleitet und durchgeführt (100%)

(2) zur Durchführung der einzelnen Untersuchungen und Experimente

EMG hat die Durchführung der Datenaufnahme angeleitet und Mitarbeiter für Datenaufnahme angelernt und diese koordiniert (70%)
BPL hat die Mitarbeiter bei der Datenaufnahme logistisch unterstützt und die die Verbindung zur Wildtierbehörde in Indien hergestellt (10%), NS hat die Verbindung zur Wildtierbehörde in Nepal hergestellt (5%), VRN hat die Verbindung zur Wildtierbehörde in Sambia hergestellt (5%), LLL hat die Mitarbeiter in Tansania bei der Datenaufnahme logistisch unterstützt und die die Verbindung zur Wildtierbehörde hergestellt (10%).

(3) zur Erstellung der Datensammlung und Abbildungen

EMG hat alle im Feld erhobenen Daten gesammelt und für die Analyse aufgearbeitet sowie Abbildungen erstellt (70%), OJ hat einen Teil der Abbildungen erstellt (30%)

(4) zur Analyse und Interpretation der Daten

EMG hat die Daten interpretiert und analysiert (70%) OJ hat bei der Interpretation und Analyse der Daten mitgewirkt (30%)

(5) zum Verfassen des Manuskripts

EMG hat das Manuskript hauptsächlich verfasst (70%), OJ hat einen Teil der Statistik verfasst (20%), die weiteren Co-Autoren haben Teile des Manuskripts überarbeitet BPL (2,5%), NS (2,5%), und VRN (5%)

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Zustimmende Bestätigungen der oben genannten Angaben

Unterschrift Betreuer: ______________________________ Datum/Ort: _______________________

Does traditional and advanced guarding reduce crop losses due to wildlife? A comparative analysis from Africa and Asia

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Abstract

Crop damages on farms located within conservation landscapes, caused by herbivorous wildlife species, are an important source for human-wildlife conflicts (HWCs). Over six years (2009 to 2014) we have continuously examined the extent of crop damages by three groups of wildlife species in two African and two Asian study areas prone to HWCs, using a standardized HWC assessment scheme. Analysis of costs of crop damages revealed substantial losses especially caused by elephants and other large herbivores. When wildlife had entered farms, crop protection measures by farmers were only able to reduce damage costs when applied as a communal, strategic guarding system. Other traditional crop protection strategies have proven ineffective in reducing crop damage costs. Electrical fences further bear the risk of increasing crop damages when combined with guarding and chasing of wildlife. We therefore recommend reviewing traditional guarding strategies and fostering objective evaluation.

Keywords:

bush pig; communal guarding; conflict assessment; crop protection; elephant; fence; human-wildlife conflict; mitigation strategies; wild boar; zebra

3.1 Introduction

The damage of crops by wildlife species has been described as one of the main drivers for conflicts between people and wildlife in African and Asian countries (Thirgood et al. 2005). When the species concerned are protected by law and therefore not to be killed by the farmer, this conflict actually is a matter between farmers and governmental as well as non-governmental wildlife conservation agencies (Madden and McQuinn 2014). People affected by crop damage are mostly living adjacent to protected areas or in multiple-use zones (Treves et al. 2006), where natural wildlife habitat and agriculture are interspersed or in areas that have been lately transformed from natural habitat to human dominated forms of land-use (Distefano 2005).

Further, biodiversity hotspots and extreme poverty are geographically coincident. Due to lack of resources, institutions and governance structures, people in rural areas located close to protected areas face difficult income situations (Barrett et al. 2011). When subsistence farming is the only livelihood, crop damages can directly affect survival. Wildlife species involved in crop damages range from small mammals like macaques (*Macaca* spec.) or baboons (*Papio* spec.) (Taylor et al. 2016) to larger mammals like bush pigs (*Potamochoerus larvatus*) or wild boars (*Sus scrofa*) (Barrios-Garcia and Ballari 2012) to the largest terrestrial herbivores, the Asian and African elephants (*Elephas maximus* and *Loxodonta africana*) (Hoare 2000; Sukumar 2006).

In order to decrease the amount of crop damages by wildlife species, farmers have developed several methods to protect their fields against hungry visitors. Traditional protection measures range from guarding and scaring intruding wildlife by drumming and shouting, to the use of natural barriers (Thapa 2010) or olfactory repellents (Osborn 2002). Governmental and non-governmental conservation agencies propagate and support community based approaches (Treves et al. 2009) and low-tech improved protection strategies such as bee hive fences (King et al. 2011) or highly cost intensive installation like electric fences (Sapkota et al. 2014) or trenches (MacKenzie 2012).

The tangible and intangible costs for farmers to protect their fields can be considerable (Barua et al. 2013), however not much is known about the effectiveness of guarding methods and their potential to decrease costs of damage (Davies et al. 2011; Graham and Ochieng 2008).

Over six years we have continuously examined the extent of crop damages by three different groups of wildlife species (i.e. elephants, other large herbivores, and small herbivores) in two African and two Asian study areas prone to human-wildlife conflicts

(HWCs). With this study we aim at understanding the magnitude of crop damages for local farmers caused by different wildlife species, and evaluating the effect different crop protection strategies have on income losses through crop damages.

3.2 Materials and methods

3.2.1 Study area

Data were collected continuously from January 2009 to December 2014 in three study areas (South Luangwa/Zambia, Bardia/Nepal and Manas/India) and from January 2010 to December 2011 in Tarangire/Tanzania. The economies of Zambia and India are classified as low middle income and those of Tanzania and Nepal as low income (World Bank Group 2017).

South Luangwa/Zambia (SL): This study area encompasses five chiefdoms of the Lupande Game Management Area (GMA) (Fig. 1a) adjoining South Luangwa National Park in the Eastern Province of Zambia. The rural per capita income has been calculated at 24.82 USD per month (CSO 2015). The population (predominantly Kunda ethnic group) of the Lupande GMA is estimated at 51457 people in 9962 households (CSO 2012), utilizing about 45.4% of the GMA for living, agriculture and infrastructure (Watson et al. 2014). Small-scale subsistence farming of maize (*Zea mays*), sorghum (*Sorghum bicolor*) and finger-millet (*Eleusine coracana*) is the main agricultural activity in the study area (Gross et al. *subm.*). The Luangwa valley holds the largest elephant (*Loxodonta africana*) population of the country (DNPW 2016) as well as large populations of other herbivores.

Tarangire/Tanzania (TA): East of Tarangire National Park in northern Tanzania, this study area encompasses the community of Loibor Siret in Simanjiro District (Fig. 1b), with a total land holding of 550 km^2 (Lichtenfeld et al. 2014). The largest ethnic group is Kisongo Maasai (Cooke 2007), which traditionally performs transhumant pastoralism (Baird and Leslie 2013), but today increasingly is involved in agricultural activities, especially the farming of maize, groundnuts (*Arachis hypogea*) and beans (*Phaseolus vulgaris*) (Cooke 2007). The rural per capita income for this region (Manyara) is estimated at 55.79 USD per month (UNDP 2015). The area belongs to one of East Africa’s most important wildlife habitats with large numbers of migratory ungulates.

Bardia/Nepal (BA): In the lowlands of Nepal this study area is located in the western Buffer Zone (BZ) of Bardia National Park, encompassing four Village Development Committees (VDC) on the Western bank of the Geruwa River and four VDCs on the Eastern side (Fig. 1c). With about 306 people/km^2 (Thapa and Chapman 2010) the study area is densely populated with a majority of indigenous Tharu (Studsrod and Wegge 1995). Subsistence farming and livestock keeping are the main economic activities (Gross et al. *subm.;* Thapa Karki 2013), resulting in a rural per capita income of 56.0 USD per month in the Bardiya district (UNDP 2014b). The national park holds a high density of herbivores, including the largest number of resident elephants (*Elephas maximus*) in Nepal and a small population of reintroduced greater one-horned rhinos (*Rhinoceros unicornis*) (Flagstad et al. 2012; Wegge et al. 2009).

Manas/India (MA): This study area includes the southern belt of private agricultural and community lands bordering the Manas National Park (MNP) of Assam, encompassing 156 villages (Fig. 1d). With approximately 1280 people/km^2 the study area is heavily populated. The ethnical composition is diverse, with 35.7% of indigenous Bodo people (Sarma et al. 2015) making their living from paddy (*Oryza sativa*) cultivation and the sale of crops from homestead gardens (Gross et al. *subm.*). In contrast to the rest of India, the economic situation of North-East India is more difficult (UNDP 2014a), the rural per capita income of Baksa district south of MNP is estimated at 25.23 USD per month (UNDP 2014a). MNP is home to a wide range of fauna including Asian elephant (Borah et al. 2013). The greater one-horned rhino is being re-introduced since 2008 (Lahkar et al. 2011; Sarma et al. 2009).

3.2.2 Data collection

The data collection on crop damages was conducted within a broad study on human-wildlife conflicts, which also included property damages, livestock predation, and human accidents with wildlife. Therefore, an observation of the conflict site by locally trained independent enumerators (HWC officers) as well as structured interviews with victims were conducted using the *Awely* HWC assessment scheme during six consecutive years from 2009 to 2014, as described in Gross et al. (*subm.*). Wildlife species causing damage were identified through tracks, dung and bite marks. Costs of damages were estimated by measuring damaged proportions and calculating potentially achieved revenues in local currency, taking into consideration crop value based on annual market prices and quality. Further, the degree of damage was ranked into six categories (just a bit; less than half; half; more than half; almost everything; everything), in relation to the total farmland utilized by the victim. Demographic data of crop owners/victims were gathered through interviews and were categorized. Information on the exact crop protection measures used against wildlife crop damage, during a particular incident, was collected through interviews and field verification. Unprotected fields experiencing crop damages were used as control. Protected and unprotected fields damaged by wildlife were mapped using Quantum GIS Geographic Information System, Version 2.14.3 Essen (QGIS Development Team 2016).

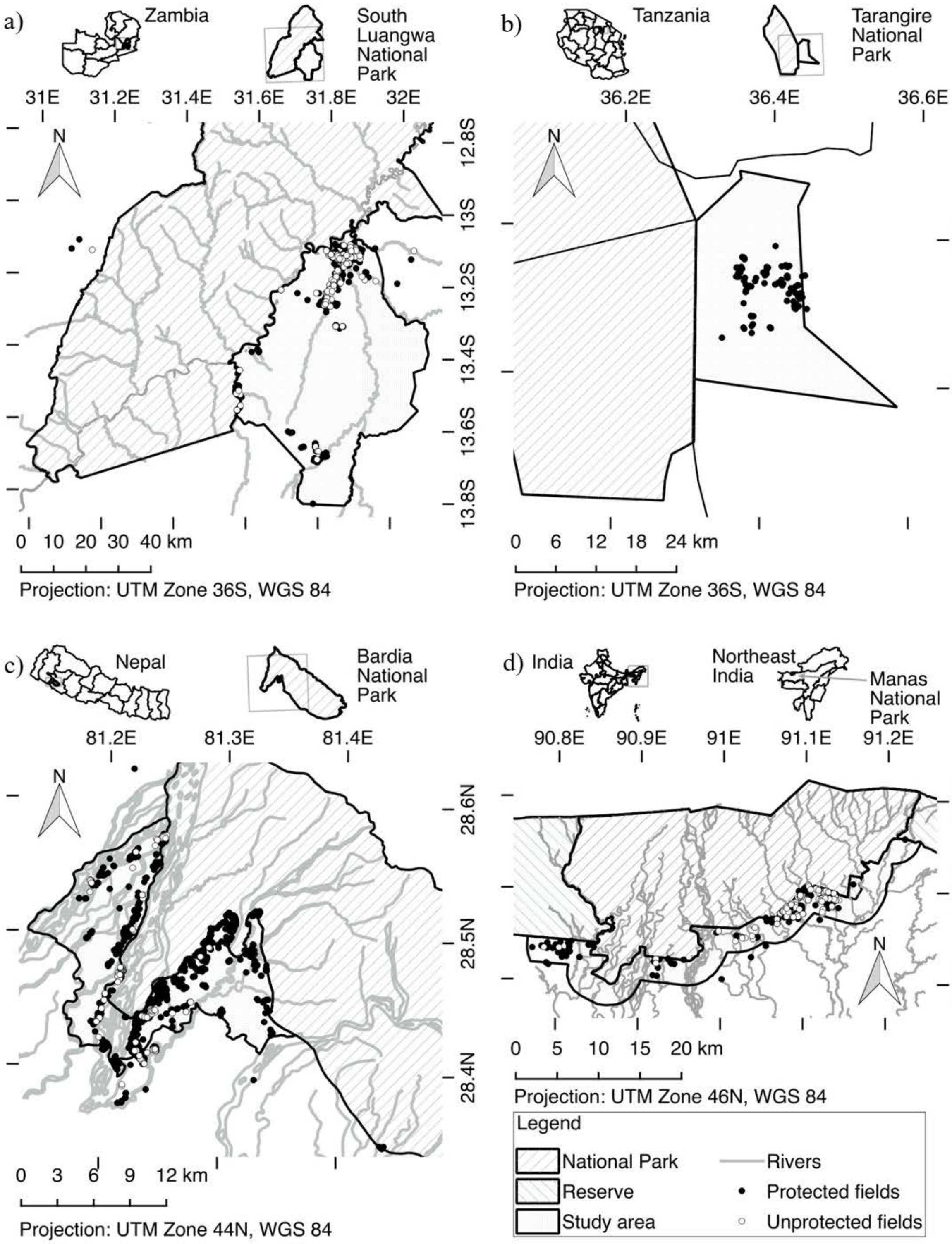

Fig. 1: Distribution of damaged crop fields in the study areas a) SL, b) TA, c) BA, d) MA. Fields protected by guarding and/or with barriers are indicated as black dots, fields without any protection are indicated as white dots. Permanent water bodies (rivers) are indicated as grey lines. Few crop damages located outside of the exact study area were included in the study. Author: Eva Klebelsberg

3.2.3 Data analysis

All costs of damage were converted from local currency into USD, using the rate on 30 June of each year (XE Currency Converter 2017). Species were pooled into three groups (Table 1): Elephants (> 2500 kg), other large herbivores (150-2500 kg; rhino, hippo, buffalo, zebra, and large antelopes) and small herbivores (< 150 kg; small antelopes/deer, boars/hogs, primates, and porcupine).

The protection measures taken by farmers were categorized into active guarding (people being present on field with the aim to guard fields), passive guarding (people sleeping in nearby dwellings and rushing out to scare away wildlife when alarmed), and barrier (electric, wire, or natural fences; trenches). Active or passive guarding combined with barrier were defined as separate categories. Fields without any crop protection measure (no protection) were seen as control. Statistics were calculated with R version 3.2.5 (R Core Team 2016).

The costs of damages were analysed using linear mixed effect models (with R-package *lme4*; (Bates et al. 2015)). The response variable cost of damage had to be log-transformed for all following analysis to ensure normally distributed residuals. For each study area a separate model was calculated and simplified according to backwards model selection using likelihood ratio test (model selection results SOM 01). For the final model least-squares means (with R-package *lsmeans*; (Lenth 2016)) were used to conduct pairwise comparisons between species groups and protection strategies, respectively (using tukey-adjustment of p-values). The difference in the costs of damages between the three groups of species in each of the four study areas was analysed using species group, season and their interaction term as fixed, protection strategy, crop and year as crossed random variables.

The influence of protection strategies and of the three groups of wildlife species on the costs of damages in each of the four study areas were calculated using species group, protection strategy and their interaction term as fixed, crop and year as crossed random variables. For this analysis we restricted the data set to damage events in the rainy (RS) and intermediate season (IS) and excluded costs of damage events in the dry season. Farming and guarding practices of the RS and IS can be assumed as being similar; staple crops farming generally starts in the RS and is finalized in the IS (Gross et. al *subm.*). Dry season farming may differ in terms of guarding strategies, but for small and other large herbivores only low numbers of damage were available.

As data were exclusively collected on fields experiencing crop damage, we were not able to include data from fields that were not visited by wildlife species and therefore created no cost of damage.

3.3 Results

For this study, data on 5366 crop damages from four study areas (SL, TA, BA, MA) were collected and analysed.

3.3.1 Characteristics of crop damage

In all four study areas the majority of crop owners with damaged crops were men (SL: 77.7%, TA: 72.9%, BA: 90.6%, MA: 96.1%), mostly aged 36 to 50 years. The main source of income was agriculture (SL: 81.1%, TA: 98.1%, BA: 97.5%, MA: 90.5%), only small proportions of the crop raiding victims made their living mainly from other sources of income, including livestock-keeping, wage earning, trade or craft. On average six to seven family members were dependent on the damaged crops (SL: 6.2 ± 3.9, TA: 6.8 ± 5.0, BA: 7.9 ± 5.1, MA: 6.3 ± 4.0). In the two African study areas farmers have been farming on their land since an average of 6.8 ± 7.2 years (SL) and 5.0 ± 4.0 years (TA), respectively. In the two Asian study areas, however, farmers have been cultivating their fields much longer; in BA 29.3 ± 21.2 years and in MA 31.4 ± 3.5 years. The majority of crop raiding victims explained that they experienced crop damages more than once a year (SL: 82.7%, TA: 55.7%, BA: 72.2%, MA: 75.8%) with an average of three to four crop damages per year (SL: 3.53 ± 2.39, TA: 4.36 ± 1.15, BA: 3.49 ± 5.66, MA: 3.67 ± 4.64).

3.3.2 Severity of crop damage

In relation to total field sizes the aggrieved farmers had under cultivation, the majority of crop damages through wildlife affected up to 40% (Table 1). In SL the proportions of large crop damages (> 40% of total field size) were highest with 22.1%, followed by BA (20.2%) and TA (18.9%), MA showed the lowest proportion of such large damages (10.8%). Most large crop damages (> 40% of total field size) were due to elephants in SL, BA and MA, and due to other large herbivores (mainly zebra) in TA. Small herbivores like primates, small antelopes/deer and hogs/boars caused more damages below 40%, in all four study areas. The majority of crop damages below 40%, nevertheless, were caused by elephants (SL, BA and MA) and zebra (in TA).

Table 1: Frequencies of small (< 40%) and large (> 40%) crop damage incidents per study area caused by different species groups from 2009 to 2014. Percentages of all incidents per study area are indicated in brackets.

Herbivore category	SL		TA*		BA		MA	
	damages < 40%	damages > 40%	damages < 40%	damages > 40%	damages < 40%	damages > 40%	damages < 40%	damages > 40%
elephants[1]	661 (67.7)	208 (21.3)	4 (3.9)	2 (2.0)	899 (53.4)	227 (13.5)	329 (86.6)	41 (10.8)
other large herbivores[2]	33 (3.4)	6 (0.6)	38 (37.3)	18 (17.6)	172 (10.6)	71 (4.2)	6 (1.6)	0
small herbivores[3]	67 (6.9)	2 (0.2)	40 (39.2)	0	269 (16.0)	44 (2.6)	4 (1.1)	0
total	761 (77.9)	216 (22.1)	82 (80.4)	20 (19.6)	1340 (79.7)	342 (20.3)	339 (89.2)	41 (10.8)

[1] SL and TA *Loxodonta africana*, BA and MA *Elephas maximus*

[2] SL: hippo (*Hippopotamus amphibius)* and African buffalo (*Syncerus caffer*), TA: African buffalo, Burchell's zebra (*Equus quagga burchellii*) and common eland (*Taurotragus oryx*), BA: greater one-horned rhino (*Rhinoceros unicornis*), and blue bull (*Boselaphus tragocamelus*), MA: greater one-horned rhino and wild water buffalo (*Bubalus arnee*)

[3] SL: bushpig (*Potamochoerus larvatus*), vervet monkey (*Chlorocebus pygerythrus*), baboon (*Papio cenocephalus*), and cape porcupine (*Hystrix africaeaustralis*), TA: bushpig and warthog (*Phacochoerus africanus*), impala (*Aepyceros melampus*), vervet monkey, and crested porcupine *(Hystrix cristata),* BA: wild boar (*Sus scrofa*), spotted deer (*Axis axis*), common langur (*Semnopithecus entellus*), and Indian porcupine (*Hystrix indica*), MA: wild boar

[*] Damage numbers for TA refer to the years 2010 and 2011 only.

3.3.3 Costs of crop damage

The costs of damage wildlife caused to farmers through feeding on their fields or trampling crops varied considerably (Table 2), with minimum costs ranging from SL: 0.39, TA: 3.72, BA: 0.4, and MA: 0.06 USD to maximum costs up to SL: 952.38, TA: 930.53, BA: 557.66, and MA: 1008.97 USD. However, the distribution of costs is skewed towards lower values.

The mean costs of crop damages varied between the different species categories (Fig. 2). In SL elephants caused significantly higher damages than other large (mainly hippo) and small herbivores (mainly bush pig and porcupine). In TA large herbivores (mainly zebra and common eland) caused significantly higher damages than small herbivores (mainly bushpig, warthog and impala). Mean costs of damage through elephants, however, did not differ statistically, neither from large nor small herbivores. In BA no significant difference for the costs of crop damage caused by the three species groups throughout the year was observed. However, seasonal differences exist: In the rainy season significantly lower costs of damages were produced by elephants compared to small herbivores, whereas in the intermediate season significantly larger costs were observed for other large (mainly rhino) compared to small herbivores (mainly wild boar and spotted deer). In MA no variable showed any statistical difference regarding the crop damage costs caused by the three species groups (as "species group" as well as "season" was not included in the final model).

Table 2: Total number of farmers with fields damaged by wildlife in four different study areas from 2009 to 2014 as well as mean and standard deviation of losses per farmer per damage incident in USD.

Parameters	SL	TA*	BA	MA
Number of farmers with damaged fields	2760	107	1689	810
Total costs of damage 2009 to 2014 [USD]	90,338.98	9,055.03	46,413.60	8,358.17
Mean ± sd of cost of damage per incident per farmer [USD]	32.73 ± 49.89	84.63 ± 119,72	27.48 ± 29.06	10.32 ± 39.25
Median cost of damage per incident per farmer [USD]	19.32	47.51	19.22	4.21

*2010/2011

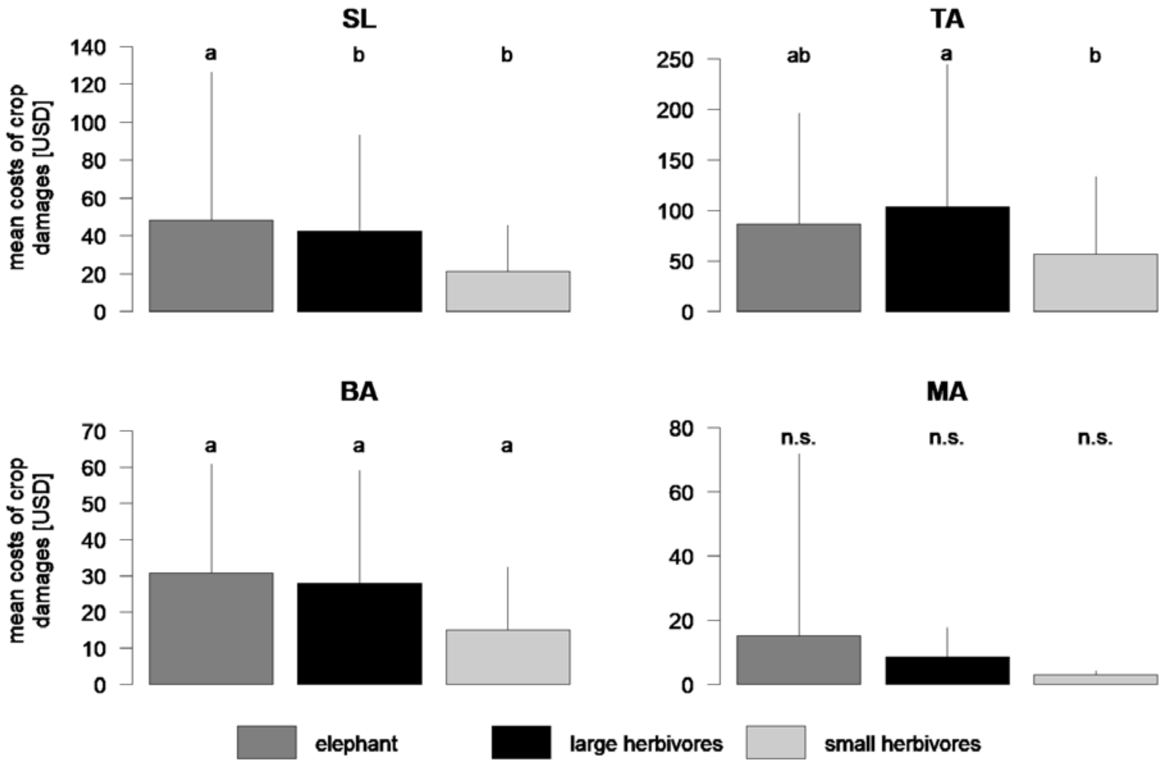

Fig. 2: Mean costs of crop damage by species groups per study site [USD] from 2009 to 2014 (TA 2010/2011). Different lower case letters indicate significant differences ($p < 0.05$) between species groups. Whiskers indicate standard deviation over the six study years

3.3.4 Influence of crop protection measures on costs of damage

On the majority of damaged fields crop protection measures were used (SL: 69.5%, TA: 100%, BA: 93.8%, MA: 52.7%). Protected and unprotected fields were distributed homogenously over the study area (Fig.1). Protection measures were grouped into seven categories (see Appendix A, Table A1). Active and passive guarding were the most frequently used strategies in all four study areas. In TA and BA barriers were also used frequently, either as single measure (BA) or in combination with active (TA, BA) or passive guarding (BA). Barriers used in BA generally were two-strand electric fences (4 to 5 kV), located along the boundary of the forest, while in TA barriers consisted of thorny bushes around fields. In MA active guarding has been carried out as a community based guarding system, strategically protecting a large farming block, whereas in SL, TA and BA active guarding was carried out by single or small groups of farmers guarding single plots of land. The costs of crop damages on fields with different protection categories varied between the study areas as well as between species categories (Fig. 3).

In SL no significant difference in costs of crop damage by elephants or small herbivores were observed between any of the crop protection categories including non-protected fields (Fig. 3). Only large herbivores cause significantly higher costs of crop damage on fields, which were passively guarded compared to non-protected fields ($p = 0.0043$). In TA no significant cost reduction between protection measures was observed for any of the species groups (during model selection neither the variable *mitigation* nor its interaction was found to be significantly affecting the *cost of damage*).

In BA elephants caused significantly higher costs of damage on fields protected by active guarding + barrier compared to non-protected fields ($p = 0.0009$) (Fig. 3). For all other crop protection strategies no significant difference in costs through crop damage by elephants was observed compared to unprotected fields. Further, on fields protected by active guarding, active guarding + barrier as well as passive guarding + barrier significantly higher crop damage costs by elephants were observed than with barriers alone ($p = 0.004$; $p < 0.001$ and $p = 0.004$, respectively). Additionally, active guarding + barrier produced higher costs of damage than passive guarding + barrier ($p = 0.003$) and active guarding + barrier caused higher costs than passive guarding ($p = 0.001$). For the group of large herbivores in BA costs of crop damage on fields protected by passive guarding + barriers as well as barriers alone were significantly lower than on non-protected fields ($p = 0.045$ and $p < 0.001$) and all other protection categories ($p < 0.05$). However, costs of crop damage on fields protected by active guarding were significantly higher than on non-protected fields ($p = 0.015$). Costs of crop damages by small herbivores were significantly lower in BA on fields with barriers compared to active ($p = 0.010$) or passive guarding ($p = 0.006$).

In MA (Fig. 3) actively guarded fields were the only fields on which costs of crop damage by elephants were significantly lower than on non-protected fields ($p = 0.007$). Between all other protection categories no significant differences in costs through crop damage were observed, compared to non-protected fields or between different crop protection categories.

3.4 Discussion

3.4.1 Social dimension of crop damages

Since the beginning of farming, the protection of crops against pests is a major issue for farmers all over the world (Dehne and Schönbeck 2012; Zadoks 2013). It is estimated that today farmers in South Asia and Southern Africa lose on average 40% (Eastern Africa even 50%) to weeds, pathogens and pests before the harvest (Oerke 2006). The majority of crop losses due to wildlife in this study are below 40%. However, it has to be taken into consideration that the crop losses due to weeds, insects and rodents, viruses and other pathogens are not included and will additionally affect the crops not consumed by wildlife. With a very low per capita income (UNDP 2014a; UNDP 2014b; UNDP 2015; UNDP 2016) and high dependency on agriculture, farmers of the four study areas do not have means to attenuate crop losses. In the two African study areas the mean loss caused by a single crop damage by wildlife exceeds the monthly rural per capita income of a farmer, in the Asian study areas the mean loss per damage is about half of the monthly rural per capita income. Losing a monthly or half monthly income is a heavy drawback for any farmer, especially for those living in poverty. Although India and Zambia today are classified as low-middle income countries (World Bank Group 2017), both are characterized by a strong inequality of income generation by States (Directorate of Economics and Statistics 2014) or regions (UNDP 2016). Assam’s economic situation differs greatly from peninsular India’s and especially in the rural parts of the study area per capita income is low (UNDP 2014a). The economy of the Eastern Province in Zambia is even ranked as low income (UNDP 2016). The vulnerability of farmers in MA and SL are therefore comparable to BA or TA. Although large crop losses with a damage of over 40% appear proportionally less frequently in all study areas (10% to 20%), they should not be underestimated. Such incidents may have life threatening consequences with a catastrophic character (Thirgood et al. 2005).

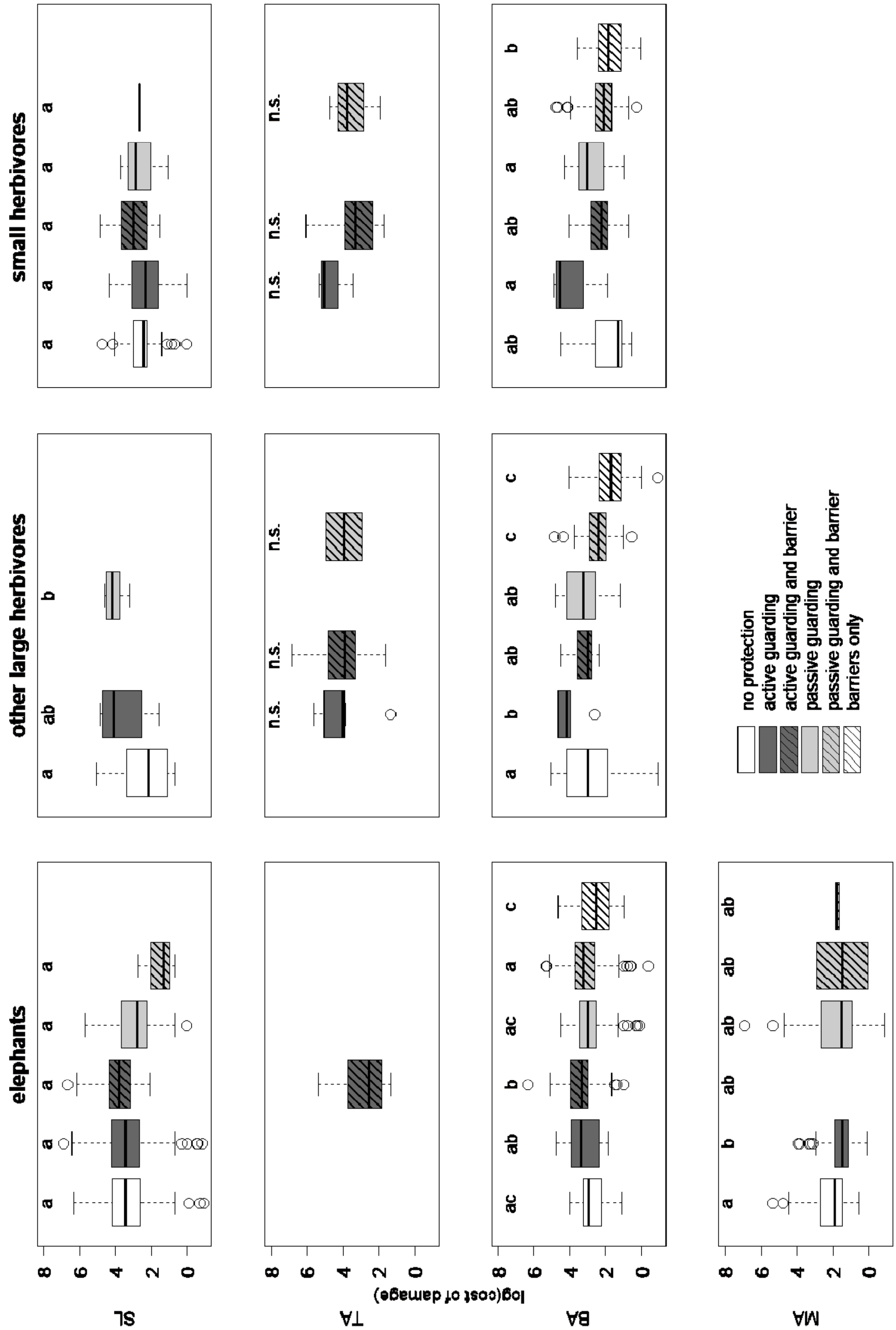

Fig. 3: Box plots of mean costs of crop damage [USD] caused by three different wildlife species groups in four different study areas on fields with different protection strategies from 2009 to 2014 (TA 2010/2011). Different lower case letters indicate significant differences ($p < 0.05$) between protection strategies.

3.4.2 Effectiveness of crop protection

An increase in local guarding practices is meant to reduce the number and severity of crop damage by wildlife species (Hoare 2001; Linkie et al. 2007). In Kenya, guarding effort combined with active deterrents such as lighting fires and banging tin drums decreased the likelihood of farms being damaged (Sitati et al. 2005). In Nepal guarding on watchtowers and the use of scaring devices, flaming sticks and noise was regarded as effective by farmers against elephants, and barriers (net wires, trenches) were regarded as useful against deer and wild boars (Thapa 2010) and elephants were deterred by electric fences in Namibia (O'Connell-Rodwell et al. 2000). Although protecting crops against wildlife was an important activity for the majority of farmers of the damaged farms in our study areas, the traditionally performed way of guarding actively or passively did not reduce the costs of crop damage. Also in Kenya a study on the effectiveness of farm based crop protection measures against elephants showed no difference between treatment and control (Graham and Ochieng 2008). By contrast, in SL costs of crop damage during passive guarding exceeded costs of crop damages on non-protected fields, caused by large herbivores (mainly hippo). One reason might be that hippos, when being chased by people, rage through the fields, causing even more damage through trampling than they had caused if left alone. A similar effect was observed in BA for elephants as well as large and small herbivores. Only for large herbivores in BA a significant cost reduction of crop damages was observed in the presence of barrier and passive guarding plus barrier. The main difference of the study site BA as compared to the other sites, is the presence of an electrical fence along the forest boundary in large parts of the study area. This fence was installed mainly to limit the movements especially of large wildlife species between the national park and the buffer zone (WTLCP 2011). It has to be emphasized that we were not able to collect data on how often wildlife has attempted to challenge the fence and has been repelled successfully. However, the massive number of crop damages caused despite the presence of a fence (1267 crop damages) is putting the success of this measure to question. Once wildlife species break through a fence, its repellent effect is overcome (Watve et al. 2016). Especially elephants manage to overcome electric fences by damaging them in multiple ways (Kioko et al. 2008; Thouless and Sakwa 1995). Further, low maintenance and lacking resources for repair may reduce the voltage to zero, turning an electrical fence into a simple wire fence. If wildlife has managed to enter a crop field through the fence and then is chased by farmers, the way back to the natural refuge is cut off and more damage may be caused through trampling during the search for the passage through the fence (Durant et al. 2015). Further, human noise as a less directional deterrent method could be disorienting to elephants or even cause panic (Davies et al. 2011). Such a scenario could at least partly explain the reason for significantly increased costs of crop damages by elephants and large herbivores (mainly rhino) in areas guarded actively in the presence of fences.

The only positive effect by a guarding system has been observed in MA in reducing costs of crop damages by elephants. In contrast to BA, SL and TA farmers here had set up a community based guarding system, applying a strategic way of guarding along the national park boundary, protecting a large farming block with paddy fields belonging to many community members. Every 50 m a watchtower was constructed on an earth mound surrounded by a deep trench (Fulconis et al. 2014). Farmers formed guarding teams, and took turns in guarding. The moment one team spotted wildlife approaching the farming block, the neighbouring guarding farmers were alarmed with shouts and noise. Guards then moved from the watchtowers towards the animal, using fire torches and producing noise, to chase it back into its natural habitat. Strategic guarding by a community of farmers, aiming at detecting wildlife before it enters the fields seems to be a key in crop protection against elephants (Sitati and Walpole 2006; Sitati et al. 2005). Through such strategies labour can be reduced for the individual, as the communal system allows protecting a larger agricultural area, on which crop damages by elephants may decline (Graham et al. 2010; Nyirenda et al. 2012).

Another strategy to decrease crop damages by elephants that should be investigated in future studies is the choice of crops which are less attractive to elephants than staple crops. Given the marketability, the specific plantation of crops containing so called antifeedants (Gross et al. 2016) bears the potential for a safe income generation in areas prone to crop damages by elephants (Gross et al. 2017).

This study focussed on evaluating crop damages only. In case no wildlife damages occurred on fields, e.g. due to successful crop protection measures, these were not registered in the survey. For this reason, conclusions can only be drawn for situations during which wildlife managed to enter fields, but not on the preventive effect of guarding techniques. Due to the large number of crop damages which occurred despite protection measures being taken, such an analysis nevertheless bears importance for conservation and farmers' practice. We strongly propose thorough long term evaluation on the total effectiveness of crop protection measures against various wildlife species, especially of those measures implemented by third parties, such as governmental and non-governmental conservation agencies.

3.5 Conclusions

Despite the application of labour and cost intensive guarding systems by farmers, the loss of crops to herbivorous wildlife species is considerable in all four study areas. Contradictory to our expectations, higher efforts in protection through human presence on fields and by actively scaring wildlife species, overall did not lead to the reduction of crop damage costs, when applied in traditional ways. Based on our results, only strategic communal guarding of larger farming blocks bears the potential to significantly reduce crop damages. We therefore emphasize the need to re-think non-strategic, small scale guarding practices and emphasize the need for preventive and collaborative approaches. Strategic guarding implies detecting wildlife before entering fields and chasing it back into their refuge habitat. The aggregation of cultivated areas protected by a well-developed strategic communal guarding system combined with areas leaving natural refuges for wildlife to use undisturbed, could lead to a less conflict-laden land-use concept for people and wildlife. We further emphasize the need for more in-depth studies on the total effectiveness of HWC mitigation strategies as well as on the potentially negative consequences when combining different measures.

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3.8 Appendices

Appendix A

Table A.1: Number and proportions of damaged fields with different crop protection types per study areas from 2009 to 2014.

Crop protection type	SL	TA*	BA	MA
no protection	291 (30.5%)	0	104 (6.3%)	114 (47.3%)
active guarding[1]	257 (27.0%)	11 (10.4%)	45 (2.7%)	108 (44.8%)
active guarding and barrier[2]	53 (5.6%)	90 84.9%)	270 (16.1%)	0
passive guarding[3]	329 (34.5%)	0	255 (15.2%)	14 (5.8%)
passive guarding and barrier[4]	5 (0.5%)	5 (4.7%)	835 (49.9%)	2 (0.8%)
barriers only[5]	0	0	162 (9.7%)	2 (0.8%)
other[6]	18 (1.9%)	0	2 (0.1%)	1 (0.4%)
TOTAL	953	106	1673	241

[1] Farmers/guards spending the night out in their fields with the intention to chase away approaching wildlife. In MA only active guarding represents a strategic community based guarding approach
[2] Active guarding plus the presence of an electrical or non-electrical fence
[3] Farmers sleeping in dwellings, rushing out when being alarmed
[4] Passive guarding plus the presence of an electrical or non-electrical fence
[5] Electrical or non-electrical fence
[6] Mainly scare crows, excluded from analysis due to low case numbers
* Data refer to the years 2010 and 2011

4. ELEPHANTS IN THE VILLAGE: CAUSES AND CONSEQUENCES OF PROPERTY DAMAGE IN ASIA AND AFRICA

Erklärung zu den Autorenanteilen

an der Publikation: **Elephants in the village: Causes and consequences of property damage in Asia and Africa**
Status: eingereicht (With Journal)
Beteiligte Autoren und Autorinnen:

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Was hat die Promovierende bzw. was haben die Koautoren beigetragen?

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Promovierende (EMG) hat die Planung und Entwicklung der Studie geleitet und durchgeführt (100%)

(2) zur Durchführung der einzelnen Untersuchungen und Experimente

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(5) zum Verfassen des Manuskripts

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Elephants in the village: causes and consequences of property damage in Asia and Africa

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Abstract

Crop damages on fields are one of the most important drivers of human-elephant conflicts (HEC), however, only little is known about elephant damages in rural villages, for example destroying houses, foraging on stored food and harvested crops or even using exurban areas to forage. In this study, we have examined the extent of property damage by elephants (*Loxodonta africana* and *Elephas maximus*), in one African and two Asian study areas over a six-year period (2009 to 2014). A standardized HEC assessment scheme was used involving detailed on-site observations as well as interviews with aggrieved parties and witnesses. The majority of damage caused were attributed to single individual elephants or pairs of males during their search for food.

Constructions containing staple crops were significantly more often damaged in search for food versus trampling without searching for food. The majority of property damages occurred in the intermediate and dry season and did not correlate with crop damages on fields. Guarding did not generally reduce the costs of property damage compared to unprotected properties. Furthermore, property damages caused higher mean losses than crop damages on fields in all study areas. Property damages by elephants have been largely underestimated and need to be the focus in future HEC research. There is an urgency for HEC to be addressed, as habituation of elephants to human disturbance in villages paired with low knowledge of rural and exurban human populations on elephant behaviour might lead to a new dimension of HECs in the future.

Keywords: property damage; human-elephant conflict management; human-wildlife conflict database; land-use planning; conflict mitigation; attractive crops

4.1 Introduction

Landscapes in many areas of the world are changing rapidly with expanding human dominated areas due to growing urban development. Wildlife species adapting to these newly developing niches require a change in behaviour, such as reduced migratory behaviour, changes in foraging behaviour, and tameness toward man (Luniak 2004). In addition to farmlands, rural villages and even urbanized areas are used by wildlife species to forage (Gross et al. *subm.;* Magle et al. 2012). Especially opportunistic species with regard to food and habitat needs and wide behavioural plasticity are capable to adapt to new habitat types (Adams et al. 2005). Additionally, species in anthropogenic characterized areas need to deal with human disturbances (Ciuti et al. 2012). To succeed in these areas, animals have to trade-off between optimal forage and anthropogenic disturbance. In the suburbs of greater Chicago metropolitan area, white-tailed deer (*Odocoileus virginianus*) for instance, thrive as a result of enhanced forage availability due to fertilized lawns, gardens and restored natural areas (Etter et al. 2002). A rising wild boar (*Sus scrofa*) population in Berlin causes damages of parks and backyards and even soccer stadiums (Kotulski and Konig 2008). They mainly forage within urban areas with abundant natural resources and use anthropogenic sources, such as garbage, as fallback food when access to natural resources is limited (Stillfried et al. 2017). The common ringtail opossum (*Pseudocheirus peregrinus*) and the common brushtail opossum, (*Trichosurus vulpecula*) are abundant in many Australian cities as they are fed by citizens. However, when settling in houses, they can become a nuisance due to nocturnal activity, loud vocalizations and the consumption of garden flowers (Temby 2004).

Most studies on wildlife species in urban, suburban or exurban areas concentrate on North America, Europe and Australia (Magle et al. 2012), although the emerging urbanization in African and Asian countries suggests an increase in urban abundance of wildlife species as well. African elephants (*Loxodonta africana*) and Asian elephants (*Elephas maximus*) require large areas to meet their forage requirements and are bound to water sources (Pradhan and

Wegge 2007; Thouless 1995). Studies on human-elephant conflicts (HECs) mainly focus on crop damages on fields (Goswami et al. 2015; Pittiglio et al. 2014), as these seem to make up most of the damages caused by these species (Gubbi 2012; Mackenzie and Ahabyona 2012), or on accidents with humans, as these cases are most severe (Acharya et al. 2016; Das and Chattopadhyay 2011). Little is known about elephants causing damages in rural villages, damaging houses, foraging on stored food products and post-harvest crops or even using suburban or exurban areas to forage. A small number of reports and documentations, however, raise awareness on such issues. In Zambia elephants were reported to search for locally brewed beer in houses (Chomba et al. 2012), and in Odisha, India they damage houses, consuming stored food and salt (Palei et al. 2015). Similar damages were reported from Nepal and Sri Lanka (Pant et al. 2015; Santiapillai et al. 2010). Furthermore, elephants have been reported to forage on garbage in Zimbabwean open dump sites resulting in the death of eight elephants (Gogo 2016). In Sri Lanka, large herd sizes have been observed regularly at garbage and landfill sites (AFP 2017). Beyond these reports, there are currently no studies available on use and resource selection of African and Asian elephants in suburban areas and rural villages.

In this study, we explored the property damages caused by elephants in one African and two Asian study areas at the interface between people and wildlife over six years: 1) parameters influencing property damage behaviour, 2) the seasonal patterns of property damages, and 3) the economic dimension of property damages.

4.2 Materials and methods

The property damage data were collected within a broader study on human-wildlife conflicts (HWC) carried out from January 2009 to December 2014 in three study areas (South Luangwa/Zambia, Bardia/Nepal and Manas/India) (Gross et al. *subm.*).

4.2.1 Study areas

South Luangwa/Zambia (SL): In Zambia national parks are adjoined by Game Management Areas (GMAs), multiple use-zones for agriculture, tourism, hunting and conservation (Lindsey et al. 2014). The Luangwa valley holds the largest elephant (*L. africana*) population of the country (DNPW 2016), utilizing both, national parks and GMAs. This study area encompasses five chiefdoms of the Lupande GMA (Fig. 1a) adjoining South Luangwa National Park. The population (mainly Kunda ethnic group) of the Lupande GMA is calculated at about 10,000 households (CSO 2012), utilizing about 45.4% of the GMA for living, agriculture and infrastructure (Watson et al. 2014). Large parts of the study area are characterized by rural activities (Nyirenda et al. 2013), and villages hold a very basic infrastructure (community boreholes for drinking water, small shops, dirt roads) and houses are made of mud or bricks, covered with thatch or metal sheets. The market center in Kakumbi chiefdom (Mfuwe) is located directly at the national park boarder and is characterized by income generation through tourism and trade (Lewis et al. 2011; Mvula 2001), a main tar road and large concrete or brick houses covered with metal sheets. The per capita income of the study area has been calculated at 24.82 USD per month (CSO 2015).

Bardia/Nepal (BA): This study area is located in the western Buffer Zone (BZ) of Bardia National Park. It holds a high density of herbivores, including the largest number of resident elephants (*E. maximus*) in Nepal (Flagstad et al. 2012; Wegge et al. 2009). Elephants are dwelling the national park as well as BZ community forests and traversing to the adjacent Indian Katerniaghat Wildlife Sanctuary (Talukdar and Sinha 2013). The study area encompasses four Village Development Committees (VDC) on the Western bank of the Geruwa River and four VDCs on the eastern side (Fig. 1b). The indigenous Tharu are the major ethnic group in the study area (Studsrod and Wegge 1995), which is densely populated with 306 people/km^2 (Thapa and Chapman 2010). In most parts subsistence farming and livestock keeping are the main economic activities (Thapa Karki 2013), with people living in vernacular houses made of wattle and daub walls with thatch roofs (Bodach et al. 2014). Villages are supplied with water by irrigation canals and most households have water wells with hand pumps. The VDC Thakurdwara in the south-eastern part of the study area is influenced by tourism and trade. In this area more concrete or brick houses covered with metal sheets as well as paved roads are found. The per capita income in Bardiya district is calculated at 56.0 USD per month (UNDP 2014b).

Manas/India (MA): Manas National Park is located in the State of Assam, south of the Bhutanese boarder. The national park is an important core habitat for the Asian elephant population at the northern bank of the Brahmaputra River, with an estimated number of 3250 individuals (Choudhury 1999). The study area includes the southern belt of private agricultural and community lands bordering the Manas National Park (MNP) of Assam, encompassing 156 villages (Fig. 1c). With approximately 1,280 people/km^2 the study area is heavily populated with an ethnically diverse composition of people. The indigenous Bodo people make up 35.7% of the population (Sarma et al. 2015), and the main rural activities are rice (*Oryza sativa*) cultivation and the sale of crops from homestead gardens. People live in vernacular houses made from processed mud, wood and bamboo covered with thatched roofs or galvanized tin sheets (Singh et al. 2009). Most houses are supplied by water through wells with hand pumps. The center part of the study area, close to the national park entry, is influenced by tourism and trade as well as tea plantations. Here more brick houses covered with metal sheets as well as paved roads are found. Each village cluster has a market place, with permanent and temporal shops and stalls, mainly constructed from wood and bricks. The rural per capita income of Baksa district south of MNP is estimated at 25.23 USD per month (UNDP 2014a).

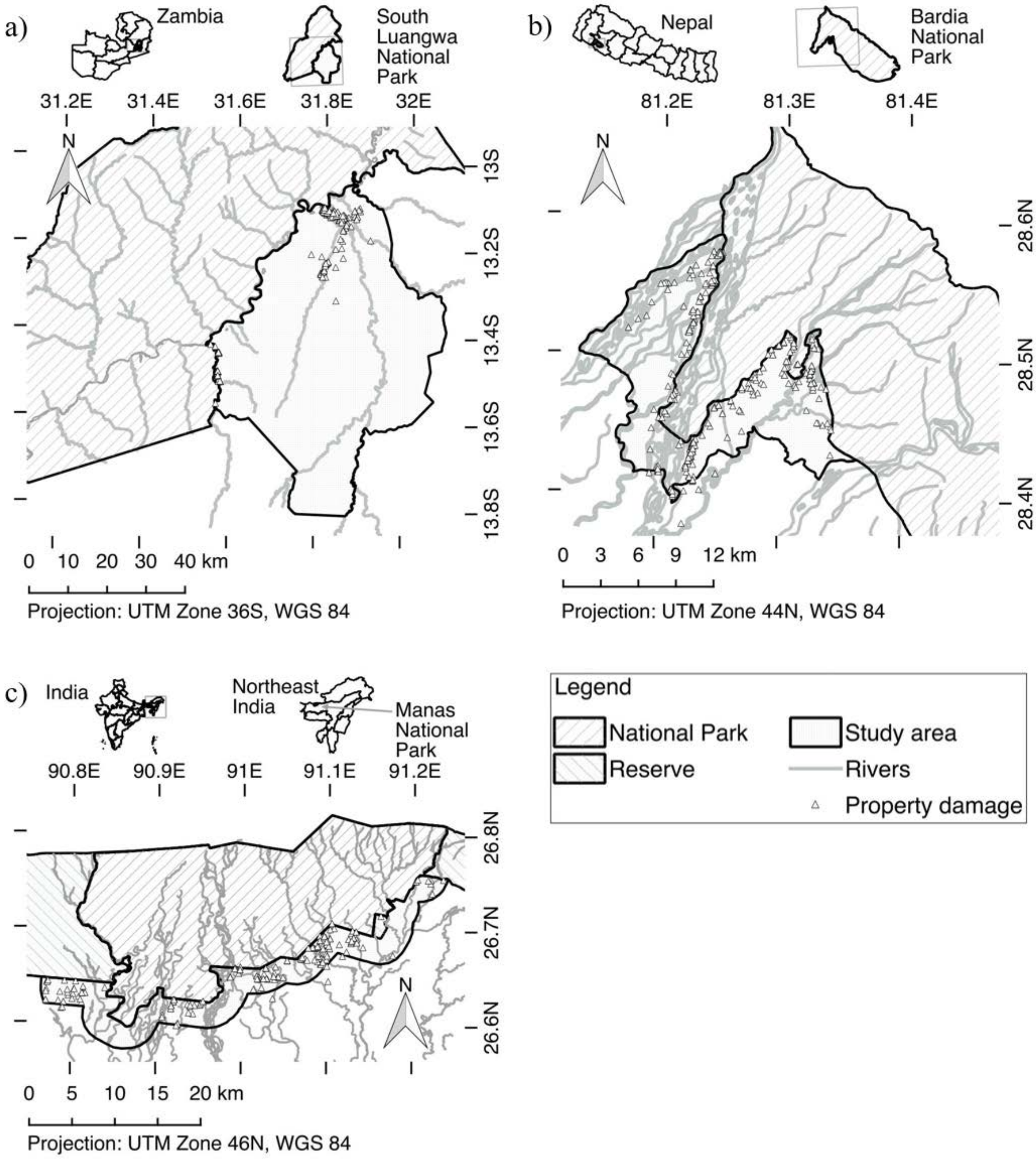

Fig. 3: Distribution of property damages in the study areas a) SL, b) BA, and c) MA. Permanent water bodies (rivers) are indicated as grey lines. Also a few adjoining property damages located outside of the exact study area were included in the study. Author: Eva Klebelsberg

4.2.2 Data collection

Data on property damages were collected within a study on HWCs, which also included crop damages, livestock predation, and human accidents with wildlife. Therefore, an observation of the damage site by locally trained independent enumerators (HWC officers) as well as structured interviews with victims were conducted using the Awely HWC assessment scheme during six consecutive years from 2009 to 2014, as described in Gross et al. (*subm*. a). Elephants causing damage were identified through tracks, dung and damage structure. Group sizes were identified through tracks (single or multiple) and group composition through the measurement of foot sizes (circumference in cm), to identify number of adults, sub-adults and calves (Lee and Moss 1995; Sukumar et al. 1988). Personal observations by eyewitnesses were also taken into consideration and validated with on-site observations. Each damaged property was inspected regarding the cause of damage; either damage in search for food (e.g. breaking of wall, window or roof with tusks or trunk, searching for food with trunk) or trampling by accident or in panic, without searching for food. Further observations were carried out regarding food content of the damaged properties. All stored eatable goods, whether damaged or not, were listed. Costs of damages were estimated by measuring damaged proportions of construction as well as damaged interior/food content and calculating re-construction cost as well as value of damaged goods, based on local market prices in local currency. Demographic data of crop owners/victims were gathered through interviews and were categorized. Information on the exact property protection measures used against damage, during a particular incident, was collected through interviews and field verification. Unprotected properties experiencing damages were used for comparison. Properties damaged by elephants were mapped using Quantum GIS Geographic Information System, Version 2.14.3 Essen (QGIS Development Team, 2016).

4.2.3 Data analysis

All costs of damage were converted from local currency into USD, using the rate on June 30th of each year (XE Currency Converter 2017). Seasons were determined by date (Appendix A, Table 1). Elephants causing damage were pooled into five groups (male single/pair: 1-2 males; male group: > 2 males; unknown group: 3-8 individuals with sex unclear; family group: female led group > 2). Constructions of properties were pooled into three groups: weak, medium, and strong construction (Appendix A, Table 2). Food content was pooled into nine categories: alcohol, staple crops, fruits, legumes/nuts, salt, straw/hay, sweets/sugar, vegetables, other (Appendix A, Table 3). The protection measures taken by farmers were categorized into active guarding (people being present at the property with the aim to guard it), passive guarding (people sleeping in the property or nearby houses and rushing out to scare away elephants when alarmed) or no protection (no person took notice of damage, no chasing of elephants).

Statistics were calculated with R version 3.2.5 (R Core Team, 2016). For all analyses the R-packages *lme4* (Bates et al. 2015) and *lsmeans* (Lenth 2016) were used. A generalized linear model (GLM) using a quasipoisson family was applied to analyze the number of property damage events during the whole study period depending on seasonality, study area, elephant group composition and combination with crop damages. Further, the influence of construction type, food content and study area on the cause of damage (searching for food or trampling) was determined by a generalised linear mixed effect model (GLMM) using a logit link function for a binomial response. The year was modelled as a random factor. Finally, the cost of damages per protection strategy was analysed using linear mixed effect models. The response variable cost of damage had to be log-transformed for the analysis to ensure normally distributed residuals. Year and the interaction protection and year were modelled as random effects. All models were simplified according to backwards model selection using likelihood ratio test (model selection results SOM 1). For the final models least-squares means were used to conduct pairwise comparisons between relevant explanatory variables for each study area (using tukey-adjustment of p-values.

4.3 Results

Within a six–year period (2009 to 2014), 99.5% of the property damages from a total of 782 assessed events were caused by elephants. For this reason, this study takes into consideration data only on property damages (n = 778) caused by African elephants in SL and Asian elephants in BA and MA, encompassing a total of 1172 aggrieved households.

4.3.1 Demography of Property Damage

In all three study areas, the majority of the 1172 property owners who experienced damages were men (SL: 56.9%, BA: 82.3%, MA: 91.2%), mostly aged 20-50 years. The main source of income was agriculture (SL: 70.2%, BA: 95.3%, MA: 59.5%), only small proportions of the property damage victims made their living mainly from other sources of income, including livestock-keeping, wage earning, trade or craft. Around six household members were dependent on the damaged property (SL: 5.8 ± 3.3, BA: 6.1 ± 3.3, MA: 6.1 ± 5.9).

4.3.2 Characteristics of property damage

The majority of properties damaged by elephants were domicile houses (SL: 53.4%, BA: 83.5%, MA: 53.2%), followed by grain stores in SL (34.2%) and kitchens in BA and MA (8.9% and 19.1%) (Plate 1). In most of the studied cases, property damages were a one-time incidence but in 15% of the cases in BA and MA and 39% in SL property damages occurred to the same household repeatedly within a years' time.

Plate 1: Property damages caused by elephants in search for food (A) in MA to a grocery store at Gadulee Market in May 2009, Bansbari, and (B) to a farmhouse in BA at Suryapatuwa in May 2009, the entire wall has been removed by the elephant, clearing the view on traditional rice storages on the ground floor.

Damaged properties mainly contained edible goods (SL: 79.9%, BA: 95.2%, and MA 93.7%). The majority of properties were damaged in search for food (SL: 62.5%, BA: 73.9%, and MA 76.7%), e.g. by opening the house selectively and searching inside with the trunk. Damaging of properties, however, occurred to some extent without search for food (SL: 37.5%, BA: 26.1%, and MA: 23.3%), involving accidental damages of houses while feeding on fruits of a tree close to the house or smashing a construction when being chased by a mob of people. Properties damaged by elephants in search for food contained food more often than properties damaged by trampling (Fig. 2). In contrast, properties not containing eatable goods were more often damaged through trampling than through searching for food. Staple crops (i.e. rice, maize, wheat and sorghum) as well as salt where significantly more often found in properties damaged by elephants through searching for food than in properties damaged through trampling only (Table 1). Although a strong correlation is observed between the storage of salt and staple crops, no conclusions were derived if only salt or the combination of salt and staple crops influences the searching for food behaviour of elephants. Apart from SL, no difference in the proportions of the cause of elephants damaging properties in terms of construction types was determined where proportionally more properties with a medium construction type were damaged by trampling only than through searching for food.

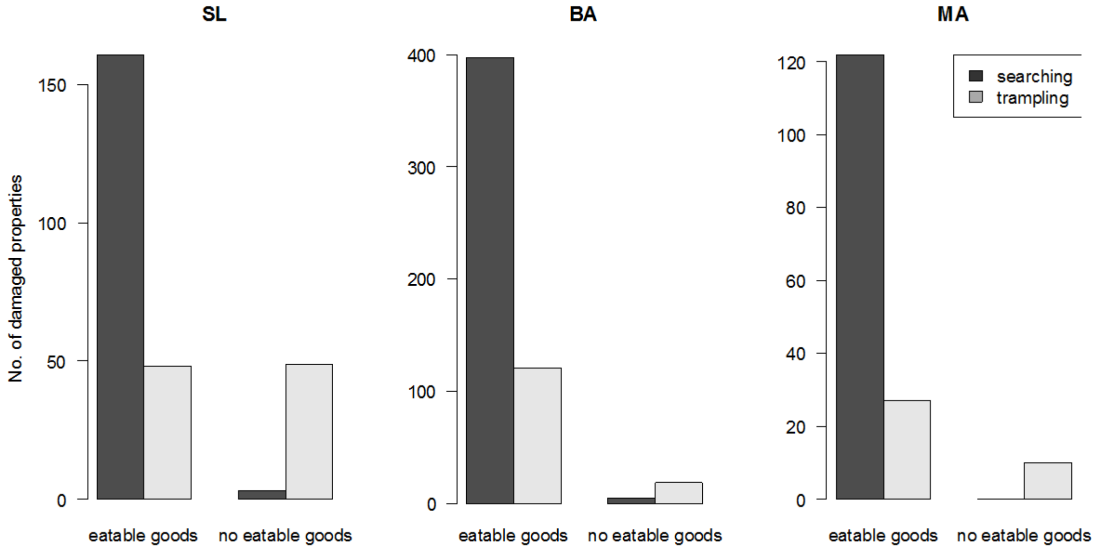

Fig. 2: Number of properties damaged by elephants in SL, BA and MA in search for food (dark colour) and by trampling only (light colour), in constructions containing eatable goods or no eatable goods, from 2009 to 2014. Statistically significant difference of the relation of searching to trampling between properties containing eatable goods and those containing no eatable goods in SL ($p < 0.0001$) and BA ($p < 0.0001$), but not in MA ($p = 0.7926$).

In all three study areas property damages mainly occurred in IS and DS (Fig. 3). In SL property damages occurred in both, IS and DS significantly more often than in the RS. In BA, no statistical difference in property damage frequencies was found between IS and DS, whereas in MA significantly more property damages occurred in the DS.

It was seen that singles and pairs of male elephants caused significantly more property damages than all other elephant group compositions throughout all seasons (SL: 67.1%, BA: 86.4%, and MA 84.6%) ($p < 0.0001$), followed by groups of 3-8 elephants (sex unclear) in SL (20.7%) and MA (4.6%) and male groups in BA (4.0%). Only a small number of female groups damaging properties was identified (SL: 5.0%, BA: 1.0%, and MA 3.8%) (Table 2). Furthermore, property damages throughout all seasons were significantly more often independent, single damage events than events occurring in combination with crop damages ($p < 0.0001$).

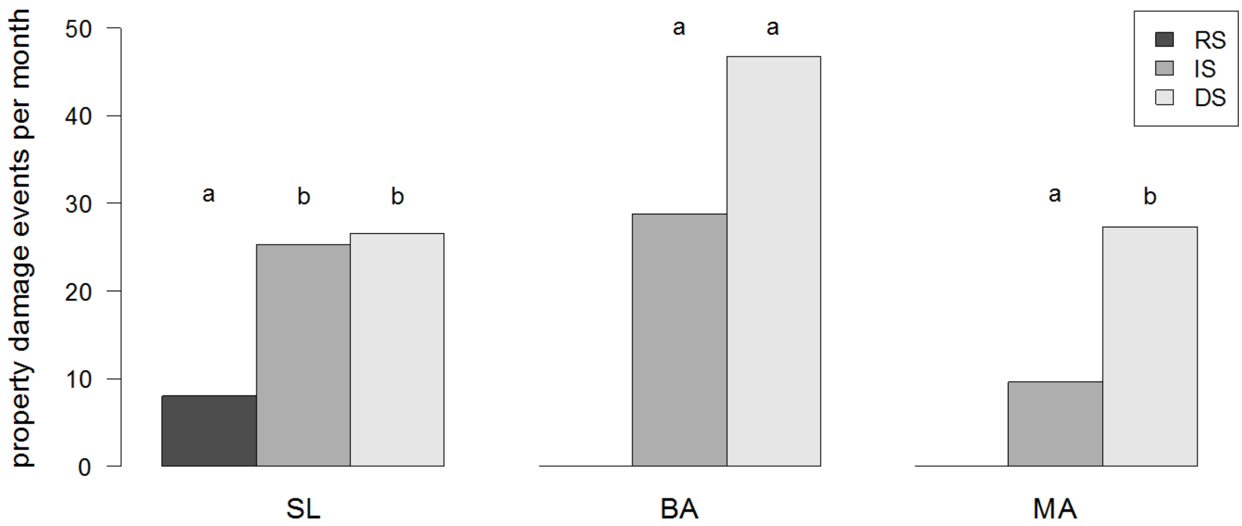

Fig. 3: Number of property damage by elephants per month in different seasons (RS: rainy season, IS: intermediate seasons, DS: dry season) for the three study areas (SL, BA, MA). Different lower case letters indicate significant differences between groups within one study area ($p < 0.0001$).

Table 1:
Number of properties damaged by elephants searching for food or trampling per study area, containing specific food items (multiple food contents in one property were possible). Percent of total damaged properties containing eatable goods are indicated in brackets.

	SL		BA		MA		total	
	searching	trampling	searching	trampling	searching	trampling	searching	trampling
staple crops***	154 (95.1)	39 (79.6)	391 (98.2)	113 (93.4)	103 (84.4)	21 (77.8)	648 (95.5)	173 (87.8)
vegetables	25 (15.4)	7 (14.3)	30 (7.5)	7 (5.8)	13 (10.7)	4 (14.8)	68 (10.0)	18 (9.1)
fruits	6 (3.7)	2 (4.1)	0	0	6 (4.9)	1 (3.7)	12 (1.8)	3 (1.5)
legumes/ nuts	6 (3.7)	0	17 (4.3)	0	1 (0.8)	0	24 (3.5)	0
salt***	33 (20.4)	16 (32.7)	317 (79.6)	79 (65.3)	84 (68.9)	12 (44.4)	434 (63.6)	107 (54.3)
alcohol	3 (1.9)	0	36 (9.0)	26 (21.5)	13 (10.7)	3 (11.1)	52 (7.6)	29 (14.7)
sugar/ sweets	18 (11.1)	6 (12.2)	2 (0.5)	6 (5.0)	34 (27.9)	9 (33.3)	54 (7.9)	21 (10.7)
straw/hay	0	0	3 (0.8)	6 (5.0)	2 (1.6)	3 (11.1)	5 (0.7)	9 (4.9)
others***	3 (1.9)	3 (6.1)	262 (65.8)	36 (29.8)	3 (2.5)	1 (3.7)	268 (39.3)	40 (20.3)

*** indicates significant difference in the proportions of eatable goods/no eatable goods between searching and trampling ($p < 0.05$), referring to the overall set of data.

Table 2:
Numbers of property damage events caused by different compositions of elephant groups in the three study areas (SL, BA, and MA) from 2009 to 2014 in the rainy season (RS), the intermediate seasons (IS) and the dry season (DS). The percentage is indicated in brackets.

	SL				BA				MA			
elephant group categories	RS	IS	DS	total	RS	IS	DS	total	RS	IS	DS	total
1-2 males	29 (13.3)	51 (23.4)	69 (31.7)	149 (68.3)	0	112 (37.1)	149 (49.3)	261 (86.4)	0	39 (31.0)	71 (56.3)	110 (87.3)
male group	1 (0.5)	0	0	1 (0.5)	0	0	12 (4.0)	12 (4.0)	0	0	0	0
group 3-8 (sex unclear)	6 (2.8)	18 (8.3)	22 (10.1)	46 (21.1)	0	0	8 (2.6)	8 (2.6)	0	2 (1.6)	4 (3.2)	6 (4.8)
female group	2 (0.9)	3 (1.4)	2 (0.9)	7 (3.2)	0	0	3 (1.0)	3 (1.0)	0	4 (3.2)	1 (0.8)	5 (4.0)
composition unknown	2 (0.9)	4 (1.8)	9 (4.1)	15 (6.9)	0	3 (1.0)	15 (5.0)	18 (6.0)	0	3 (2.4)	2 (1.6)	5 (4.0)

4.3.3 Severity and costs of property damages

More than 30% of all damaged property constructions were destroyed at least half or more (Table 3). Furthermore, the costs of damage elephants caused to aggrieved households varied considerably, with minimum costs ranging from SL: 0.97, BA: 2.80, and MA: 1.12 USD to maximum costs up to SL: 454.55, BA: 672.04, and MA: 835.24 USD.

Table 3:
Total number of victims of property damages by elephants in three different study areas from 2009 to 2014 as well as mean and standard deviation of losses per aggrieved households per damage incident in USD.

Parameters	**SL**	**BA**	**MA**
Number households aggrieved by property damage	327	575	270
Proportion of construction damage under 50% and above 50%*	61.8% | 36.7%	63.1% | 36.1%	62.7% | 33.5%
Total costs of property damage 2009 to 2014 [USD]	21,273	55,965	12,666
Mean ± sd of cost of damage per aggrieved household [USD]	65.3±73.2	97.3±93.1	46.9±81.0
Median cost of property damage per incident per farmer [USD]	41.2	72.7	21.6

* Difference to 100% was indicated as „proportion unknown“

4.3.4 Protection of properties

In SL, the majority of damaged properties was not protected at all (45.5%), followed by properties protected by passive guarding (20.9%) and the smallest proportion was protected by active guarding (11%). In BA and MA, passive guarding was the most commonly used protection practice on the properties involved in damage events (59.7% and 70.0% respectively), followed by active guarding in BA (23.1%) and no protection in MA (28.1%). Active guarding did not reduce the costs of property damages compared to unprotected properties experiencing damages. In contrast, in SL damaged properties, which were actively guarded, showed higher costs of property damage compared those which were not or passively guarded (Fig. 4). In MA properties, which were passively guarded, showed significantly lower costs of damage compared to damaged properties without protection. In BA no difference in the costs of damage relating to any guarding strategy could be determined.

4.4 Discussion

Crop damages caused by elephants on fields in Asia and Africa have been described as the main drivers for HECs (Hoare 2000; Sukumar 2006; Thirgood et al. 2005). Property damages as well as damages to harvested and stored crops were only investigated in a few studies (Chomba et al. 2012; Palei et al. 2015; Pant et al. 2015; Santiapillai et al. 2010; Treves et al. 2009). However, our research highlights the relevance of HECs also within rural settlements and exurban areas, as in all three study areas, the frequency and severity of property damages is not negligible.

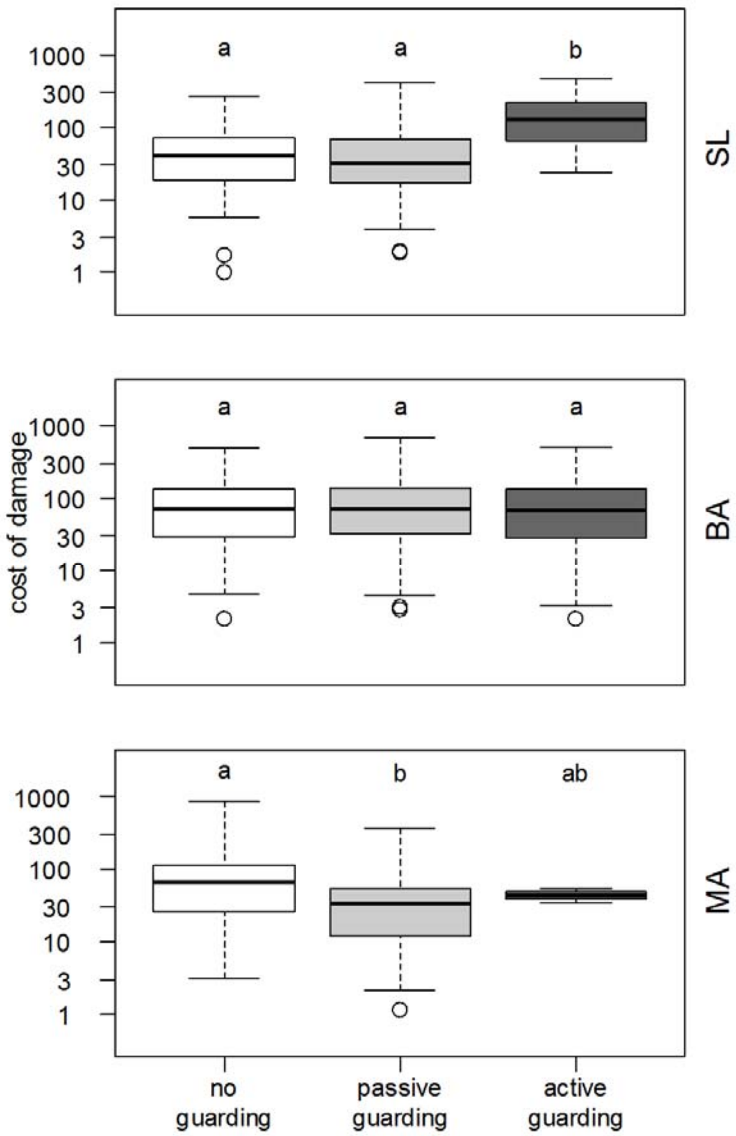

Fig. 4: Mean costs of damage [USD] caused by elephants in the three different study areas to properties protected by different strategies from 2009 to 2014. Different lower case letters indicate significant differences ($p < 0.05$) between protection strategies in each study area.

4.4.1 Why do elephants damage properties?

In a previous study, we found that crop damages by elephants on fields, both in African and Asian countries, coincided with the time of ripening of crops (Gross et al. *subm.*). Therefore the RS and IS were identified as main crop damage seasons. Property damages, however, occurred rather towards the DS when staple crops were harvested and stored in the villages. Our findings suggest that elephants were selectively searching for food in properties independent of crop damages on fields. Elephants seldom incur more than 50% damage to the targeted construction - they opened it until the desired food was accessible. A well-documented example from BA described how a single elephant bull searched six houses in one village one after the other, opening them specifically where food was stored (e.g. attic with stored rice, kitchen with different food stuffs), while being followed by a crowd of people trying to scare it away. This exemplifies a change in behaviour of an individual wild elephant regarding the habituation to human disturbance as well as the directed behaviour of searching for food in houses. Such behaviour change has been identified as distinctive for urban wildlife species (Luniak 2004).

Human density is negatively correlated with elephant populations from a certain threshold onwards (Hoare and Du Toit 1999) and the proximity to towns has been negatively correlated with crop damages by elephants (Sitati et al. 2003). As the movement and behaviour of species are influenced by multiple factors (Chiyo and Cochrane 2005; Songhurst et al. 2015), a clear determination on what exactly affects elephants to move into the villages is impossible. A change in home ranges due to high poaching levels in a specific area, habitat destruction or drought may explain changes in elephants' behaviour. However, also taking into consideration the optimal foraging strategy of elephants (Sukumar 1990), the results of our study suggest elephants moving to villages in a directed search for food. Moving into villages or even urbanized areas is a high-risk behaviour for elephants. Yet, stored crops or processed human food are more nutritious than wild forage and therefore taking the risk to forage on these, pays off as it enhances nutritional state and growth (Chiyo et al. 2011) and therefore may positively influence reproductive success (Hollister-Smith et al. 2007). Similarly to their foraging preference for staple crops on fields (Gross et al. *subm.*) we found elephants also searching mainly for staple crops in the villages. Whether elephants are further searching specifically for other food items, cannot be confirmed by our data. Particularly salt, which was also found frequently in buildings damaged by elephants searching for food, was in most cases stored together with staple crops. Due to the very low number of houses damaged in search for food combined with alcohol content, it is very unlikely that elephants are specifically searching for alcohol, as reported by Chomba et al. (2012).

Although the field situation (e.g. sudden encounter in the dark, stressful situation for villagers) did not allow reliable identification of property damaging individuals in all cases, we were able to identify the majority of elephants in all three study areas as single males or males in pairs. Family groups were seldom involved in property damage. The large portion of property damaging groups with 3-8 individuals (sex unclear) in SL was probably rather due to bachelor groups than family groups. In the Luangwa valley elephants formed bachelor groups of up to five individuals (Lewis, 1987). In India elephants were reported to form larger bachelor groups when feeding on field crops (Sukumar and Gadgil 1988). The formation of larger groups while taking a high risk, might be an explanation for the large portion of bachelor groups involved in property damage.

Elephants are social animals, passing on knowledge on resource availability and location within their kinship (Fishlock et al. 2016; Greco et al. 2013). In Amboseli, Kenya, learning of crop damage behaviour has been described for associations of male elephants (Chiyo et al. 2012), where younger males learned crop damaging behaviour from older males. Such learning behaviour might explain the development of property damaging behaviour in our three study areas. Furthermore, the change of social structures through poaching, retaliation killing and so called problem elephant control might further intensify property damaging behaviour in elephants. Behavioural effects have been observed, when young, unexperienced bulls or groups without an experienced leader continued their learned damaging behaviour (Chiyo et al. 2012) or showed untypically aggressive behaviour towards other species (Bradshaw and Schore 2007).

4.4.2 Social dimension of property damage

In our three study areas, people have been experiencing crop damages by wildlife species since a long time (Nath et al. 2009; Nyirenda et al. 2011; Thapa 2010). Although the number of pre-harvest crop damage events by elephants throughout the study period was 2.5 times higher than the number of property damages (Gross et al. *subm.*), the mean financial loss per property damage was much higher (SL: by 200%, BA: by 350%, and MA: by 450%) compared to crop damage. Losing around two monthly incomes per property damage is a financial and social disaster for any household, in particular families with high economic vulnerability and a low resilience. In BA and MA the total loss through property damages throughout the six study years was even higher than the total loss through crop damages (BA: by 120% and MA: by 150%). Based on the findings of this study, we reason that property damages have largely been underestimated regarding their severity and economic impact.

Another important aspect of property damages is the potential of fear these incidences provoke. The largest proportion of damages happened to domicile houses. As most property damages occurred at night, victims were confronted with an elephant damaging their home while sleeping. Many victims expressed their fear in interviews, especially when children where present and started to scream and cry. The low number of human accidents, despite the high number of property damages in our study areas, should not mask the potentially perceived threat in such situations.

Furthermore, elephants in all study areas did not stick to rural village environments, but also targeted more built-up areas, such as a market place in MA (Plate 1A), a school canteen in SL, constructed of bricks and metal tin sheet or a solidly built clinic in BA. The habituation of elephants to human disturbance is a risk factor, which is likely to increase, especially when guarding techniques are carried out in an uncoordinated and ineffective way (Gross et al. *subm.*). The low effectiveness of property guarding strategies in our study areas further supports the theory of habituation. Higher costs of damage in SL during active guarding of properties indicates a counterproductive activity, at least in some cases. An explanation might be that elephants were disoriented or stressed through less directional deterrent methods (Davies et al. 2011), causing even more damage by running over constructions and causing damage on their way back to their natural refuge, thus explaining the higher proportion of property damage without search for food in SL (34.8%) compared to BA and MA.

4.5 Conclusions

Many details on property damaging behaviour of elephants are yet to be clarified. This study demonstrates that elephants are able to enter villages and even exurban areas, to search for food in properties, and show a high level of habituation to human disturbance. Elephants causing massive and repeated property damage are likely to be injured or even killed as retaliation or so called "problem elephant control". These measures do not solve the problem, as most probably other individuals will occupy the "niche" (Chiyo et al. 2012). For this reason, even small damages need to be prevented, to avert positive enforcement of such behaviour and therewith the occurrence of larger damages. Similar to the strategies to reduce conflicts with American black bears (*Ursus americanus*) through proactive approaches for garbage management and developing comprehensive bear education programs (Spencer et al. 2007), we suggest to reduce the attractiveness of villages by cleaning up litter and storing food in locked and safe places away from sleeping areas. First attempts were made through the Awely Red Caps projects and construction of elephant safe grain stores (Fulconis et al. 2014). These activities are small initiatives that need to be further developed and closely monitored. Property damages by elephants need to be the utmost focus by conservation agencies and research.

4.6 Acknowledgements

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4.8 Appenices

Appendix A, Table 1:
Timing and length of seasons in each study area.

	SL	BA	MA
RS[1]	Dec – April 5 months	Jul – Oct 4 months	June – Sept 4 months
IS[2]	May – July 3 months	Nov – Feb 4 months	Oct/Nov; March-May 5 months
DS[3]	Aug – Nov 4 months	Mar – June 4 months	Dec – Feb 3 months

[1]RS (rainy season), [2]IS (intermediate season), [3]DS (dry season)

Appendix A, Table 2:
Construction categories based on different construction materials of roofs and walls of properties in three study areas.

		ROOF	
WALLS		**mud, bamboo, wood, straw/grass**	**brick, concrete, tiles, metal sheet**
	mud, bamboo, wood, straw/grass	weak	medium
	stone, brick, concrete	medium	strong

Appendix A, Table 3:
Categories of food content found in properties in all three study areas.

Category	Details
alcohol	local brews, brewing sites, bottled alcoholic drinks
taple crops	rice, maize, wheat, sorghum/millet
fruits	banana, mango, apple
legumes/nuts	lentil, soybean, groundnut
salt	salt stones, grounded salt
straw/hay	dried grasses and stalks
sweets/sugar	sugar, sweets, sweet tea, honey, sugar cane
vegetables	green leaves, tomato, potato, pumpkin, peas, beans
other	cotton, fish/meat, milk, butter, spices, mustard, chilli, coconut, oil

5. CULTIVATING ALTERNATIVE CROPS REDUCES CROP LOSSES DUE TO AFRICAN ELEPHANTS

Erklärung zu den Autorenanteilen

an der Publikation: **Cultivating alternative crops reduces crop losses due to African elephants**
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Beteiligte Autoren und Autorinnen:

- Eva M. Gross (EMG)
- Rachel McRobb (RMR)
- Jürgen Gross (JG)

Was hat die Promovierende bzw. was haben die Koautoren beigetragen?

(1) zu Entwicklung und Planung

EMG hat die Planung und Entwicklung der Studie geleitet und in allen Bereichen maßgeblich mitgewirkt (70%)
JG hat beratend bei der Entwicklung und Planung des Freilandexperiments mitgewirkt (30%)

(2) zur Durchführung der einzelnen Untersuchungen und Experimente

EMG hat die Durchführung des Freilandexperiments angeleitet und Mitarbeiter für das Freilandmonitoring angelernt und diese koordiniert (80%)
RMR hat die Mitarbeiter im Freilandexperiment logistisch unterstützt und die die Verbindung zur Wildtierbehörde hergestellt (20%)

(3) zur Erstellung der Datensammlung und Abbildungen

EMG hat alle im Feld erhobenen Daten gesammelt und für die Analyse aufgearbeitet sowie die Abbildungen erstellt (90%)
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(4) zur Analyse und Interpretation der Daten

EMG hat die Daten interpretiert und analysiert (80%)
JG hat beratend bei der Interpretation und Analyse der Daten mitgewirkt (20%)

(5) zum Verfassen des Manuskripts

EMG hat das Manuskript hauptsächlich verfasst (70%)
JG hat einen Teil der Diskussion zur chemischen Ökologie verfasst (25%)
RMR hat einen Teil des Manuskripts überarbeitet (5%)

Datum/Ort: 28. September 2017, Schriesheim

Unterschrift Promovendin: ____________________________

Zustimmende Bestätigungen der oben genannten Angaben

Unterschrift Betreuer: _______________________________Datum/Ort: _______________________

J Pest Sci (2016) 89:497–506
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ORIGINAL PAPER

Cultivating alternative crops reduces crop losses due to African elephants

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Abstract Throughout the sub-Saharan African countries, in which populations of the African Elephant *(Loxodonta africana)* exist, farmers come into conflict with these pachyderms. Attracted by nutritious crops on the fields they destroy substantial amounts of harvest by crossing through the plantations and feeding on the crops. As this species is protected and listed as a threatened species by the IUCN Red List and therefore must not be killed, new ways need to be found to repel or not attract the pachyderms to fields. The replacement of crops, which are attractive to elephants by such, which are not attractive, might be a solution for the agricultural sector in and close to elephant habitats. A field experiment has been conducted to test the attractiveness of potential alternative crops (ginger, onion, garlic, and lemon grass) compared to a control plot with maize as a very attractive crop. Elephants visited both, the test crops and the control of maize and completely destroyed the maize 6 weeks prior to its harvest time. In contrast, the test crops were only slightly damaged, mostly through trampling. In a very late state of the experiment lemon grass and ginger were consumed by the elephants in small quantities. Yields that have been obtained from the test crops would have exceeded the yields of the maize. The selection of crops which are less attractive to large herbivores such as elephants needs to be considered as a strategy to reduce conflicts between farmers and endangered wildlife species.

Keywords Crop raiding · Human-elephant conflict · Lemon grass · *Loxodonta africana* · Ginger · Garlic · Unpalatable crops

Key message

- The African Elephant (*Loxodonta africana*) causes crop losses to farmers in African countries but lethal control is not an option due to its protection status.
- Crops bearing chemical defense (lemon grass, ginger, garlic) are less attractive to elephants and therefore hold a higher economic value.
- To gain more certainty on the long-term non-palatability of alternative crops research on this topic needs to be encouraged.

Introduction

Being rich in wildlife and large wilderness areas, Zambia is one of the Southern African top destinations for Safari tourism. Although the country's main income comes from services, mining, and other industries, agriculture is an important economic sector with 10.8 % of the GDP (World bank 2013). Today over 70 % of the Zambian farmers live from small-scale subsistence farming (Hichaambwa and Jayne 2014), especially on maize, sorghum, cassava, ground-nuts, and sweet-potatoes (Jayne et al. 2007). The average farm size for smallholders is 0.68–1.43 ha (Jayne et al. 2008); the soil is cultivated by hand or, in areas where

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Tse-tse flies are not abundant, by oxen (Haggblade and Tembo 2003). The Zambian climate ranges from semi-arid to semi-humid with annual rainfall of 650–1000 mm (Baudeon et al. 2007). Besides the food insecurity through drought, pests like the Red Locust *Nomadacris septemfasciata* (Okhoba et al. 2012), the African Armyworm *Spodoptera exempta* (Guerrero et al. 2014; Cheke and Tucker 1995) or the Red-billed Quelea *Quelea* quelea (Bruggers and Elliot 1989; Jones et al. 1999) can cause considerable losses to smallholders. In the vicinity of conservation areas, however, another agricultural pests occur, the African Elephant (*Loxodontha africana*) (Schmutterer 1969). Throughout sub-Saharan Africa these large pachyderms come into conflict with farmers (Hoare 1999), when they destroy their fields, crops, harvests, or even houses (Kiiru 1995). Although their abundance is limited, where elephants step into farmland they can cause large damages within a very short time (Naughton-Treves 1998). For this reason crop damages by elephants are largely seen as a catastrophic event (Thirgood et al. 2005). Besides the losses of crop damage that often cover more than 50 % of a farm's crops (Sam et al. 2005), people fear the risk of getting injured by the pachyderms, when they want to protect their fields. Many attempts are made to guard farms and crops with different methods such as barriers, scaring devices or even lethal methods (Hoare 1995; Osborn and Parker 2003; Treves et al. 2009). The most commonly used strategy on smallholders' farms in sub-Saharan Africa is the personal guarding by farmers in their fields (Sitati and Walepole 2006). This activity, however, is time-consuming, giving the farmers only little time to sleep during months they actually have to use their manpower in weeding, plowing, and harvesting (Ngure 1995). Further, they risk being attacked by angry elephants or hungry predators (Quigley and Herrero 2005).

As an alternative to engage time and efforts to protect highly attractive crops, such as maize or sorghum, that deliver high nutrition to elephants, it could be a wise approach to rather cultivate crops that elephants do not prefer (Parker and Osborn 2006). If such crops being unattractive or even unpalatable to elephants and still being suitable to the soils and other environmental factors existed, the risk of high damages could be reduced. The commercialization of the alternative crops is another important aspect to consider, in order to secure safe income and to avoid encounters with elephants.

It is a common belief that plants containing essential oils are unattractive or even repellent to elephants (Thapa 2010). The cultivation of such crops at the border of National Parks is known from Asian countries, like Nepal and India (Martin and Martin 2010). Unfortunately, systematic approaches to test the attractiveness of these crops are not found in scientific literature. If those crops are used for the production of essential oils or herbal teas they can hold a high potential for the safe income in areas frequently damaged by pachyderms (Tiller 2010). For this reason, a first systematic test was run in South Luangwa, Zambia. We planted maize as control plant and four alternative crops in an experimental area and recorded the damage caused by elephants, the amount of harvested crops and their total revenue calculated from the local market prices.

The location for this test was chosen in an area where crop damages through elephants occur frequently. Within one kilometer radius, 75 conflict events were caused by elephants in the years 2009 and 2010 (Gross EM, unpublished data) and in which farmers are suffering from high losses to the pachyderms.

Materials/methods

Study area

The study was carried out in the Lupande Game Management Area (GMA), East of South Luangwa National Park, Zambia. The Luangwa valley is known for its high abundance of wildlife species such as zebra, buffalo, impala as well as the top predators as lions, leopards, and hyena and the large herbivores, like hippopotamus and the African elephant (Ndholvu and Balakrishnan 1991). Wildlife ranges freely throughout South Luangwa National Park (9050 km^2) and the adjacent GMA (4950 km^2) (Jachmann and Billiouw 1997), without fences. The only natural boarder is the river Luangwa that shapes the whole landscape, but is crossed easily by most of the large mammals, especially during the dry season. The study area is located in the agro-ecological zone I of Zambia, defined by the FAO, with mean annual rainfall <830 mm per year (Nyirenda et al. 2011).

Test plot location

Located at the Western edge of a large traditional farming block, the test plot was exposed directly toward the Miombo woodlands (Fig. 1; 13°15.777′S, 31°47.903′E). This site was chosen due to its location close to a regularly used farming area facing large amounts of crop losses to elephants, and its exposure toward the natural habitat of elephants. Being located about 100 meters away from the operational farming block a direct exposure to wildlife was enabled. Neither guarding nor any other human presence took place on the test plot during night time. The test plot was directly surrounded by uncultivated area. About 350 meters toward north-east and 530 meters toward east river Matizye meanders, supplying the farming block with water throughout the year. The small influent Kabila is located

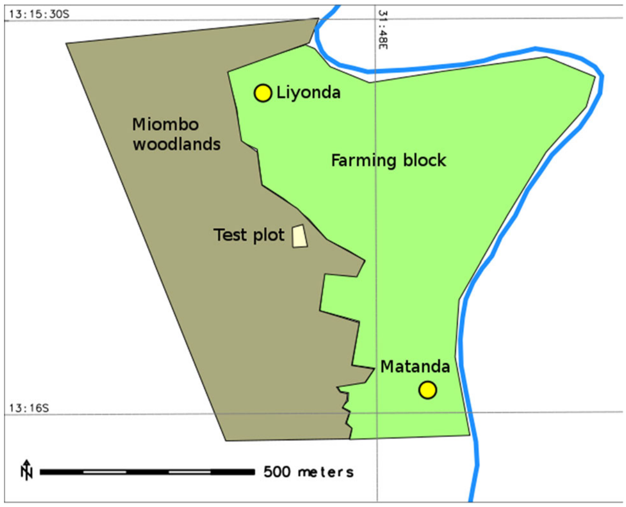

Fig. 1 Map of test plot location

just 40 meters east of the test plot, carrying water only during heavy rains of the rain season (December to March). The closest village, Liyonda, is located 350 meters to the north, and Matanda, located 360 m toward south-east.

Experimental design

For our test plot, we chose two crops containing essential oils (ginger *(Zingiber officinale)*, lemon grass *(Cymbopogon citratus))* and two crops having a strong smell (garlic *(Allium sativum)* and onion *(Allium cepa))*, as these crops are locally available and used in small scale by farmers. For this reason, they hold a certain potential for sale on local markets as well as being suitable for the local climate and soil. Maize being a staple food in the area and being raided regularly by elephants (Nyirenda et al. 2011) was used as positive (attractive) control.

Measuring 50 m in length and 25 m in width the test plot was set up of 48 squares measuring 3.5 by 3.5 meters (Fig. 2). Paths of 50 cm were left open between the squares. In the center 24 squares of potentially alternative crops were located in a plot of 4 m × 6 m. Each variety of the test crops appeared once in each row, being distributed in a randomized block-design. On the right and left edges of the test plot two rows of 6 squares of maize were located. Between the maize and the test crops a space of 8.5 m was left open and cleared. This design was developed to avoid an accidental destruction of alternative test crops through elephants when approaching attractive control crops. The total area of potentially alternative crops (24 squares) was the same as of the attractive control (2 × 12 squares).

With the onset of rains in December 2010 all crops were planted. Maize and onion were seeded by hand, lemon grass was planted by saplings, garlic was planted by cloves and ginger by cuttings of the bulbs. All seeds and saplings were purchased from local farmers. Depending on germination success the numbers of crop plants per square varied. In the beginning of February 2011, the number of plants per each square was exactly 20 for maize ($n = 480$), the number of garlic plants ranged from 86 to 150 per square ($n = 771$), for ginger from 55 to 78 ($n = 406$), and for lemon grass from 22 to 27 ($n = 152$). The germination of onion failed in all plots ($n = 0$).

Monitoring was carried out during two periods. The first monitoring period (14.01. to 31.05.2011) was conducted until the harvest time of the latest crop (ginger), monitoring period 2 started subsequently and ended on 23.09.2011. The test plot was visited for monitoring every three days; weeding was done at the same time. Besides this human presence of about one hour every three days during day time, the test plot was abandoned. Neither watering nor plant treatment took place.

Monitoring was done by a trained field staff of the Awely Red Cap project, a non-governmental project aiming at finding solutions to human-wildlife conflicts (Gross and Fulconis 2009). During each monitoring visit, it was observed whether wildlife had shown presence on the plot or not. This was determined by animal foot prints, feeding marks or droppings. Further, it was observed whether tracks of elephants were found within 500 meters to the test plot. Any presence of wildlife was captured in a standardized form. If any crops were damaged by wildlife a second detailed form was used. The number of damaged plants was enumerated on each square and the type of damage was specified for each plant. All data were then entered into an excel sheet and the total number of damaged plants, mean number of damaged plants, and standard deviation were calculated.

Besides the damages also actual and potential yields and rating of quality was registered for the regular harvest date. The two most promising types of crops were then left on the field and regularly monitored in monitoring period 2.

Statistics

The statistical analyses were done between the test crops with remaining plants at harvest time (monitoring period 1, only onions excluded) by Kruskal–Wallis chi-squared tests and within each test crop species by Kruskal–Wallis chi-squared tests followed by post hoc tests (asymptotic Wilcoxon Mann–Whitney rank sum test). The statistical analyses within the two test crops ginger and lemon grass after harvest time (monitoring period 2) were done over all by Kruskal–Wallis rank sum tests and due to the significant results followed by post hoc tests. Here pairwise comparisons using bonferroni corrected Wilcoxon rank sum test were applied. The differences between the two plant

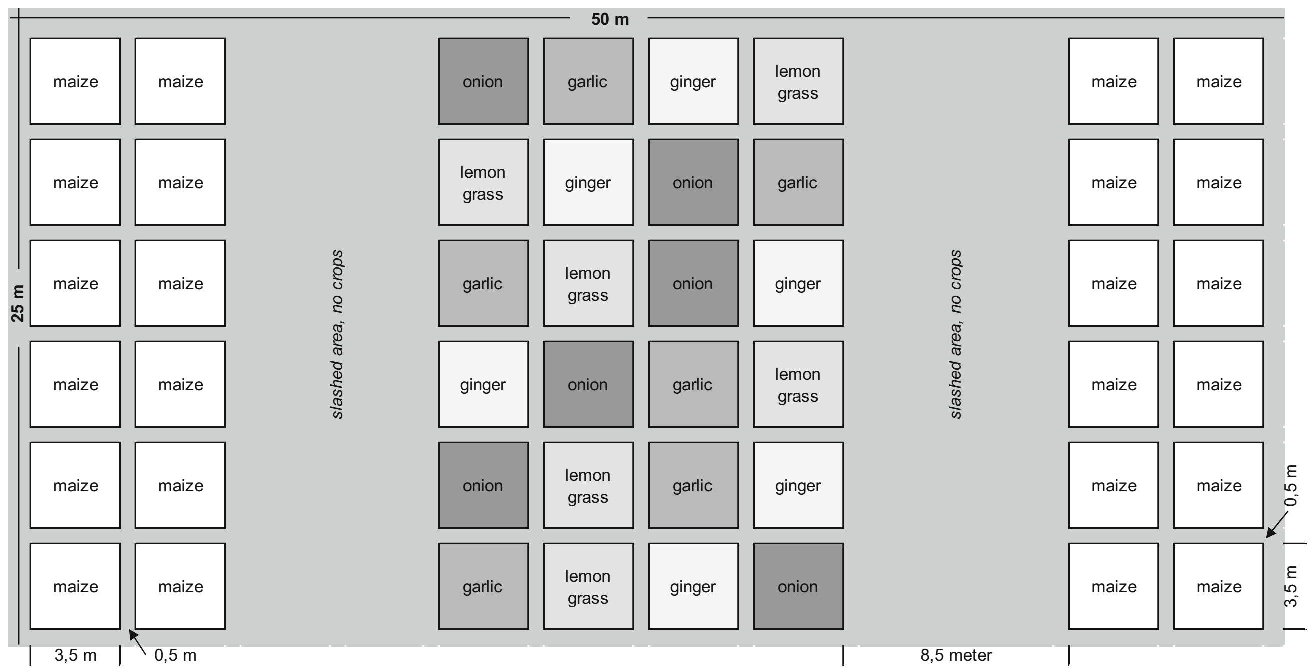

Fig. 2 Illustration of the test plot

species were calculated by asymptotic Wilcoxon Mann–Whitney rank sum tests. For statistical analyses, the software package RStudio Version 0.99.467—© 2009-2015 RStudio Inc., was used.

Results

Within the monitoring period 1 (138 days), the test plot was visited 49 times by the enumerator. On 33 of the monitoring days presence of wildlife on either or both the test or the control fields was registered. Besides the African elephant observed animal species ranged from baboons *(Papio cynocephalus)* over bushpig *(Potamochoerus larvatus)* and bushbuck *(Tragelaphus scriptus)* to lions *(Panthera leo)*. Damage to the test and control crops however was only caused by elephants. Within the monitoring period 2 (108 days) the test plot was visited 12 times by the enumerator.

In total 18 visits of elephants were recorded during both monitoring periods, visiting either alone or in groups of up to seven individuals (Table 1). They damaged both, the maize as well as the test crops. However, a much higher percentage of all test crops survived the elephant visit, compared to maize (Fig. 3). Within four elephant visits (with group sizes of two to seven individuals) the maize was completely destroyed, not a single plant survived (Table 1). By then, the maize had grown up to 1.40 m, but still was immature. The normal harvest time would have been 5–6 weeks later.

The test crops were damaged to a smaller extent and remained on the field until the scheduled harvesting time (Fig. 3). None of the test plants were completely eaten by the pachyderms, but some damages however occurred. Whereas the maize was completely eaten by the animals, without any plant survival, the test crops were mainly trampled (Table 2). Lemon grass appeared to be the most trampled crop, followed by garlic and ginger, but the differences were not statistically significant (Table 2). Elephants also tasted some parts of ginger and lemon grass plants (partly eaten), but they did not so for garlic.

The potential yields for each crop type were estimated for each particular harvest date (Table 3). Local market prices during the time of harvest were used for calculation. Maize would have been harvested mid-April, but the whole field was destroyed. Garlic was harvested on the 5th of May, with poor quality and low yields (Table 3). Lemon grass and ginger however performed well and their quality was very good. Their potential yields were calculated on the regular harvest days. Lemon grass would have been harvested on the 17th of May, ginger on the 31st of May. Due to its good yields (10.9 kg/ha) and high local marked value ginger holds the highest potential to achieve high revenues (35.1 US$/ha), followed by lemon grass (21.9 US$/ha).

Ginger and lemon grass were left on the test plot for further study purposes (monitoring period 2). In mid-June elephants started to graze parts of the lemon grass and ginger plants for the first time (Table 4). During one occasion in mid-June (Table 1: 16.06.2011) several lemon

Table 1 Visits of elephants on the test plot during two monitoring periods

Monitoring days	Date	No. of elephants on test plot	Crops partly or totally eaten
Monitoring period 1			
Day 33	15.02.2011	2	Maize
Day 47	01.03.2011	7	Maize
Day 49	03.03.2011	4	Maize
Day 54	08.03.2011	7	Maize completely eaten
Day 77	31.03.2011	4	None
Day 83	06.04.2011	2	None
Day 96	19.04.2011	3	None
Day 107	30.04.2011	3	None
Day 112	05.05.2011	7	None
Day 115	08.05.2011	4	None
Day 117	10.05.2011	5	None
Day 124	17.05.2011	2	Lemon grass
Day 131	24.05.2011	3	Ginger and lemon grass
Monitoring period 2			
Day 154	16.06.2011	4	Ginger and lemon grass
Day 155	17.06.2011	1	None
Day 167	29.06.2011	2	Lemon grass
Day 219	20.08.2011	3	None
Day 246	16.09.2011	2	None

The number of elephants and the consumed crops are given

Graphic 1 Percentage of survived crops throughout the time (days) of the experiment. Regular harvest dates per crop type are indicated as vertical lines.

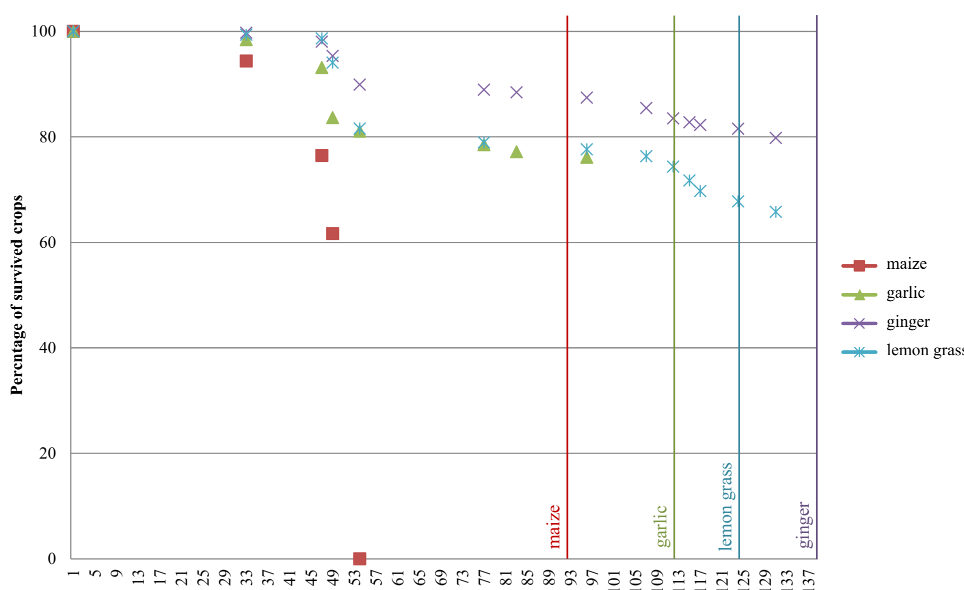

Fig. 3 Percentage of survived crops throughout the time (days) of the experiment. Regular harvest dates per crop type are indicated as vertical lines

grass and ginger plants were even completely consumed by elephants (lemon grass totally eaten 11.0 % and ginger totally eaten 3.5 %). After this single event ginger was not consumed by elephants anymore, lemon grass was consumed in very small quantities. Most of the damages however did not go along with feeding, but with trampling (ginger) and uprooting, without consumption (lemon grass). These differences were statistically significant. Lemon grass was significantly more often uprooted than ginger plants (Table 4).

Table 2 Mean ± standard deviation of plants per square damaged by elephants at scheduled harvest time

	Maize	Garlic	Ginger	Lemon grass
Totally eaten	20.0 ± 0.0 (100 %)	0.0a	0.0a	0.0a
Partly eaten	0.0	0.0 (0 %)a	0.5 ± 1.22 (0.74 %)a	0.67 ± 1.03 (2.63 %)a
Trampled	0.0	30.67 ± 26.24 (23.87 %)b	13.17 ± 4.22 (19.46 %)b	8.17 ± 5.78 (32.24 %)b

Maize was totally eaten 6 weeks prior to scheduled harvest time

The percentage of damaged crop plants referring to the total amount of its crop type is indicated in brackets. Maize $n = 480$ (24 squares), garlic $n = 771$ (6 squares), ginger $n = 406$ (6 squares), lemon grass = 152 (6 squares). The statistical analyses were done between the test crops with remaining plants at harvest time (monitoring period 1) by Kruskal–Wallis chi-squared tests (partly eaten: $\chi^2 = 2.52$, df = 2, $p = 0.28$; trampled: $\chi^2 = 1.13$, df = 2, $p = 0.57$) and within each test crop species by Kruskal–Wallis chi-squared tests (garlic: $\chi^2 = 16.13$, df = 2, $p < 0.001$; ginger: $\chi^2 = 14.84$, df = 2, p < 0.001; lemon grass: $\chi^2 = 14.21$, df = 2, $p < 0.001$) followed by post hoc tests (asymptotic Wilcoxon Mann–Whitney rank sum test; Totally eaten vs. partly eaten: ginger: $Z = -1.00$, $p > 0.05$; lemon grass: $Z = -1.48$, $p > 0.05$; partly eaten vs. trampled: garlic: $Z = -3.0767$, $p < 0.01$; ginger: $Z = -2.9887$, $p < 0.01$; lemon grass: $Z = -2.9341$, $p < 0.01$). Different lowercase letters indicate significant differences in means both within test crop species and between elephant damages

Table 3 Real and calculated yields for scheduled harvest time on the test plot in 2011 and calculation of potential revenues based on local market prices

	Harvest amount on test plot (kg)	Harvest amount (kg/ha)	Local market price (USD/kg)	Total revenue (USD/ha)
Maize	0.0	0	0.54	0
Garlic	1.0	136	15.05	2048
Ginger	80.0	10,884	3.23	35,102
Lemon grass	50.0	6803	3.23	21,939

Table 4 Mean ± standard deviation of plants per square damaged by elephants after scheduled harvest time (monitoring period 2)

	Ginger	Lemon grass
Totally eaten	2.33 ± 3.01 (3.54 %)ab	2.33 ± 2.73 (11.02 %)ac
Partly eaten	1.50 ± 1.64 (2.28 %)ab	3.17 ± 3.13 (14.96 %)ac
Uprooted	0.00 (0.00 %)b	8.83 ± 4.54 (41.73 %)c
Trampled	7.00 ± 3.79 (10.63 %)a	1.67 ± 1.37 (7.87 %)a

The percentage of damaged crop plants referring to the total amount of its crop type is indicated in brackets. Ginger: $n = 395$ (6 squares), lemon grass: $n = 127$ (6 squares). The statistical analyses were done between two test crops after harvest time (monitoring period 2). The differences within plant species were done by Kruskal–Wallis rank sum tests (ginger: $\chi^2 = 18.76$, df = 4, $p < 0.001$; lemon grass: $\chi^2 = 16.74$, df = 4, $p < 0.01$) followed by post hoc tests (Pairwise comparisons using Wilcoxon rank sum test, bonferroni corrected; Within both ginger and lemon grass, only the comparison between uprooted and trampled showed a significant difference). The differences between plant species were calculated by asymptotic Wilcoxon Mann–Whitney Rank Sum Tests. Lemon grass was more often uprooted than ginger ($Z = -3.08$, $p < 0.01$). Different lowercase letters indicate significant differences in means both within test crop species and between elephant damages

Discussion

In African savannah habitats, crop damages by elephants are reported to be especially severe at the beginning of the dry season, when the crops are ripening (Hoare 1995; Bhima 1998; Osborn 2004; Nyirenda et al. 2011). In our test the elephants invaded the plot earlier than this. After the plantation of the test crops and control crop it took only 2 months until the elephants moved into the field for the first time. After having reached a height of about 140 cm, the elephants started to graze on the maize and just walked over the test crops, without tasting them. Here the general browsing height of the African elephant has to be taken into consideration. Average browsing height was measured within 108 and 153 cm in Chobe/Botwana (Stokke and du Toit 1999) and 180–200 cm in Pongola game reserve South Africa (Shannon 2006). Elephants seldom fed on seedlings in south-eastern Tanzania (Malima et al. 2005). During the time of crop raiding of maize in our experiment the alternative test crops were lower in growth (ginger 20–40 cm, lemon grass 30–50 cm, garlic 15 cm). However, African elephants show flexibility in browsing height and are able to feed on short growing plants. In the hot dry season their diet can consist of up to 20 % of roots (Owen-Smith and Chafota 2012) and during the rainy season they shift from browsing to grazing (Field and Ross 1976; Guy 1976). Elephants further consume saplings of their preferred shrub and tree species if they are under 50 cm height (Owen-Smith and Chafota 2012) or even intensively feed on ground level (Wyatt and Eltringham 1975). Feeding on crops in seedling stage however did not take place on our test plot and therewith underlines the findings of Malima et al. (2005).

Within the fourth elephant visit, the immature maize was completely destroyed and eaten, but the test crops were still not consumed before scheduled harvest time. In the following months the elephants visited the test plot seven times without any consumption of the test crops. These results indicate the lower attractiveness of the alternative crops compared to maize, probably not only due to their lower height but also other factors. Crop damages on alternative crops only occurred through trampling. In mid-May, after the scheduled harvest time of garlic, lemon grass, and ginger, the first feeding upon lemon grass was recorded, whereby only a few plants were consumed partly. 1 week later elephants fed upon some ginger plants again. In the following weeks some single individuals of the test crops were even completely consumed. However, after these three incidences the crops were not consumed again. As the elephants did not raid the alternative crops evenly distributed over the test plot, but chose a few plants, which were close to another on the small plots, we obtained a contagious distribution, indicated by high standard deviation.

Elephants are generalist herbivores, consuming over 130 different plant species throughout the seasons in a woodland habitat (Guy 1976) but also avoid large numbers of plant species because of toxic content or chemical defense mechanisms by plant secondary compounds (Owen-Smith and Chafota 2012). Numerous organisms produce chemical compounds for defense, which adversely influence the physiology of their consumers, classified as allomones (Gross 2013). While animals defend themselves against predators, many plant species defend against herbivores by the production of secondary plant compounds. Chemical defenses against mammalian herbivores can be classified either toxins or antifeedants. While toxins are often present in low amounts and poisonous, antifeedants are typically present in higher quantities and not very toxic to herbivores (Kimball and Provenza 2003). Accordingly, the alternative test crops used in the presented experiment are herbaceous plants containing antifeedants, chemical compounds that produce a strong scent and taste, and in some cases also toxins. *Allium* species like garlic and onions are a rich source for sulfur-containing molecules. Alliin (2-propenyl-L-cysteine sulfoxide) e.g., is the precurser of volatile aroma of garlic. The volatile compound allicin is formed by the action of the enzyme alliinase after tissue disruption (Crozier et al. 2008). Allicin protect garlic to pathogens and herbivores. The ingestation of *Allium* can cause deadly toxifications in herbivorous livestock like cattle (Koch 1992). Lemon grass *(Cymbopogon citratus)* contains unusual C-glycosides of the flavones luteolin and chrysoeriol, as well as caffeic acid and chlorogenic acids (Cheel et al. 2005). Some of these constituents e.g.. luteolin can cause emesis and nausea in mammals (Yu et al. 2010). The essential oil of ginger *(Zingiber officinale)* contains the sesquiterpenes (−)-zingiberene, zingiberol, and humulene (α-caryophyllene), as well as the monoterpenes (+)-borneol and cineol which can irritate the mucosa of mammals (Roth et al. 2012).

Generalist herbivores like elephants cannot cope with toxic compounds in the way many specialist can do, due to the huge amount of different toxic compounds they are confronted with (Owen-Smith and Chafota 2012). Thus, generalists avoid highly defended herbaceous plants and prefer plants with lower amounts of toxic compounds like woody plants (Schoonhoven et al. 2005). However, mammalian herbivores possess some biochemical pathways to process secondary plant compounds which consist of primary metabolism, conjugation and elimination. This means that detrimental allomones are transformed into more polar compounds by conjugation of polar groups to the ingested secondary plant compounds and are eliminated by urine or feces (Kimball and Provenza 2003). However, this process is a costly biochemical process. Thus, a herbivore that has consumed plant material high in toxins needs complimentary foods high in proteins and energy (Kimball and Provenza 2003). Furthermore, when mammalian herbivores feed on plants information on olfactory and gustatory signals is processed. Their learning ability integrates the post-ingestive feedback from eating a food item with its flavor. Thus, food intake increases with positive consequences and decreases with negative ones (Kimball and Provenza 2003). It was shown recently that elephants feed selectively on the plant species available to them in a specific environment resulting in avoidance of two-third of these species (Owen-Smith and Chafota 2012).

Elephants have a large olfactory bulb and are able to detect volatile components over long distances. This can be signals from food or volatiles signaling the presence of human predators (Bates et al. 2007). Taking into consideration that their food choice depends on previous experiences they have made, they cautiously taste newly available plants and then decide on its palatability (Sukumar 2003). In our experiment, elephants have tried small amounts of lemon grass and ginger within a few weeks' time on the test plot. After that, they stopped consuming the test crops, but unearthed or trampled them in some minor cases.

Raiding crops on fields is a high-risk behavior of elephants as crops are often located close to human habitations and are protected by people. However, crops such as maize, are more nutritious than wild forage and feeding on them means gaining an energetic and growth pay-off (Chiyo et al. 2011). Taking this "high risk—high gain" behavior into consideration, crops which are less nutritious or chemically defended requiring costly detoxification would imply lower gain and therewith a lower risk-taking behavior. For the choice of alternative crops, their content of nutritions as well as their toxin or antifeedant contents needs to be taken into consideration.

Also the availability of other browse and grasses has an influence on the food choice (Osborn 2004). With the dry season start, which in the study area is in May, the nutrition content of grasses is reduced. This has been identified as a trigger for crop raiding behavior (Osborn 2004). During times where alternatives are getting scarce even less attractive crops might fall into the spectrum of edible crops. However, during the peak of the dry season in August and September only small parts of lemon grass and ginger plants were consumed, although elephants still visited the field regularly. Larger amounts were now just uprooted without consumption.

It can be concluded that garlic, ginger, and lemon grass are less attractive to elephants than maize. However, even though the test crops are less attractive to African elephants, they may not be completely unpalatable or even repellent to them. Depending on the plants species, the repellent activity may differ between leaves, shoots, flowers, or fruits. In chilli plants *(Capsicum annuum and C. frutescens),* which are used in many elephant damage mitigation practices (Parker et al. 2007), the plant as such does not prevent elephant visits. As in contrast to fruits the leaves of chilli plants do not contain remarkable amounts of capsaicin, the alkaloid responsible for causing pain in mammals, it is not surprising that even the leaves of chilli plants are consumed from time to time by elephants (Gross EM, unpublished data). In that case also unattractive crops might get raided. Despite these aspects, these less attractive crops seem to be more suitable in farming areas with high elephant abundance.

The ecological suitability as well as market value of the grown crop has to be taken into consideration when making the crop choice for farming (Parker and Osborn 2006). Although grown in the region and available on markets the onion failed in the stage of germination, probably due to bad seed quality or unsuitable soils. As there is a high local demand for garlic and it can achieve good market prices and therewith holds some potential as cash crop. However, in our test garlic grew with bad qualities, probably due to unsuitable soil and insufficient water availability. Further, the fragile garlic plants are stronger affected by trampling than robust crops like lemon grass. Despite the lack of watering and absence of fertilizers or pesticides, both ginger and lemon grass performed very well on the test plot. Taking into consideration the local market value, lemon grass holds high potentials as an alternative cash crop, followed by ginger with lower market value but high yields. Given the local purchasing power and market access, lemon grass and ginger promise high income compared to the traditionally grown maize. Further research on options for marketing considerable amounts of alternative crops in remote areas of Zambia still needs to be conducted.

In agricultural areas with high abundance of large herbivores, especially elephants, new approaches to crop protection are needed. The IUCN Red List ranks human-elephant conflicts as one of the three major threats to the species survival (Blanc 2008). The selection of appropriate, less attractive or even unpalatable crops is an important step to tackle these conflicts. If the pachyderms do not find nutritious and attractive crops on the farms in their home range, reduction of crop losses is very likely. To foster this approach, however, more detailed studies are needed, to observe the resistance of the crops in long-term and to identify a larger diversity of unattractive crops. Given a good market access these crops should serve both, people and threatened wildlife species.

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Author contribution statement EMG conceived and designed study, analyzed data, wrote ms. RMcR monitored field experiments. JG developed field experiment design, made statistics and wrote ms. All authors read and approved ms.

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6. THE POTENTIAL OF MEDICINAL AND AROMATIC PLANTS (MAPS) TO REDUCE CROP DAMAGES BY ASIAN ELEPHANTS (*ELEPHAS MAXIMUS*)

Erklärung zu den Autorenanteilen

an der Publikation: **The potential of medicinal and aromatic plants (MAPs) to reduce crop damages by Asian Elephants (*Elephas maximus*)**
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- Naresh Subedi (NS)
- Jürgen Gross (JG)

Was hat die Promovierende bzw. was haben die Koautoren beigetragen?

(1) zu Entwicklung und Planung

EMG hat die Planung und Entwicklung der Studie geleitet und in allen Bereichen maßgeblich mitgewirkt (70%)
JG hat beratend bei der Entwicklung und Planung des Freilandexperiments mitgewirkt (30%)

(2) zur Durchführung der einzelnen Untersuchungen und Experimente

EMG hat die Durchführung des Freilandexperiments angeleitet und Mitarbeiter für das Freilandmonitoring angelernt (75%)
NDH hat die Mitarbeiter im Freilandexperiment koordiniert (20%)
NS hat die die die Verbindung zur Wildtierbehörde hergestellt (5%)

(3) zur Erstellung der Datensammlung und Abbildungen

EMG hat alle im Feld erhobenen Daten gesammelt und für die Analyse aufgearbeitet sowie die Abbildungen erstellt (90%)
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The potential of medicinal and aromatic plants (MAPs) to reduce crop damages by Asian Elephants (*Elephas maximus*)

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ABSTRACT

In all 13 Asian range countries of the wild Asian elephant (*Elephas maximus* L.), farmers suffer from crop damages caused by this endangered and highly protected species. As elephants are lured by highly nutritional crop types into agricultural lands, measures to deter or repel them from the high attraction will always be costly and labour intensive. The cultivation of crops, which are less attractive to elephants, yet economically viable for local farmers could lead to a new direction of land-use and income generation in human-elephant conflict areas. In this study, seven medicinal and aromatic plants (MAPs) containing higher amounts of specific plant secondary compounds were explored for their attractiveness to wild Asian elephants against a control of rice (*Oryza sativa* L.) and maize (*Zea mays* L.). The results show that chamomile (*Matricaria chamomilla* L.), coriander (*Coriandrum sativum* L.), mint (*Mentha arvensis* L.), basil (*Ocimum basilicum* L.), turmeric (*Curcuma longa* L.), lemon grass (*Cymbopogon flexuosus* (Nees ex Steud.) W. Watson) and citronella (*Cymbopogon winterianus* Jowitt.) were less attractive and were not consumed by elephants compared to rice. Damages to the MAPs occurred only through trampling, with mint being most prone to being trampled. Other wildlife species, however, were observed to feed on lemon-grass. Long-term learning effects and the eventual palatability of crops with less efficient antifeedants need to be further explored. This study, however, gives first evidence that MAPs bear a high potential for a secure income generation in and close to Asian elephant habitats. Furthermore, the strategic plantation of crops unattractive and attractive to elephants could lead to new land-use strategies and improve functionality of elephant corridors.

1. Introduction

Asian elephants (*Elephas maximus* L.) inhabit an area of more than 870 000 km^2 of land in 13 Asian countries (Choudhury et al., 2008; Leimgruber et al., 2003), with India holding 60% of the total wild population of an estimated 38 500–52 500 elephants (Sukumar, 2006). About 50% of the Asian elephant's geographic range is characterized by agriculture. The other half can be considered wildlands, which are increasingly surrounded and isolated by agriculture (Leimgruber et al., 2003). The remaining fragments of natural forests and grasslands, are bordering directly on agricultural fields where highly nutritional crops as rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) or maize (*Zea mays* L.) are farmed. Elephants are lured to these crop fields by highly attractive staple crops, especially during the maturing growth stage (Gross E.M., unpublished data). Large amounts of crop damages are reported from India (Madhusudan, 2003), Sri Lanka (Santiapillai et al., 2010), Indonesia (Hedges et al., 2005) and Nepal (Pant et al., 2015). Compared to the national level of crop losses through other pests like weeds, insects or rodents (Oerke, 2006), crop losses due to elephants may not be as economically important, however the catastrophic character of elephant invasions and the constraints to react on them due to the high conservation status of elephants (IUCN Red List endangered) (Choudhury et al., 2008), making this a serious agricultural and conservation issue.

Multiple techniques have been implemented across the Asian

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and African elephant ranges to prevent them from entering crop fields or to scare them away when they were found feeding on the farms. Mitigation strategies for crop damages includes shooing away elephants through noise or fire, protecting fields with chilli smoke, construction of electric fences or using bees in hive fences to prevent elephant intrusions (Hoare, 2012). All of these methods are highly labour and/or cost intensive. Thus, in agricultural areas, which face great crop damages through large herbivores, especially elephants, new approaches to crop protection are needed (Gross and Gündermann, 2016).

Nepal has a long tradition in farming medicinal and aromatic plants (MAPs), which are sold as herbal raw material or are further processed into essential oils (Olsen, 1998). It was shown recently that such MAPs, plants which contain higher amounts of secondary plant products, were less attractive to elephant (*Loxodonta africana* Blumenbach) than maize (Gross et al., 2016). However, these plants may not be completely unpalatable or even repellent to them, but their chemical compounds (antifeedants) could cause avoidance behaviour. The selection of appropriate, less attractive or even unpalatable crops might be a solution for the agricultural sector in or close to elephant dwelled habitats to tackle these conflicts (Gross et al., 2016). As local farmers reported that elephants did not consume MAPs on their fields, the cultivation of such crops increased in agricultural areas adjacent to Bardia National Park in Nepal (Thapa and Chapman, 2010) and in Sri Lanka (Santiapillai et al., 2010).

The first scientifically testing of the attractiveness of different crop types towards elephants has been reported recently from Zambia (Gross et al., 2016). Based on this to this study, a similar experiment was conducted at the western boundary of the Bardia National Park in Nepal. Here we describe the first experiments on testing the attractiveness of aromatic crops for elephants in Asia.

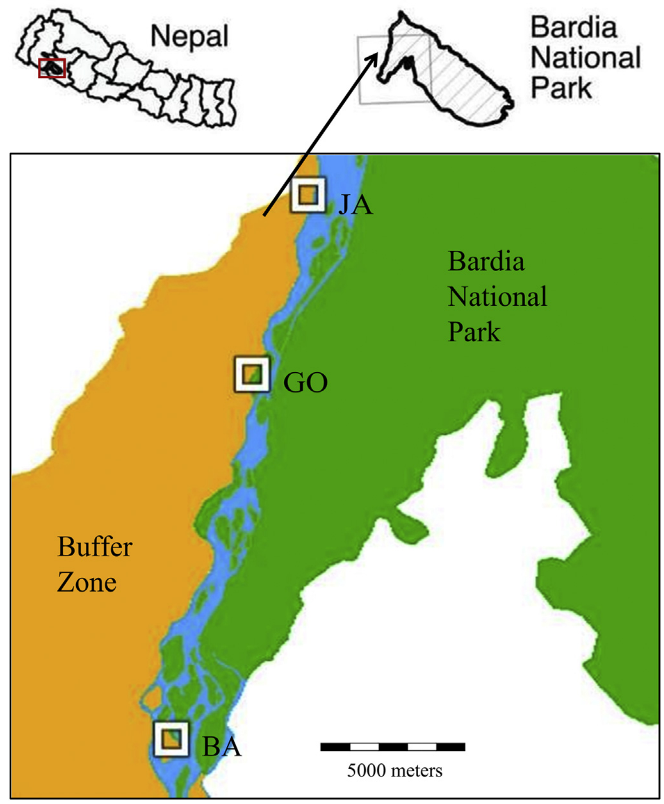

Fig. 1. Map of test plot locations in Nepal at the border of Bardia National Park (natural habitat: green) and Western Buffer Zone (farmland and villages: yellow). Test plots are indicated as white squares (JA: Janaknagar, GO: Gola, BA: Bajpur). *Source:* Author's screenshot from Google Earth 1/1/2017. Overview maps produced by Eva Klebelsberg using Quantum GIS Geographic Information System, Version 2.14.3 Essen. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Material and methods

2.1. Study site

The experiment was conducted at the western boundary of Bardia National Park (968 km^2), in the lowlands of Nepal. The subtropical monsoon climate is characterized by heavy rainfalls between July to October, the mean annual rainfall is around 1500 mm (Dinerstein, 1979). The vegetation in the south-western part of the park is characterized by tropical deciduous Sal forest, early riverine forests and tall grass flood plains (Jackson et al., 1994). Bardia is known for its high abundance of wildlife species, such as spotted deer (*Axis axis* Erxleben), hog deer (*Axis porcinus* Zimmermann) and barking deer (*Muntiacus muntjak* Zimmermann) and holds the largest number of resident Asian elephants in Nepal as well as a growing population of reintroduced Greater one-horned rhinoceros (*Rhinoceros unicornis* L.) (Flagstad et al., 2012; Wegge et al., 2009). The natural border between the national park and the western buffer zone is formed by the Geruwa River, a tributary of the Karnali River. Large wildlife species regularly cross this river to feed on crops cultivated in the buffer zone.

2.2. Test plot locations

The three test plots were located at the western bank of the Geruwa River, between the western boundary of the national park and private farmland (Fig. 1). The test plot Janaknagar (JA) was located in the northern 28° 34′ 29,604″ N, 81° 14′ 48,48″ E, test plot Gola (GO) in the middle 28° 31′ 23,808″ N, 81° 13′ 43,5″ E, and the test plot Bajpur (BA) in the southern part 28° 25′ 5988″ N, 81° 12′ 8136″ E of the study area. These sites were chosen based on the frequently observed movements of elephants from the national park to the farmlands, especially during the monsoon season when paddy and maize are cultivated (Gross E.M., unpublished data).

2.3. Experimental design

Seven crops (basil (*Ocimum basilicum* L.), chamomile (*Matricaria chamomilla* L.), citronella (*Cymbopogon winterianus* Jowitt.), coriander (*Coriandrum sativum* L.), lemon grass (*Cymbopogon flexuosus* (Nees ex Steud.) W. Watson), mint (*Mentha arvensis* L.) and turmeric (*Curcuma longa* L.) containing essential oils (MAPs) were selected for all three test plots (Table 1) as well as the staple crops rice and maize, which are frequently damages by elephants in Nepal (Thapa, 2010) and were chosen as a positive control. For all crop types locally available cultivars were selected, based on ecological suitability and common utilization in the study area.

Rice was used as control on two plots (JA and GO) and maize at BA. Measuring 82.5 m in length and 33.5 m in width, the test plot consisted of 60 squares measuring 5 by 5 m (Fig. 2). Paths of 50 cm were left open between the squares. In the centre, 36 squares of essential oil crops were located in a plot of 32.5 m × 32.5 m. Each test crop species appeared once in each row, being distributed in a randomized block-design. On the right and left edges of the test plot, three rows of six squares of rice (JA, GO) or maize (BA) were located. Between the maize and the test crops, a space of 11.5 m was left open and cleared, so elephants could choose to either feed on the control or test squares. This design was developed to avoid an accidental destruction of essential oil crops by elephants when

Table 1
Species of MAPs and control crops tested on test plots in 2012 and 2013 on their attractiveness towards elephants. Crude protein (CP) content, as well as plant secondary metabolites (PSM) and their proven effects on foragers including sources are presented. n/a = information not available/not applicable.

Crop type	CP	PSM	Effect on foragers	Source
Basil *(Ocimum basilicum)*	3%	Phenylpropenes: eugenol, methyl eugenol and estragol; methyl chavicol	Hepatotoxic, can cause convulsions, diarrhoea, nausea, unconsciousness, dizziness, or rapid heartbeat to humans	Fujisawa et al., 2001; Joshi, 2014; Thompson et al., 1998
Chamomile *(Matricaria chamomilla)*	NA	120 different PSMs Flowers: apigenin, quercetin, patuletin, luteolin and their glucosides (all flavonoids) Essential oil: terpene bisabolol, farnesene, chamazulene, flavonoids (including apigenin, quercetin, patuletin and luteolin) and coumarin	Bisabolol deterrent to mice but not to voles and haresEmesis and nausea in mammals	Hansen et al., 2015, 2016; Mann and Staba, 1986; McKay and Blumberg, 2006; Reichardt et al., 1990; Singh et al., 2005
Citronella *(Cymbopogon winterianus)*	2%	Geraniol, Citral, geranyl acetate	Geraniol, linalool, and citronella are repellent against mosquitoes	Chen and Viljoen, 2010
Coriander *(Coriandrum sativum)*	2%	Leaves: decanal, trans-2-decanal Seeds: linalool, geraniol, terpine-4-ol, alpha-terpineol, limonene, alpha-pinene, camphene, myrcene	n/a	Mandal and Mandal, 2015
Lemongrass *(Cymbopogon flexuosus)*	2%	Unusual C-glycosides of the flavones luteolin and chrysoeriol, as well as caffeic acid, chlorogenic acids and geraniol	Luteolin can cause emesis and nausea in mammals	Chen and Viljoen, 2010; Yu et al., 2010
Mint *(Mentha arvensis)*	4%	Menthol, menthone, decanol, limonene, up to 42 minor constituents	Stimulate the cold-sensitive receptors in mucous membrane and skin	Eccles, 1994; Singh et al., 2005
Turmeric *(Curcuma longa)*	8%	235 compoundsMain curcumin (diarylheptanoid) and also monoterpenes like limonene etc.	n/a	Li et al., 2011
Rice *(Oryza sativa)*	10.3%	Oxalic acid in rice straw	Excessive feeding of rice straw produces harmful effects to grazers, as calcium is bound	Patel, 1966
Maize (*Zea mays*)	7.9%	n/a	n/a	Holm, 1973

approaching attractive control crops. The total area of essential oil crops (36 squares) was the same as of the attractive control (2 × 18 squares). The test plot was placed with the long side towards the national park boundary, which was the direction elephants were expected to approach the test plot from.

Plantation started with chamomile, coriander and mint in mid-February 2013, followed by basil in the beginning of April. Chamomile and coriander were harvested at the end of April, after which turmeric was planted on the former coriander plots in the beginning of June. Rice and maize cultivation started with the onset of rains in late June, followed by lemon grass and citronella to be planted at the end of July. At the end of October, all crops were harvested and monitoring came to a halt. In early 2014, the cultivation started again, following the scheme of 2013 and was carried on until the end of October 2014.

Chamomile, coriander and maize were seeded by hand, while rice, basil, lemon grass and citronella were planted by seedlings. For turmeric, cuttings of the bulbs were used and for mint, cut suckers were planted. All seeds and saplings were purchased from local farmers. In the beginning of 2013 for the test plots JA and GO, the number of plants per each square was 1024 for rice (n = 36 864), whereas in BA the number of maize plants per square was 120 (n = 4320). For all three test plots, the number of chamomile plants were 2500 per square (n = 15 000), coriander 5000 per square (n = 30 000), mint 144 per square (n = 864), basil per square 88 (n = 528), turmeric 96 per square (n = 576), and for lemon grass and citronella 130 per square (n = 780 each).

Monitoring was carried out weekly from 18th March 2013 onwards to the end of October 2014 with an interruption from November 2013 to April 2014. Human presence, comprising local farmers employed to irrigate and weed the plots (neither fertilizers nor pesticides were applied), were limited (roughly 1 h during the

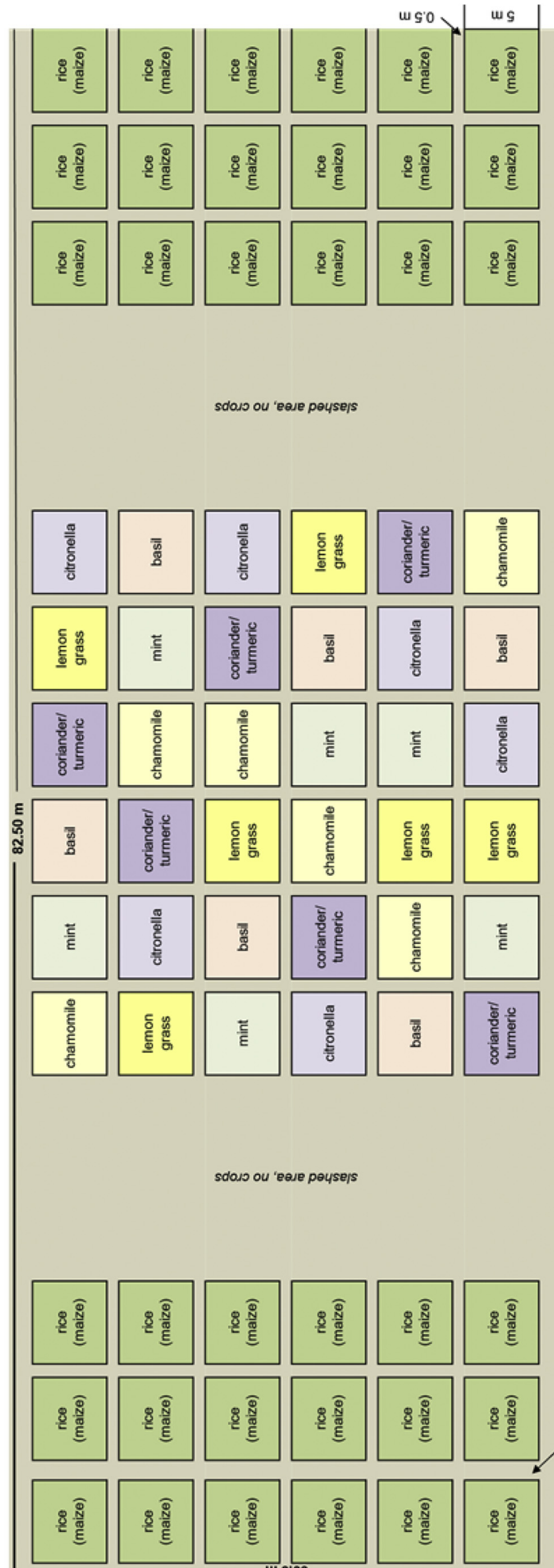

Fig. 2. Illustration of the test plot design at JA and GO with rice as control crop, whereas maize served as the control crop in BA.

day every three days) during the dry months from March to June; otherwise the plots were undisturbed.

Monitoring was conducted by a trained field staff of the Awely Red Cap project, a non-governmental project aiming at finding solutions to human-wildlife conflicts (Gross and Fulconis, 2009). During each monitoring visit, wildlife presence or absence based on animal foot prints, feeding marks or droppings on the plot was observed. Any presence of wildlife was captured in a standardized form. If any crops were damaged by wildlife, a second detailed form was used. The number of damaged plants was enumerated on each square and the type of damage was specified for each plant. All data were entered into an excel sheet and the total number of damaged plants, mean number of damaged plants and standard deviation were calculated.

All crops were left in the fields until their respective harvest times. Harvest was carried out by local farmers and yields for each crop type were measured by weight. For the calculation of potential revenues, the local market prices during the time of harvest were used.

2.4. Statistical analysis

Damaged plants were compared between control and test crops at harvest time by Wilcoxon Mann-Whitney rank sum tests. The statistical analysis between the trampled test crop species was done by Kruskal-Wallis chi-squared tests and, due to significant results, followed by post hoc tests. Here, pairwise comparisons using Bonferroni corrected Wilcoxon rank sum tests were applied.

For statistical analysis, data of test plots with the same set up (GO and JA both with rice as control) were pooled; data for BA (maize as control) were analysed separately. Statistical tests were performed using RStudio version 3.2.5 (R CoreTeam, 2016).

3. Results

Within the 431 days of the experiment in 2013 and 2014, each test plot was visited by the Red Caps more than 60 times. On 18 of the monitoring days, presence of wildlife was registered on either of the three test plots. Besides the Asian elephant, observed animal species included the Greater one-horned rhinoceros (*Rhinoceros unicornis*), the blue bull (*Boselaphus tragocamelus*) and the spotted deer (*Axis axis*), which all caused damages to the crops (Table 2). Elephants were observed eleven times on the test plots, exclusively in the year 2013. For this reason, the data analysed for crop preferences by elephants refer to the 2013 data (273 days) only.

Elephants entered the test plots either alone or in pairs but were never observed in larger groups. They caused damages to both test crops and control (rice or maize). However, a higher percentage of all test crops survived the elephant visit when compared to the control crops rice or maize (Fig. 3). Elephants exclusively fed on the control crop rice (81.3 ± 151.9; 3.97%) but did not consume any of the MAPs ($U = 0$, $p = 0.000625$). Test crops (MAPs) only damaged by trampling (32.9 ± 84.7; 1.42%), but rice was not damaged by trampling only ($U = 72$, $p = 0.001849$).

Rice or maize, however, was exclusively damaged through feeding upon. Chamomile, coriander, mint, basil, and turmeric were all trampled by elephants to some extent, with a maximum of 5.32% for mint. No difference was observed in the intensity of trampling between any of these crop types. Lemon grass and citronella were the only crops that were not at all trampled by elephants (Table 3).

Rhinos visited the test plots three times in 2013 only. They entered the fields alone or in pairs and damaged rice through feeding, and mint, lemon grass and citronella through trampling. Shortly before the harvest of lemon grass, a small portion of lemon grass was consumed by one rhino. Due to the low case numbers, these observations could not be compared statistically.

The test plot BA, with maize as control crop, was excluded from statistical analysis, as it was visited only once by a rhino and once by an elephant.

Chamomile and coriander were the first crops to be harvested at the end of April. The quality of chamomile was very good and obtained a harvest of 1450 kg/ha in GO and JA, with wildlife damages taken into consideration (Table 4). As coriander did not germinate and grow properly, this crop type was excluded from the calculation of revenues. All other test crops and the rice were harvested in JA and GO in the first week of November 2013. Basil and mint obtained the highest yields with 21 681 kg and 11 191 kg respectively. The lowest yields of the test crops were obtained by citronella and lemon grass (2924 kg and 2881 kg respectively). With 2073 kg per ha rice obtained the smallest yield. Plants containing essential oils

Table 2
Visits of wildlife ($n = 18$) on three test plots (JA, GO and MA) during two monitoring periods (year 2013: 273 days, year 2014: 158 days). Damages crops and type of damage are mentioned.

Monitoring days	Date	Test plot	Wildlife observed	Crops damaged
Year 2013				
34	18.03.2013	JA	1 elephant	Coriander and chamomile trampled
41	25.03.2013	JA	2 elephants	Coriander and chamomile trampled
48	01.04.2013	JA	1 elephant	Coriander and chamomile trampled
52	05.04.2013	GO	1 elephant	None
137	17.06.2013	GO	1 elephant	Mint and basil trampled
155	05.07.2013	JA	2 elephants	Rice eaten, basil and turmeric trampled
157	07.07.2013	GO	1 elephant	Rice eaten
189	08.08.2013	BA	1 elephant	Maize eaten
196	15.08.2013	JA	1 elephant	Rice eaten, turmeric trampled
199	18.08.2013	GO	1 elephant	Rice eaten
206	25.08.2013	GO	2 rhinos	Rice eaten, mint trampled
223	11.09.2013	JA	1 rhino	Rice eaten, lemon grass and citronella trampled
264	22.10.2013	GO	2 elephants	Rice eaten, mint, basil and turmeric trampled
273	31.10.2013	BA	1 rhino	Lemon grass eaten and trampled
Year 2014				
23	26.04.2014	JA	1 blue bull	lemon grass partly eaten
114	26.07.2014	JA	12 spotted deer	maize eaten
131	12.08.2014	JA	15 spotted deer	maize eaten
132	13.08.2014	BA	10 spotted deer	maize eaten

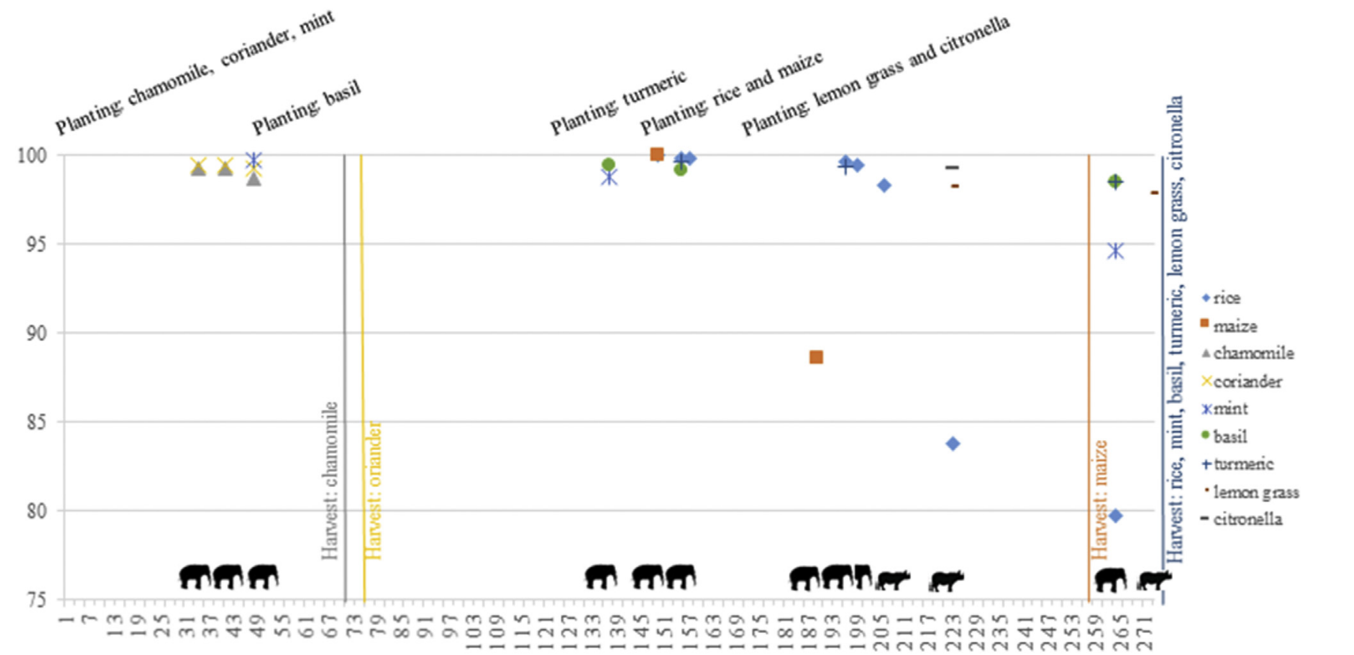

Fig. 3. Percentage of survived crops (scale starting at 75%) throughout the time (days) of the experiment. Harvest dates per crop type are indicated as vertical lines. Planting dates are indicated on top, elephant symbols stand for elephant damages, rhino symbols stand for rhino damages.

Table 3
Mean ± standard deviation of elephant damage per square to seven MAP species in JA and GO test plots in 2013.[a]

	Mint	Basil	Turmeric	Chamomile	Coriander	Lemongrass	Citronella
Eaten	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trampled	15.3 ± 22.3 (5.32%)[a]	4.0 ± 7.6 (2.27%)[a]	4.2 ± 6.5 (2.17%)[a]	97.3 ± 117.4 (1.95%)[a]	109.7 ± 165.8 (1.1%)[a]	0.0	0.0

[a] The percentage of damaged crop plants referring to the total number of the respective crop type is indicated in brackets. The statistical analyses were done between the test crops with damaged plants up to harvest time by Kruskal–Wallis chi-squared tests (trampled: $c^2 = 13.443$, df = 6, p = 0.0365) followed by post hoc tests (asymptotic Wilcoxon Mann–Whitney rank sum test; trampled chamomile vs. coriander: Z = 0, $p > 0.05$; trampled chamomile vs. mint Z = −2.37, $p > 0.01$; trampled chamomile vs. basil: Z = −2.23, $p > 0.01$; trampled chamomile vs. turmeric: Z = −2.23, $p > 0.01$; trampled coriander vs. mint: Z = −1.44, $p > 0.05$; trampled coriander vs. basil: Z = −1.08, $p > 0.05$; trampled coriander vs. turmeric: Z = −1.08, $p > 0.05$; trampled mint vs. basil: Z = −0.27, $p > 0.05$, trampled mint vs. turmeric: Z = −0.199, $p > 0.05$; trampled basil vs. turmeric: Z = 0, $p > 0.05$). Same superscript letters indicate no significant differences in means between elephant damages.

Table 4
Crop yields at harvest time on the test plots JA and GO in 2013 and calculation of potential revenues based on local market prices. n/a = not applicable as not used for production of essential oils.

	Harvest amount on test plots (kg/ha)	Yield of essential oil (kg/ha)	Local market price (USD/kg)	Production cost (USD/kg)	Total revenue (USD/ha)
Turmeric	8682	n/a	0,15	0,00	1270,10
Basil	21 681	124	12,54	140,00	1259,00
Chamomile	1450	5	240,34	108,00	973,52
Rice	2073	n/a	0,25	0,00	519,91
Mint	11 191	23	16,72	38,00	339,52
Lemon Grass	2881	15	14,63	22,00	197,44
Citronella	2924	15	14,63	22,00	197,44

Prices for rice and turmeric refer to raw materials, prices for chamomile, mint, basil, turmeric, lemon grass and citronella refer to their essential oils.

(chamomile, mint, basil, lemon grass and turmeric) were processed to essential oils in local steam distillieries. Yields per kg of raw material varied between 2.5 kg/ha for chamomile, and 124.36 kg/ha for basil. Market prices for crops (rice and turmeric) and essential oils varied strongly, with turmeric being the cheapest crop type (0.15 USD/kg) and chamomile oil the most valuable essential oil (240.34 USD/kg). For the production of essential oils, 10% of the gross revenue was subtracted, leading to revenues ranging from 197.44 USD/ha for citronella and lemon grass to 1270.10 USD/ha for turmeric. Rice in comparison brought a low to medium income of 519.91 USD/ha.

4. Discussion

The objective of this field experiment was to gain certainty on whether MAPs are less attractive for consumption to elephants or not. Despite the low number of visits by elephants in the test plots, our results provide evidence that elephants prefer feeding on rice but not on MAPs.

Elephants are generalist herbivores, which are able to consume many different plant species throughout the seasons, making their choice depending on palatability and acceptability (Heady, 1964) and avoid large numbers of plant species due to toxic or unpalatable plant secondary metabolites (PSM) (Owen-Smith and Chafota, 2012). It has been recently shown that elephants rely on olfaction to locate food (Plotnik et al., 2014) and to distinguish between preferred and avoided natural forage by odour (Schmitt, 2016). In the present experiment, MAPs have been used containing antifeedants, chemical compounds that produce a strong scent and taste, and in some cases also toxins (Table 1). We assume that the odours evaporated from MAPs have an influence on the choice of feeding (or not) upon them. Also, the lower content of crude protein of MAPs compared to rice (Table 1) might have an influence. As shown by Schmitt (2016), the crude protein content however, does not seem to drive elephant feeding choices.

Many plant species are defended against herbivores with the production of PSMs, and their odour, flavour, and palatability provides the basis for foraging selections in mammalian herbivores (Hansen et al., 2016). PSMs play a key role in this interaction and can act as antifeedants through regulating the food intake of herbivores (Dearing et al., 2005). PSMs are found in high amounts in MAPs adversely influencing the physiology of their consumers.

The PSM produced by leave parts, flowers and seeds of tested MAPs are mainly terpenoids, especially mono- and sesquiterpenes (Table 1), some of them being well-known insect repellents. Different plant parts can also contain essential oil, differing in their chemical constituents (Singh et al., 2005).

All MAPs used in this experiment contain multiple PSMs which may have a repellent activity against elephants. However, it must be taken into consideration that these compounds are mainly identified in the extracted essential oils of the plants and are not necessarily found in all plant parts. Their content and composition characterizes the repellent abilities and can differ between flower, stem, leaves and seeds within the same plant. Further examination of which compound may influence an elephant's avoidance of them is required. Furthermore, it has to be understood that MAPs could be repellent, but not deterrent to elephants. As observed in the test plots, elephants may pass through fields with unattractive crops without feeding, but they may cause damage through trampling.

The experiment was designed to gain insight on the elephant's crop choice when exposing it to a variety of MAPs and an attractive crop type. As elephants can cause damage to crops only by walking over them, we chose to separate the attractive control crop from the test crops. To decrease spatial effects, test crops were mixed randomly. In this experimental design, the attractiveness of MAPs is exclusively tested against an attractive crop type. Insights on elephant's crop choice in case no highly attractive crops were available are not given. Further, in case of strongly deterrent effects of one MAP this could influence the choice of the neighbouring crops. To gain more certainty about the attractiveness, repellent or deterrent capabilities of MAPs, more tests focussing on single crop types as well as feeding and olfactory experiments with elephants, as described by Schmitt (2016), are needed.

Our test plots were visited by elephants during the dry as well as the rainy season. As control crops were available on the fields in the rainy season only, typical dry season crops such as coriander and chamomile were present on the fields without control crops in their vicinity. During the five dry season visits, the elephants, however, only damaged crops by passing through the field, thus maintaining low levels of damage. During these visits, chamomile had grown to 30–40 cm in height, while coriander had a lower height, not exceeding 10–15 cm. During the dry season, food availability in the natural habitat is reduced and elephants in Bardia consumed more browse than grass (Steinheim et al., 2005). Asian elephants generally prefer grass or browse from 50 cm height onwards. They are, however, able to feed on freshly sprouting grasses or on tender short grasses growing beneath the coarse swards of tall grasses (Sukumar, 1989). Therefore, generally the elephants would have been able to consume crops below 50 cm. In the rainy season, elephants visited the test plot six times, consuming rice from the 7th day after planting onwards. Rice plants by that time did not exceed a height of 20 cm. Although elephants consumed rice every time they entered the test plots, they only partly damaged the control crops. This happened even though rice from August onwards had the ideal feeding height of over 50 cm and no disturbance occurred. On a similar test plot in Zambia in 2011, the control crop of maize was completely consumed by elephants within two months (Gross et al., 2016). In the experiment in Zambia, the MAP lemon grass was, to some extent, consumed by elephants, when leaving them in the field even after the scheduled harvest time. This exposure without control crop and during the main dry season was not conducted in Nepal. To demonstrate further that lemon grass and citronella are unpalatable to Asian elephants, further research needs to be conducted. Further, the damage of crops by passing elephants without feeding should also be considered. Some fragile crops, like mint, are more prone to trampling than other more robust crops like turmeric, citronella or lemon grass.

Rhino in contrast was observed in the BA test plot feeding on lemon grass in 2013 and blue bull fed on lemon grass in the JA test plot in 2014. Hence, in wildlife rich areas, the possibility of damage by wildlife during the selection of lemon grass as a crop needs to be considered.

The use of crops unattractive to elephants as a buffer between their natural habitat and rural land could be a step forward for land use planning along National Parks in Asia. In highly fragmented landscapes with patches of remaining forest habitats interspersed with agricultural land, the systematic planting of MAPs in rural areas, where elephants should not roam, in combination with the creation of highly attractive corridors (with highly preferred natural food plants) might be an option for reducing heavy conflicts between people and elephants.

Besides the suitability of crops regarding biotic and abiotic factors, the economic value and marketability plays a major role for the crop choice of farmers. Turmeric is a high-value perennial cash crop that is used for food and medical purposes and is cultivated over large parts of Asia, with India being the primary exporter (Gupta et al., 2013). Despite the comparably low price per kg, the highest revenues per ha were obtained in the test plot with turmeric. Revenues could even be increased through value adding processes (e.g. polishing) or following standards or good agricultural practice (Booker et al., 2016).

Mint, lemon grass and citronella can be farmed perennially and harvested several times per year, multiplying yields and revenues (Rajeswara Rao, 1999; Tajidin, 2012). Through production oriented farming, much higher revenues could be generated in general through the cultivation of MAPs compared to the traditional staple crops. Small scale subsistence farmers may be reluctant to change from the traditional staple crop rice to MAP cash crops. However, if losses of staple crops to wildlife are substantial and marketability of MAPs is ensured, the choice for the safer and more profitable crop types seems reasonable. Further, the globally expanding interest in MAPs (Barata et al., 2016; Kala, 2015) provides a high potential for marketability with relatively stable prices, at a reasonably high level in Nepal, India and other range countries of the Asian elephant (Booker et al., 2016).

5. Conclusions and management implications

The results of our field experiments show that the tested MAPs crops were less attractive to Asian elephants than rice. However, in case PSM defended plants were still palatable, they could start feeding on them to some extent under nutritional stress, as demonstrated in field trials in Zambia (Gross et al., 2016). As elephants visited our test plots only in one of two years, no firm conclusion can be drawn on the potential of behaviour change after long term exposure. To demonstrate that elephants will not habitually raid MAPs, long term studies with larger sample sizes of elephant visits need to be conducted.

Further, our results demonstrate that MAPs bear a high potential for a secure income, especially in and close to elephant habitats. To decrease crop damage by elephants, MAPs could be planted systematically into areas elephants should not enter. At the same time, protecting zones and corridors, which are rich in nutritional plants and forming a suitable habitat, could be created, similarly to push- and pull-strategies which are commonly used for insect pests (Gross and Gündermann, 2016).

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7. GENERAL DISCUSSION

In African and Asian countries, massive hunting has reduced wildlife species from the colonial times and beyond (MacKenzie 1987; Sramek 2006). During the 1960s, the population of greater one-horned rhinos was reduced to below 100 individuals in Nepal (Thapa et al. 2013), colonial British hunters systematically destroyed thousands of tigers in India (Sramek 2006) and, in the early 20th century, commercial elephant offtake from South Luangwa National Park, Zambia was a minimum of 2,200 elephants annually (Abel and Blaikie 1986). With the rise of nature consciousness and ecological thinking, national parks were established, hunting was restricted and the recreational, non-consumptive value of conservation areas gained importance (Pretty 2002). In parallel, a rising human population had established growing settlements and had further cultivated land, adjacent to, or sometimes within, the areas then declared as national parks (Wittemyer et al. 2008). The resettlement of people, often against their will, is the downside of many conservation efforts of the 20th century (Stevens 2014). The rising human population adjacent to conservation areas, along with it the destruction and fragmentation of natural habitats, is seen as a major driver for HWCs on larger spatial scales (Lamarque et al. 2009). On the other hand, the stronger protection of wildlife species with a decrease in hunting resulted in growing wildlife populations and therewith intensified wildlife crop and livestock damage (Messmer 2000). Whatever might have influenced the development of wildlife damage in historic and recent times, the conversion of natural habitats into agricultural land increases the spatial overlap of herbivorous wildlife species with people, especially farmers. To achieve a sustainable coexistence between people and wildlife in the future, solutions need to be developed. Such solutions need to be based on sound scientific understanding of the area of conflict. Thus, my comparative study on human-wildlife conflicts in African and Asian countries was carried out against this background.

In all four of my study areas, the livelihoods of the rural population were based on agriculture. Therefore, I focused on pre- and post- harvest damage caused by wildlife species. As with the three species categories used for data analysis in Chapter 3, I also used these categories for a comprehensive overview within this chapter. Species are grouped into elephants, other large herbivores and medium sized herbivores, based on their body weight (Table 1). For all three categories determinants for crop damage are discussed and potential crop protection strategies are addressed.

Table 1: Categorization of wildlife species found damaging crops in the study areas during the years 2009-2014

Elephants: above 2000 kg		**Body weights**	**Source**	**Study area**[1]	**Cons. status**[2]
Elephant	**African elephant** *Loxodonta africana*	m: 4,700-6,028 kg; f: 2,160-3,232 kg	Laursen and Bekoff (1978)	SL, TA	VU
	Asian elephant *Elephas maximus*	m: 5,400 kg; f: 2,720 kg	Shoshani and Eisenberg (1982)	BA, MA	EN
Other large herbivores: 100-2000 kg					
Rhino	**Greater one-horned rhino** *Rhinoceros unicornis*	m: 2,070-2,132 kg; f: 1,599-1,608 kg	Laurie et al. (1983)	BA, MA	VU
Hippo	**Common hippopotamus** *Hippopotamus amphibius*	m: 955-1999 kg; f: 995-1850 kg	Klingel (2013a)	SL	VU
Buffalo	**African buffalo** *Syncerus caffer*	m: 472-723 kg; f: 386-536 kg	Prins and Sinclair (2013)	SL, TA	LC
	Wild water buffalo *Bubalus arnee*	m: 1,200 kg; f: 800 kg	Starck (1995)	MA	EN
Zebra	**Plains zebra** *Equus quagga*	m: 222-284; f: 176-242 kg	Klingel (2013b)	TA	NT
Large antelopes	**Common eland** *Taurotragus oryx*	m: 450-540 kg; f: 317-370 kg	Thouless (2013)	TA	NE
	Nilgai *Boselaphus tragocamelus*	m: 240 kg; f: 120 kg	Starck (1995)	BA	LC
Medium sized herbivores: 5-100 kg					
Boars/hogs	**Bushpig** *Potamochoerus larvatus*	m: 55-93 kg; f: 54-85 kg	Seydack (2013)	SL, TA	NE
	Common warthog *Phacochoerus africanus*	m: 59-104 kg; f: 45-69 kg	Cumming (2013)	SL, TA	LC
	Wild boar *Sus scrofa cristatus*	m: 64-110 kg; f: 42-94 kg	Cuzin and Randi (2013)	BA, MA	LC
Small antelopes/ deer	**Impala** *Aepyceros melampus*	m: 31-62 kg; f: 23-61 kg	Fritz and Bourgarel (2013)	TA	LC
	Spotted deer *Axis axis*	ca. 75-100 kg	Starck (1995)	BA	LC
Primates	**Vervet monkey** *Chlorocebus pygerythrus*	m: 4-8 kg; f: 3-5 kg	Isbell and Enstam Jaffe (2013)	SL, TA	LC
	Yellow baboon *Papio cynocephalus*	m: 19-28 kg; f: 9-17 kg	Altmann et al. (2013)	SL	LC
	Terai grey langur *Semnopithecus hector*	5-24 kg	Agoramoorthy (2013)	BA	NT
Other	**Cape porcupine** *Hystrix africaeaustralis*	m: up to 18 kg; f: up to 23 kg	Happold (2013)	SL	LC
	Crested porcupine *Hystrix cristata*	m: ca. 11 kg; f: ca. 12 kg	Mori and Lovari (2014)	TA	LC
	Indian crested porcupine *Hystrix indica*	ca. 14 kg	Alkon and Saltz (1988)	BA	LC

[1] Species causing damages in study areas South Luangwa, Zambia (SL), Tarangire, Tanzania (TA), Bardia, Nepal (BA), Manas, India (MA).
[2] Conservation status of species following IUCN Red List Categories. EN: endangered, VU: vulnerable, NT: near threatened, LC: least concern, NE: not evaluated (IUCN 2017).

7.1 Elephants

As being the most frequent crop damaging species in three of the four study areas, African elephants (*L. africana*) and Asian elephants (*E. maximus*) play an important role in HWCs. With their massive size and a body weight of over 3 tons (Table 1), both Asian and African elephants are easily visible in fields and can cause damage to crops by just walking through them, even without consuming the crops (Chapter 2, Fig. 4 and Chapter 7, Plate 3A&B). Even though crop damage by elephants is less frequent than crop damage by rodents or insects on a large spatial scale (Bencin et al. 2016; Oerke 2006; Stenseth et al. 2003), the impact of just one elephant's damage for a single farmer can be catastrophic (Thirgood et al. 2005).

African and Asian elephants are listed as threatened species by the IUCN Red List (Table 1), and are also listed under Appendix I of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), banning any trade with the species or its body parts originating from the countries related to this study. All four countries fully protect wild elephants according to their national conservation policies, which extend to regions outside of the protected areas. Exceptions to control problematic individuals, however, are possible (Benjaminsen et al. 2013; Bist 2002; Heinen and Kattel 1992; Metcalfe and Kepe 2008). According to these legislations, governmental authorities take elephants under their full responsibility. As local communities have no stake in regulatory activities, elephants are widely seen as "the governments cattle" (O'Connell-Rodwell et al. 2000). When farmers and villagers feel neglected or are not taken seriously when experiencing losses through elephants, their support for conservation declines (Zhang and Wang 2003). On the other hand, elephants represent a precious resource that can provide value through non-consumptive use, e.g. through photographic tourism (Duffus and Dearden 1990). However, if community members do not directly benefit through such schemes, they become more open to consumptive measures or retaliation (Metcalfe and Kepe 2008). In African communities, elephant meat is desirable for consumption, and is distributed to communities after problem elephant control (PEC) (Guerbois et al. 2012). In addition, the high price that ivory currently achieves on the black market, renders the elephant population further at risk to poaching (Nyirenda et al. 2015).

Even though elephants hold a high religious and cultural meaning in Asian countries, especially in India, Nepal and Sri Lanka (Sukumar 1989), elephants are killed through electrocution, poisoning or explosives (Gubbi et al. 2014). In contrast to many African countries, in Asia these retaliation or preventive killings are mainly aimed at destroying the animal, without consumption. Strong negative attitudes against elephants may prepare the ground for further illegal activities against wildlife such as poaching for illegal trade (Hoare 1999; Zhang and Wang 2003). Preventing or mitigating damage by elephants as well as improving attitudes towards the species and its protection is an important goal of conservation (Lamarque et al. 2009).

7.1.1 Elephants in conflict

In this section the reason for elephants damaging crops in fields is scientifically discussed against the background of different theories. One theory is that the nutritional stress elephants experience within their natural habitat would force them out of this habitat. It is has been shown that the nutritional value of wild grass forage declines at the end of the rainy season; this was hypothesized as a trigger for the crop damaging behaviour of elephants (Osborn 2004). Furthermore, the degradation of the elephants' natural habitat, such as the decline of forest cover, which forced elephants out of their natural habitats, was mentioned as one reason to alter their behaviour (Chartier et al. 2011). Another theory argues that the presence of highly attractive crops has lured elephants out of their natural habitat, due to the high nutritious values and low chemical/physical defence of the crops (Chiyo et al. 2005). The rapid and massive conversion of forested areas into agricultural land, for example in Northeast India (Choudhury 2004), on the Indonesian island of Sumatra (Hedges et al. 2005), and in western Africa (Barnes 1999), has fostered further conflict. The elephants are accustomed to utilizing large areas and continue to use seasonal movement patterns and routes, even if their natural habitat has been replaced by agriculture or villages (Choudhury 2004).

In our four study areas we found evidence that the maturation of highly attractive crops rather than nutritional stress in the elephants' natural habitat, influenced their crop damaging behaviour. Mature crops, as well as those harvested, were most frequently damaged in all four study areas. Also, in southern India and Botswana, the period of ripening of crops was described as the main season for crop damage by elephants (Gubbi 2012; Jackson et al. 2008). Not much, however, is known about how elephants sense the stage of crop ripening. In all four study areas, elephants and farmers have coexisted for hundreds or even thousands of years. Rice was domesticated 10,000 years ago in Northeast India, from where it spread further westwards to Nepal and further eastwards to China (Choudhury et al. 2013; Londo et al. 2006). In the Zambian Luangwa valley farming of maize was introduced in the 16th century (Anderson et al. 2015). It is probable that elephants gain knowledge about the nutritional value of these crops through experience as well as through the identification of odour cues. In my study I have determined that not all crop types are favoured to the same extent by elephants; rice, maize and wheat were found to be the most preferred crops (Chapter 2, Fig. 4). Nevertheless, cash crops, such as cotton or betel nut, were also damaged as well through consumption by elephants, although to a lesser extent. However, it needs to be taken into consideration that the consumption of these lesser attractive crops may, indeed, rise when the proportion of the more attractive crop types is reduced.

Only in one study area (SL) was the mean cost of elephant crop damage per farmer found to be higher than the damage caused by other species. This reveals that in three of the four study areas, the severity of one case of elephant crop damage was not necessarily higher than that caused by other large herbivores or medium sized herbivores (see Chapter 7, section 7.2 and 7.3). This finding was unexpected, taking into consideration the results from many studies based on retrospective household interviews on crop damage severity by elephants (Kioko et al. 2006; Santiapillai et al. 2010; Thapa 2010). This result further indicates that only by using a standardized onsite estimation of crop damage by independent HWC officers, the factual loss and severity of damage can be assessed. In the retrospective of the aggrieved parties, the losses due to certain wildlife species may easily be influenced by attitudes and beliefs (Gillingham and Lee 2003).

However, besides the tangible financial impact on the farmer, the fear of crop damage or even fatal encounters are important, intangible or hidden costs of elephant damage (Ogra 2008). This was especially the case for farmers exposed to damage by elephants, where fear was significantly associated with the desire for an elephant population decline and the most important variable explaining negative attitudes towards wildlife species (Bencin et al. 2016; Kansky and Knight 2014). Such psychological, social and cultural aspects must not be neglected when drawing solutions for the mitigation of HWCs (Dickman 2010).

7.1.2 Property damage by elephants: a special case

A special case of damage by elephants, observed in three of the four study areas, is the damage of human dwellings and food stores (Chapter 4). Up to today, such damage has been reported in a few studies, but have never been the focus of research. It appears that property damage behaviour has been developing in recent years, localized to specific areas. By looking at the seasonal patterns of crop and property damage, it can be assumed that crop damaging elephants follow the harvest from the fields into the villages. However, it is unclear whether the same individuals causing damage in the fields are also causing property damage. As the search for food in properties seems to be a learned and specific behaviour, it could indeed be that it is generally restricted to a few individuals. My finding that it is mainly either single or pairs of male elephants showing this behaviour, underpins this assumption. However, more detailed research is needed, to understand whether the search for food in houses is an extended crop damage behaviour or if it is a specific behaviour in search for particular stored food items, as has been hypothesized in a few cases (Chomba et al. 2012; Palei et al. 2015). The findings of my study suggest that elephants are searching for stored staple crops in the properties. A selective search for other food content like salt or alcohol cannot be determined (Chapter 4, Table 1).

Plate 3: Pictures of typical elephant signs in rural areas: (A) Footprints of single elephant in a paddy field in MA, (B) Passing through a jute field, without crop consumption in MA, (C) Damaged maize field, fed upon by elephant in SL, (D) Pumpkin seeds germinating in elephant dung in SL, (E) Wall of kitchen room from a house in BA removed by elephant, the wooden cupboard contained food supplies, (F) hind footprints in spilled maize flour, SL. Pictures taken by E.M. Gross and Awely Red Caps.

The vast number of damaged properties in three of our four study areas, showed the importance of this matter further in terms of economic losses (Chapter 4, Table 3). As the mean costs of property damage exceeded crop damage costs in all study areas, this issue needs to receive greater attention. As mentioned above, fear and the perception of danger strongly influence human attitudes. The shocking experience of losing one’s home and shelter during the night, very probably has influenced the attitudes towards both elephants and the institutions taking care of their conservation, in a negative way. Offering quick support to these people is highly important for the possibility of the coexistence of people and elephants to be achieved. Furthermore, the prevention of such incidences needs to be taken into serious consideration. The reduction of access to easy food, as well as the reduction of olfactory emission of attractive food smells from villages, could be a key to prevent property damage. To reduce the risk of people being killed during property damage events at night, the separation of stored food away from the houses, seems to be an important measure. Cultural and traditional ways of housekeeping, however, need to be taken into consideration. The storage of rice in traditional clay pots in Tharu houses in BA, for example, is also used as a screen between the men’s and women’s sleeping areas (Bodach et al. 2014). In SL, the fear of the harvest being stolen by neighbours is so great that people prefer to sleep in the same room as their harvest packed into bags (E.M. Gross, own observation).

Changing these habits involves traditionally applied measures, which create a greater benefit or additional asset. The development of an elephant safe grain store in SL, for example, shows such an asset (Chapter 7, Plate 4). Together with the HWC officers of that study area, I have modified the traditional grain store, by using concrete instead of mud for construction and by adding a heavy lid and a small door opening, whilst still maintaining the traditional shape (Gross and Banda 2015). As the store can be locked, the stealing of crops can be prevented, not only by elephants, but also by neighbours.

7.1.3 Crop and property protection against elephants

Empowering farmers to take responsibility and protect their fields and properties against crop damaging elephants was mentioned as an important component to solve human-elephant conflicts (O'Connell-Rodwell et al. 2000; Osborn and Parker 2003). The evaluation of the effectiveness of the propagated measures has proven to be difficult in the field situation, as finding and maintaining control plots was difficult and random effects needed to be accounted for (Davies et al. 2011). As a result, only a few studies have attempted to assess the results of their activities (Davies et al. 2011; Hedges and Gunaryadi 2009; Sitati and Walpole 2006).

The result of my study, that traditional active guarding does not reduce the costs of damage compared to non-protected fields, was highly unexpected (Chapter 3). Consequently, guarding of fields at night in the traditional way should not be further encouraged by conservation organisations. Moreover, emphasis needs to be placed on designing cohesive and community based guarding strategies, as implemented in MA. Farmers need to act together and in a strategic way, to guard a defined line and chase elephants into defined areas, such as refuges, without blocking their way and without further hurting or disorienting the animals. A well planned, cohesive guarding has the further advantage that the investment of the individual farmer will be reduced and a large community of people will benefit (Guerbois et al. 2012).

Plate 4: Pictures of maize storage in SL: (A) Traditional maize storage in open basket, (B) Elephant safe grain store designed and supported by Awely, (C) maize is dried and separated from the cob for storage in elephant safe grain store, (D) detail of elephant safe grain store, lockable opening at base of store. Pictures taken by E.M. Gross and B. Banda.

The construction of electric fences to reduce crop damage by elephants has been a controversially discussed subject (Durant et al. 2015; Hayward and Kerley 2009). Such fences have been constructed around villages or temporally around fields (Davies et al. 2011), or they have been constructed along the demarcation of the conservation area, as in BA. A functioning fence effectively blocks off the route of the elephants, therefore, they would seek alternative routes to pass; as a result, the elephant damage may be redistributed to another site, which had no elephant damage reported prior to the installation of the fence (O'Connell-Rodwell et al. 2000). Such a shifting of crop damage was observed in BA, with the continuous elongation of the fence (Gross, unpublished data). In addition, when the fence was challenged by the elephant, which has happened more than a hundred times in BA, additional active guarding by farmers further increased the costs of the damage (Chapter 3, Fig. 3). This fact should be taken into consideration by international conservation organisations funding such expensive infrastructural interventions as well as by local organisations advising farmers on further protection strategies.

Another crop protection strategy against elephants (and potentially other wildlife species) is the cultivation of crops, which are chemically defended through plant secondary metabolites, such as the so-called medicinal and aromatic plants (MAPs), as both African and Asian elephants avoid these crops (Chapters 5 and 6). The consumption of tannins, for example, reduces the ability to absorb proteins and carbohydrates in food by binding to them (Robbins et al. 1991). Elephants and rhinoceroses, however, are able to neutralize tannins with their salivary proteins (Clauss et al. 2005; Schmitt et al. 2016). Other plant secondary metabolites though can be toxic for many herbivores even at low concentrations. As detoxification is energetically expensive, plants containing secondary metabolites, have been avoided by different herbivorous species (Conover 2002). Such an avoidance has been demonstrated for elephants and MAPs in my study as well (Chapter 5 and 6). The identification of such less attractive or even unpalatable crop types most probably is transmitted by olfactory cues. It has recently been shown that elephants rely on olfaction to locate food and distinguish between preferred and avoided forage (Plotnik et al. 2014; Schmitt 2016). Which odours or odour cues finally determine the decision of elephants to forage on a specific crop type or not, is still unknown. In order to develop new crop protection strategies based on odours, more research in this area is needed.

7.2 Other large herbivores

Other large herbivores, besides elephants, which I found were damaging crops in the four study areas, mainly included the greater one-horned rhino (*R. unicornis*), the common hippopotamus (*H. amphibius*) and the plains zebra (*E. quagga*) (Table 1). In addition, African buffaloes (*S. caffer*) and wild water buffaloes (*B. arnee*), as well as large antelopes (nilgai (*B. tragocamelus*) and common eland (*T. oryx*)), were found to damage crops, but at lower frequencies.

7.2.1 Large herbivores in conflict

The hippo is found widely in sub-Saharan Africa, where water (used as a daytime refuge) and adjacent grasslands (feeding grounds) are found (Klingel 2013a). Due to being restricted to areas containing water, hippos were only found to damage crops in the study area of SL in close proximity to the Luangwa River and its oxbow lakes. In our study, hippos consumed maize mainly when in its intermediate and mature growth stage, whilst groundnuts and rice were consumed only in their intermediate growth stage. The high proportion of maize damage in its mature stage was unexpected, as hippos generally prefer grazing on low grasses (Owen-Smith 1988). However, as they are rather unselective in their food choice, they do also consume fallen fruits, such as from the sausage tree (*Kigelia africana*, (Lam.) Benth.) (Klingel 2013a). In our study area, hippos pushed down the maize plants by walking through the fields to then pluck off leaves and cobs from the stems with their lips (Chapter 7, Plate 5F).

An estimated number of 40,000 migratory zebra have been found to utilize the Manyara-Tarangire ecosystem (Klingel 2013b). Maladapted to drought, they prefer grazing grounds close to water in the dry season and disperse to wider areas in the rainy season. The study area located in the Simanjiro plains, the dry, eastern part of the Manyara-Tarangire ecosystem, is a dispersal area for zebras in the rainy season (Rija and Hassan 2011); this was the only season when zebra were found to cause crop damage in the study area. Although zebra generally prefer short grasses to feed on, they are the first in the feeding succession in migratory systems, such as in the Serengeti (Klingel 2013b). Therefore, the feeding of zebra on maize in its intermediate and mature stage of growth in this study, perfectly fitted in with their natural feeding behaviour. Kahurananga and Silkiluwasha (1997) emphasized the threat to the sustainability of this migratory population of zebra and wildebeest that the encroachment of cultivation towards the migration corridors may bring. Thus, the large amount of crop damage caused by zebra in this area can be seen as an indicator for the rising conflict between a traditionally migratory species and the rising demand for farmland, in an area, that was traditionally exclusively used by pastoralists (Morrison et al. 2016).

The common eland was found to damage crops in TA, where it can occupy very dry landscapes and can move long distances without drinking water. Being primarily browsers, elands consume grasses to some extent as well, giving them the classification as intermediate mixed feeders, feeding from ground level to a height of two meters (Thouless 2013). As eland preferably select forage low in fibre content, such as young shoots, palatable woody species, herbs and fruits (Watson and Owen-Smith 2002), it is not surprising that they were found feeding on large quantities of beans and maize in TA.

African buffalo are abundant throughout the African study areas, forming large herds and generally grazing within 20 km of water sources. They mainly graze on grasses and sedges, but can also forage on small quantities of browse as well (Prins and Sinclair 2013). Buffaloes in our study consumed maize (and in one case rice) in its intermediate and mature stage of growth, which is in agreement with their preference for grasses with high crude protein content.

The wild water buffalo found in Asia are also grazers, feeding on tree saplings and on other browse, to a lesser extent, during the dry season (Kotwal and Mishra 2004). Although the population of wild water buffalo is comparably high in MA (Goswami and Ganesh 2014), and the species has been found damaging crops in other parts of India (Kotwal and Mishra 2004), only one crop damage was recorded by this species in MA.

Crop damages by the greater one-horned rhino was mainly found in BA, however, some damage also occurred in MA. Both, Bardia National Park, Nepal and Manas National Park, India have a similar dramatic rhino poaching history. In the lowlands of Nepal rhinos suffered a massive decline in the 1960s, when the total Nepalese rhino population was reduced to less than 100 individuals, with a complete eradication from Bardia (Subedi et al. 2013). The re-introduction of rhinos to the newly established national park started in the mid-1980s and by 2003 a total of 83 individuals had been released into the Bardia National Park (Thapa et al. 2013). A census in 2011, however, revealed that only 24 rhinos were living in Bardia National Park, indicating heavy poaching during the times of armed conflict from 1996 to 2006 (Subedi et al. 2013). Similarly, the rhino population of Manas National Park was poached to extinction during the fifteen years of ethnic and political conflict which erupted in the mid-1980s (Dutta et al. 2012; Goswami and Ganesh 2014). In 2008, the first two rhinos were re-introduced to Manas National Park from the Pobitora Wildlife Sanctuary, and a further 16 rhinos followed, up to 2012 (Dutta and Mahanta 2015). Poaching incidents in the past years, however, have again strongly affected the population (Goswami 2015). As a habitat specialist, the greater one-horned rhino primarily utilizes tall grasslands and floodplains to forage (Laurie 1982). In Bardia rhinos are found in the Karnali floodplain and the Khata forest corridor towards India. In these exact areas we found rhinos frequently feeding on six different crop types, showing a clear preference for wheat and crops at the early stages of growth. Crop damage in the dry season occurred on rare occasions. In MA, rhinos only damaged freshly planted rice crops in the RS, a finding that is supported by Dutta et al. (2012), who radio tracked the first two re-introduced male rhinos in Manas national park and found them to be straying into villages and crop fields.

The nilgai antelope is a mixed feeder and a habitat generalist, which partly explains the massive crop damage this species caused in peninsular India to crops like wheat (*T. aestivum*), chick pea (*Cicer arietinum* L.) and mungo bean (*Phaseolus mungo* (L.) Hepper) fields (Chauhan 2011; Leslie 2008). In BA, this large antelope was reported to cause heavy crop damage in the early 1990s (Studsrod and Wegge 1995). However, during the time of this study in BA, mustard, lentil and vegetable crops were only damaged at low frequencies. A reason for this may be the comparably small population of nilgai antelope and its geographical restriction to the Karnali floodplains (Subedi 2001).

7.2.2 Crop protection against large herbivores

As crop protection against elephants is said to be the most difficult, compared to other species, the results obtained for other large herbivores in this thesis were rather unexpected. Similar to the crop protection results for elephants, protection measures did not necessarily decrease the costs of damage by other large herbivores below the costs of damage of non-protected fields (Chapter 3, Fig. 3). Only barriers alone or in combination with passive guarding, were able to reduce the costs of damage by other large herbivores in BA, whilst passive guarding in SL and active guarding in BA actually caused significantly higher damage costs than in non-protected fields. Data from TA and MA, unfortunately were not sufficient for statistical analysis.

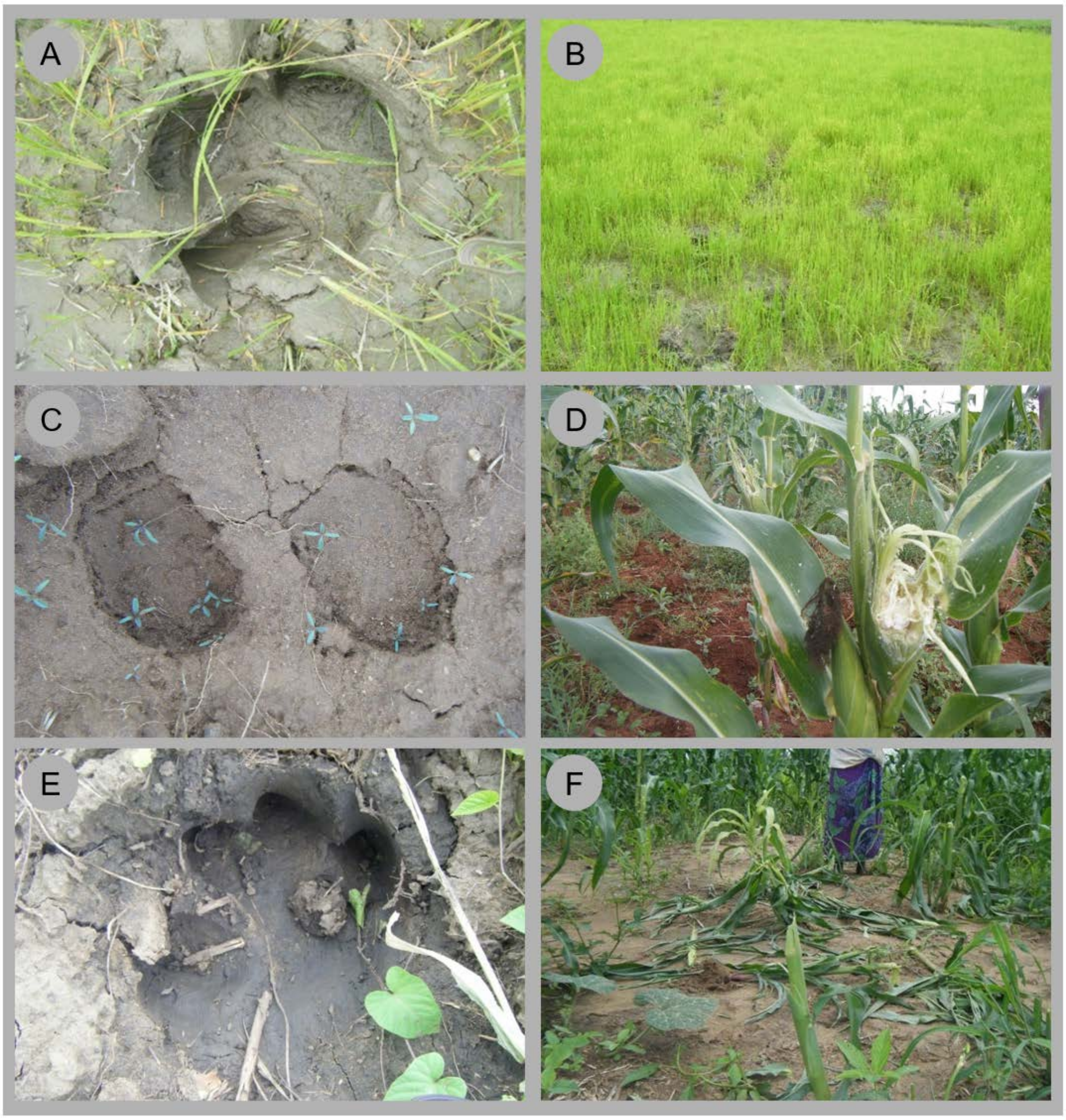

Plate 5: Pictures of typical damage by other large herbivores on crop fields: (A) and (B) Rhino footprint in paddy field and damage of rice in early intermediate stage of growth in MA, (C) and (D) zebra footprints and typical bite mark on maize cob by zebra in TA, (E) and (F) hippo foot print and damage to maize field by hippo in SL. Pictures taken by Awely Red Caps.

Understanding the behaviour of the respective large herbivores is necessary for the interpretation of these results. Within this species category, mainly hippos in SL and rhinos in BA caused the crop damage. Hippos are difficult to detect in fields, where the maize has grown high. Only when farmers were guarding actively, would they have been able to spot the hippos before entering into the fields. When guarding passively, farmers would only detect the presence of hippos once they had already started causing damage. At night, hippos grazing on land are less aggressive than during daytime (Owen-Smith 1988). Mothers, however, would defend their young ones by chasing and trying to bite the aggressor with their huge jaws (Klingel 2013a). Single, feeding hippos will try to take evasive action by rushing towards the water along the nearest path, when being chased from fields (Owen-Smith 1988).

If being chased unsystematically, with sounds and lights coming from different sides, hippos may easily get irritated and disoriented and, therefore, cause even more damage by moving back and forth through the fields, trampling large amounts of crops. Thus, systematic guarding between the water used as a daytime refuge by the hippos and the crop fields, as well as detection before they have entered the fields, would most probably be the best strategy to reduce crop damage.

In their preferred wheat fields, but also in lentil, rice and mustard fields, the greater one-horned rhinos were easy to detect. However, once within the field, chasing them away did not reduce the amount of resulting damage. Especially rhino mothers with calves could be highly aggressive, but also males during mating time would attack aggressors, whereas juveniles remained mostly timid (Laurie 1982). When being chased by a group of people, with the aim of driving the rhinos back to their natural refuges in the national park, rhinos seemed to cause more damage, than when being left alone undisturbed. This indicates a misguided effort by local farmers, which needs to be further investigated. Jnawali (1989) observed various traditional methods of chasing away rhinos from fields in Chitwan/Nepal, and has identified burning bundles of thatch grass, carried by guards to chase away rhinos, to be the most effective deterrent. During this study by Jnawali (1989) it was, however, already being observed that massive crop damage occurred despite active guarding practices, thus, the possibility of the habituation of rhinos to human disturbance was discussed. In MA, crop damage by rhinos was observed especially after the translocation and release of rhinos to their new habitats (Dutta and Mahanta 2015). Here, a person was killed by a rhino in an incident where a mother and calf became separated in the village. In such cases, farmers need to be well informed on how to react when rhinos are entering villages, especially to keep a safe distance and not to make them panic.

The call for electric fences to be employed to keep large herbivores inside of protected areas and out of farmland, is heard from many African and Asian countries. Fencing is recommended as a crop protection strategy against hippos (González et al. 2016), against rhinos (Jnawali 1989) and against large antelopes (Chauhan 2011). Although these installations may reduce crop damage at an initial phase, they have not been proven to be completely safe against any of the mentioned species in the long-term (Bayani et al. 2016; Kioko et al. 2008; Sapkota et al. 2014). One main difficulty originates in its labour and cost intensive management. This is especially the case during the rainy season, when the grasses grow quickly, a leaking of energy readily occurs, resulting in ineffective fencing. Similarly, as for elephants, any of the mentioned species will easily overcome the fence, in the case of it malfunctioning. Furthermore, when being chased, the animals would then cause even more damage as they cannot find their way out of the fence, easily.

7.3 Medium sized herbivores

This group comprises all herbivorous (including omnivorous) species with a weight ranging from 5 to 100 kg, which were found to damage crops in at least one of our study areas (Chapter 7, Table 1). Although smaller in size, this group of species must not be disregarded due to its strong destructive potential. Rodents, for example, were mentioned as the species group causing the most damage to farms in northern Tanzania, compared to elephants, hyenas, lions or jackals and were, therefore, the group of species most desirable to decrease (Bencin et al. 2016).

7.3.1 Crop damages by medium sized herbivores

Although medium sized herbivores accounted for a larger proportion of less severe damage of below 40% of the total farmed crops by one farmer (Chapter 2, Table 1), they caused the same mean cost of damage as elephants and other large herbivores in the Asian study areas (Chapter 3, Fig. 2). Exceptionally high costs of crop damage by medium sized herbivores found in the RS in BA, exceeding those of crop damage by elephants, are due to damage caused by wild boar and spotted deer (Chapter 3).

Wild boar (*S. scrofa*) and other suids are well known for their potential to damage crops in a wide geographical range (Ballari and Barrios-García 2014; Byg et al. 2017; Herrero et al. 2006). In my study I found them damaging crops in all four study areas. Wild boar and bushpigs (*P. larvatus*) are opportunistic feeders consuming browse, grasses, roots, barks, insect larvae and even scavenge (Ballari and Barrios-García 2014; Breytenbach and Skinner 1982), whereas warthogs (*P. africanus*) are specialized grazers, plucking grass and feeding on grass rhizomes (Botha and Stock 2005; Cumming 2013). As all three species also feed on the underground parts of plants, they intensively search the soil for food and rooting plants (Chapter 7, Plate 6A-D). This rooting behaviour, as well as wallowing in crop lands, can cause heavy damage, destroying crop fields completely (Li et al. 2012). In SL and TA, bushpigs and warthogs were found to damage maize and groundnuts, exclusively. This agrees with the findings of Seydack (2013), who mentioned bushpigs extensively damaging maize, groundnuts, sugar cane and beans on agricultural fields and of Vercammen and Mason (1993), who reported warthogs damaging groundnuts in the DR Congo. In MA, only rice was damaged by wild boar, but in BA a wide variety of over nine crop species including potatoes, other vegetables and fruits, were damaged. Bleier et al. (2016) found that wild boar damaged maize increasingly throughout the growing season and were probably influenced by the appearance of the corncobs. This finding is supported by our study, as boar/hogs preferred harvested crops to crops at an intermediate stage of growth. The risk of crop damage by wild boar has also been found to increase with closer proximity to the forest edge and rivers (Saito et al. 2011). The availability of cover to hide close to crop fields (Ficetola et al. 2014; Li et al. 2012), or even a buffer close to the wooded areas where hunting is banned (Amici et al. 2011), seems to foster crop damage by suids. In contrast, overground openness or the low cover of urban areas, as well as human population density, and short distances to roads, reduce the likelihood of suids damaging crops (Saito et al. 2011). It has to be mentioned that only a few studies rely on data obtained from damaged fields, with the objective calculation of losses. Many studies use secondary data, recorded for payment of compensation, or interviews with farmers (Pandey et al. 2016). The perception that suids are the most severe wildlife pest, may be influenced more by their generalist and destructive feeding behaviour, than by the costs of damage they cause; Linkie et al. (2007), regard wild boars as a species blamed for more crop damage than they actually cause.

Less obvious crop damage was found to be caused by smaller deer and antelope species. Spotted deer (*A. axis*) as well as impala antelope (*A. melampus*), are moderately sized and relatively light in weight (Table 1). Both species are mixed feeders, feeding on both grasses and browse to varying proportions; browse being consumed during the dry season and freshly re-growing grasses during the rainy season (Cerling et al. 2003; Khan 1994). The spotted deer occurs over a very wide range including the lowland forests of Nepal and throughout India, Bhutan, Bangladesh and Sri Lanka, in many large sub-populations (Duckworth et al. 2015). In Manas national park, the population of spotted deer had been decreased substantially in the 1980s, although a first new sighting was registered in January 2017 (Goswami 2017). The impala are found widely in the woodlands and savannahs of southern and eastern Africa (Fritz and Bourgarel 2013). Both, spotted deer and impala can graze in large groups, however, crop damage may not be obvious at a first glance, as they chew or nibble some specific parts of the plant (Bayani et al. 2016). In my study, spotted deer and impala preferred visiting farms with crops in the green and soft intermediate growth stage and before the dry season. Spotted deer in BA mainly fed on lentil, mustard and wheat, an observation that is supported by findings from Nepal and India, where crop damage by spotted deer was reported as being high, with animals feeding on rice, wheat, maize, mustard and lentils (Karanth and Nepal 2012; Studsrod and Wegge 1995; Thapa 2010). Despite their presence in SL, impala in our study only caused crop damage in TA. Here, they fed exclusively on beans in great quantities (Chapter 7, Plate 5E&F); this is consistent with their diet, including pods of *Acatia* spp., being high in protein (Fritz and Bourgarel 2013). Impala have not been mentioned as a major crop pest from other African countries. In Uganda, however, they have been found feeding on maize and millet (Tweheyo et al. 2012).

Although primates occur in all four study areas and are frequently observed close to villages, they were found to cause relatively few damages, mainly in SL, in this study. Here, yellow baboons (P. *cynocephalus*) and vervet monkeys (*C. pygerythrus*) preferred to feed on maize, similar to the situation in Kibale national park, Uganda, where primates have caused big losses to farmers; olive baboons (*P. anubis*) preferred consuming maize, whereas red-tailed monkeys (*Cercopithecus ascanius* Audebert) damaged sweet banana (Naughton-Treves 1998). From this study, it is known that young boys are kept out of school, to guard crops against baboons during the daytime, resulting in a low literacy level amongst boys (Mackenzie et al. 2015). In the Cape Peninsula, South Africa, chacma baboons (*Papio ursinus* Kerr) have become accustomed to feeding on human food sources, such as fruit, sugar and bread from waste areas or houses in rural and urban environments (Kaplan et al. 2011); this is a situation well known in many Indian towns and cities, where rhesus macaques (*Macaca mulatta* Zimmermann) live from scavenging waste food around markets and offerings at temples (Priston and McLennan 2013). The low frequency of recorded crop damage by primates in our study areas may have been due to underreporting, as damage caused by a few individuals or small troops may not be easily visible.

In my study porcupines (*Hysterix* spp.) mainly caused crop damage in SL, with a very low frequency and comparably less severe damage. Due to their destructive behaviour while uprooting crops, they have been compared to bushpigs in Uganda (Kagoro-Rugunda 2004). In Nepal, the porcupine has been mentioned as a less frequent crop damaging species (Karanth and Nepal 2012).

Plate 6: Pictures of typical damages by medium sized herbivores on crop fields: (A) and (B) Wild boar footprint on rice field and damage of rice in intermediate stage of growth in MA, (C) and (D) bushpig footprints and damage of maize in SL, (E) and (F) impala foot print and damage to beans TA. Pictures taken by Awely Red Caps.

7.3.2 Crop protection against small herbivores

Protecting crop fields from suids has been attempted in many areas with different levels of success. In Japan, weeding around rice paddies, electric fencing and corrugated iron fencing have been effective at reducing damage by wild boars (Saito et al. 2011), although electric fencing in Switzerland has not achieved the desired results (Geisser and Reyer 2004). In China, the guarding of fields at night has shown positive effects (Li et al. 2012). However, especially in Europe, the reduction of wild boar populations through hunting has been seen as the only effective way to reduce crop damage by this species (Bobek et al. 2017; Geisser and Reyer 2004).

In case of spotted deer and impala, chasing them away with loud sounds and drumming was found to be relatively easy, however, animals would return once no sounds were heard anymore (Thapa 2010; Tweheyo et al. 2012). Fencing with wire mesh or the planting of natural barriers of dense vegetation was found to be effective for spotted deer, provided these barriers were high enough, as the deer are able to challenge fences of a height of 1.5 meters by jumping over them (Bayani et al. 2016; Karanth and Nepal 2012; Thapa 2010). Impala, famous for their characteristic and high jumps were found to be excluded by barriers higher than 2.5 meters (Staver et al. 2014).

In our study, the only protection measure that showed a significant effect of cost reduction for medium sized herbivores compared to non-protected fields, was through electric fencing in BA. Interestingly, this fence had been set up against elephants and was met with some doubt (Chapter 3), but it seems to have provided some protection against both wild boar and spotted deer. As both species forage in larger groups, I assume that some group members did not cross the fence or were alerted due to the fence, which may have made them move onwards.

Primates, as being diurnal, were not targeted by nocturnal guarding activities and easily overcame any barrier found in the four study areas. To deter them from fields, specific guarding activities during the daytime need to be carried out (Kaplan et al. 2011; Mackenzie et al. 2015). Porcupines generally played a lesser role in crop damage in all study areas.

7.4 General conclusions: towards a coexistence of wildlife and people

From the results obtained in this study a series of conclusions and recommendations for HWC mitigation are drawn (Chapter 7, Fig. 3).

7.4.1 Standardizing and evaluating HWC programmes

The HWC assessment scheme which I used in this study (Chapter 1, Fig. 1) allowed a comparative analysis of HWCs across continents and across species. It has proven to record ecological as well as social and socioeconomic data on damage caused by 19 different wildlife species (Chapter 7, Table 1) in two Asian and two African countries. Data was used for the analysis of different aspects of damage caused by herbivorous species. Analysing data of carnivorous conflicting species will be the subject of future research.

The HWC assessment scheme was used further to evaluate the effectiveness of crop protection measures used. Results revealed that traditional crop protection mechanisms needed to be re-thought as they may be time consuming, ineffective and may even increase the costs of damage. Only the rigorous evaluation of mitigation strategies will detect failures and false assumptions. Due to the desperate need for solutions from the conservation side, as well as the short term funding of projects, technical solutions are too often developed based on anecdotal knowledge and hope, instead of being based on scientific testing (Gunaryadi et al. 2017). However, improving the assessment scheme for even more thorough evaluation and stronger explanatory powers, needs to be taken into consideration. This could include the assessment of areas without damage, to act as a control in order to determine the success of specific measures for total crop protection.

7.4.2 Exploring the importance of pre-ingestive cues

As most animals are only able to select food items that meet their nutritional needs, they make their decision on whether to consume or not to consume a crop on palatability or acceptability (Heady 1964). The information on the palatability or acceptability of a plant is determined by its pre- and post-ingestive cues. Through feedback and experience, wildlife species have learned which plants to consume or to avoid. The odour of the plant plays an important role for foraging decisions. Not much, however, is known about the odours that support or avoid feeding on different crop types for specific herbivores; this is especially the case for elephants which are strongly olfactory guided in their food choice (Plotnik et al. 2014; Schmitt 2016). Integrating chemical ecology into the analysis of crop selection by large herbivores may create new insight into their feeding behaviour in agricultural landscapes and form the starting point for the development of innovative and sustainable HWC mitigation strategies.

7.4.3 Participatory land use planning and new ways forward

Designing sustainable solutions for the coexistence of wildlife and people needs to progress from the ad-hoc interventions in order to reduce damage in the long term. Conflict-laden areas need a thorough and truly participatory local planning for the utilization of the land, before a change will become impossible (López-Bao et al. 2017; Treves et al. 2009). As Treves et al. (2009) summarized, solutions to HWCs need to be feasible, particularly cost-effective, wildlife specific and socio-politically acceptable. Solutions therefore need to be based on sound scientific knowledge, such as the seasonal crop preferences of the respective pest species and the understanding of its foraging behaviour. For elephants, especially, but also for other species such as hippos and rhinos, traditional paths, specific refuges and water bodies need to be taken into consideration when planning sustainable agricultural land use (Guerbois et al. 2012; Songhurst et al. 2015).

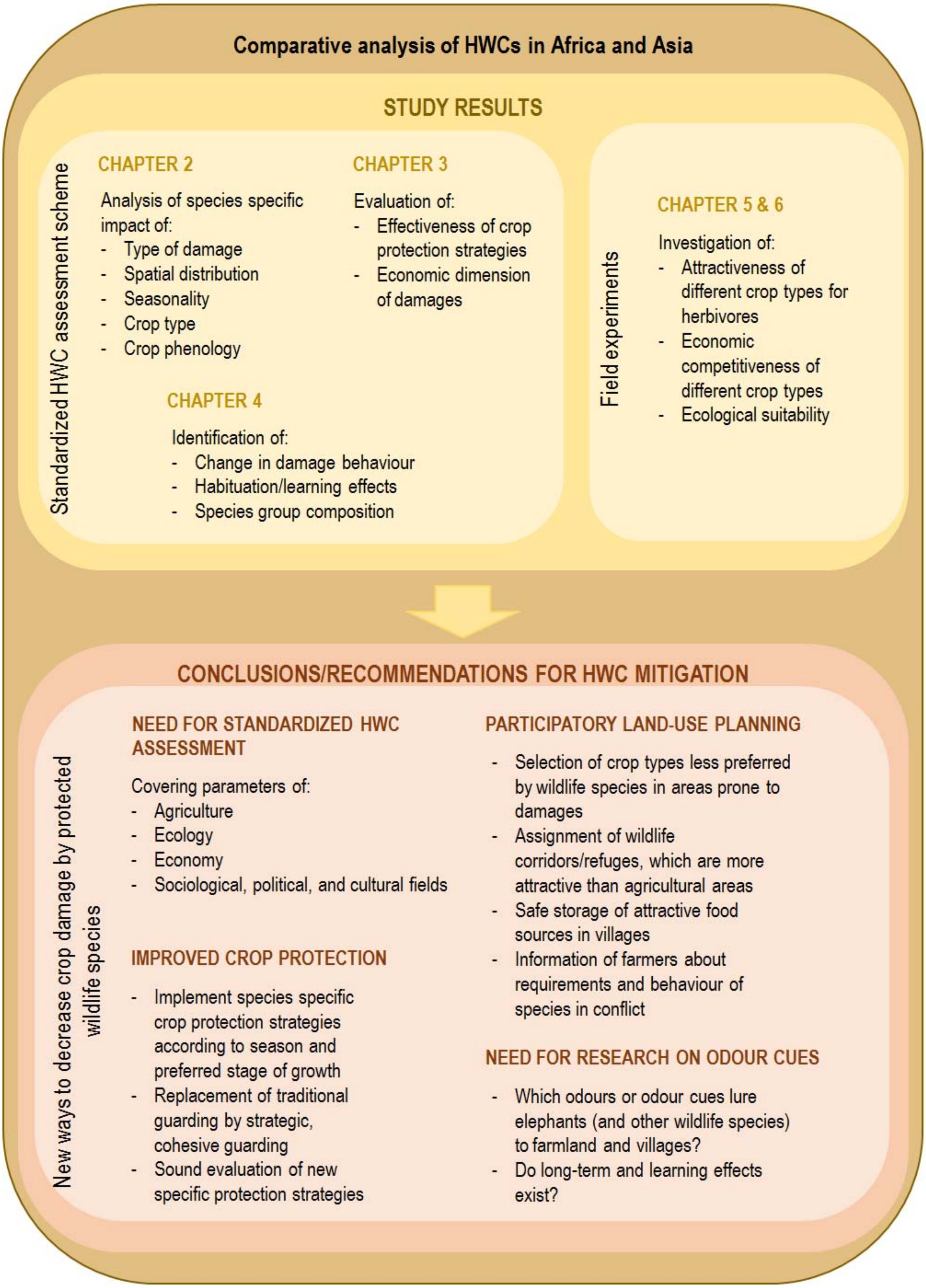

Fig. 4: Graphic overview of result and conclusions

Based on the findings of my study, designing less conflict laden areas for people and wildlife could be a new way forward. Areas close to wildlife habitats could be used for the cultivation of MAPs as cash crops, which are unattractive or at least less attractive to elephants and probably to other species. Combined with strategic cohesive guarding, the trade-off between the benefit wildlife species could gain through feeding on crops and the perceived risk would be shifted to an uneconomic proportion and therewith reduce the probability of wildlife entering farmland. Additionally, the cultivation of depredation-prone crops need to be shifted further away from these wildlife habitats, taking into consideration that they will always be attractive lures (Goswami et al. 2015). Furthermore, ecologically important areas, such as corridors or access to water, need to be retained, to allow the undisturbed movement of wildlife species; this may include putting a halt to the agricultural invasion of ecologically important wetlands (Kanga et al. 2012). Such a land-use approach could turn the cost intensive fight against wildlife into a well-adapted and economically sustainable land use.

7.4.4 Considering the human dimension in HWCs

This study had a strong focus on understanding the determinants for wildlife species entering agricultural, rural or even exurban areas and causing damage to the people's economy. The damage wildlife species cause to people living in poverty will reduce their tolerance towards these species and their protection, especially if they are not compensated or supported in another way. Unfortunately, the reciprocal assumption that a decrease in damage will automatically increase the tolerance for wildlife species, is however not perfectly correct (Dickman 2010). People's attitudes are shaped by multiple factors, such as psychological and cultural sentiment, political and legal history, as well as social norms (Hogberg et al. 2015; Liordos et al. 2017; Williams et al. 2002). If HWCs are deep-rooted, including deeply held values, high economic relevance and power imbalances, decreasing the level of damage by wildlife species will not achieve a transformation (Madden and McQuinn 2014). In the case of deep-rooted conflicts, the participation of those being negatively affected by wildlife species will be difficult to achieve, and short-term technical solutions will most likely fail. For this reason the analysis of social and political factors is highly important, before the process of HWC mitigation starts. The level of conflict needs to be analysed and the appropriate strategy for conflict resolution needs to be chosen.

The empowerment of local people and the creation of their ownership over resources are pivotal within such a process (Lindsey et al. 2013). This must co-exist with building the capacity of local communities to learn about the ecological complexity in their natural and rural environment. Furthermore, policy reforms in the patterns of ownership, new incentives and protective regulations as well as the removal of destructive subsidies need to be seriously taken into consideration (Pretty 2002). Such truly participatory approaches, respecting local culture and history, building on scientific as well as traditional knowledge and taking into consideration the principles of ecologic, economic and social sustainability, bear the potential to create a peaceful coexistence for people and wildlife for future generations.

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04/2003 – 03/2008	Project manager at *Frankfurt Zoological Society*, Frankfurt/Germany Developing, conducting and managing conservation education projects in collaboration with Frankfurt Zoo: implementation of a volunteering system for conservation education, conception and implementation of events and presentations on biodiversity conservation, development of mobile and interactive exhibits, website, fundraising, public relations

Publications

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2016	Gross EM, McRobb R, Subedi N, Gross J (2016) Cultivating alternative crops reduces crop losses due to elephants [oral presentation]. 15th International Elephant & Rhino Conservation Research Symposium, November 14-18, Singapore
2007	Gross EM (2007) Vom Sumatratiger zum Einkaufswagen [oral presentation and workshop]. Conference on Biodiversity and Conservation education, Arbeitsgemeinschaft Natur- und Umweltbildung (ANU), November 29-30, Witzenhausen, Germany
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